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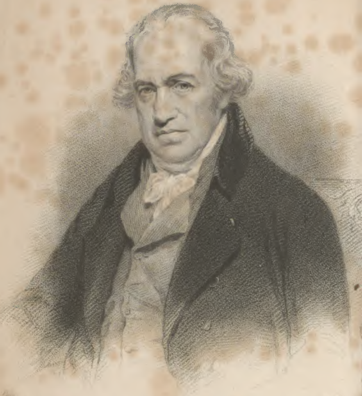

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JAMES WATT

LL.D. F.R.S.L.&E. &c.

John Bulman
Kelso
1836

THE

MECHANIC'S

POCKET DICTIONARY;

BEING A NOTE BOOK OF

Technical Terms, Rules, and Tables,

IN

MATHEMATICS AND MECHANICS.

FOR THE USE OF

MILLWRIGHTS, ENGINEERS, MACHINE MAKERS, FOUNDERS,
CARPENTERS, JOINERS,
AND STUDENTS OF NATURAL PHILOSOPHY.

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"A CHART OF THE SCIENCE OF CHEMISTRY," &c. &c.

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MDCCCXXXVII.

PREFACE.

Shortly after the publication of the Mechanic's Calculator, it was suggested to me that a Dictionary of the Technical Terms used in mechanics would be a highly serviceable book to those engaged in engineering and the study of natural philosophy. My situation as a public lecturer has every day since convinced me more and more of the justice of this suggestion, from the frequent application of my pupils for explanations of technical terms they meet with in the perusal of scientific works. With a view to supply a cheap and portable manual for this purpose, the following Dictionary was drawn up, and is now offered to the public, in the hope that if it is not perfect in all or any of its parts it is at least calculated to supply a material blank in the library of the workman. In drawing up many of the articles much more than a definition was absolutely necessary, and accordingly such practical information, and tables for facilitating, or preventing the necessity of calculation, as the compiler has found in his own practice most requisite, have been introduced. No two persons will be found entirely to agree in their views of the relative importance of the various articles contained in a work of this nature, and the compiler has little hope that his book will entirely satisfy the wishes of all his readers; but he has dwelt at greater length on those subjects which his own experience has led him to regard as more important, and trusts that when any one shall wish that one article should have been treated of more fully, he will bear in mind that many others may be of the opinion that it should have been still shorter, in order to give place to some other subject which they conceive more useful or interesting.

In drawing up such a book as the present, many sources of information require, of course, to be consulted. The labours of Newton, Smeaton, Banks, Emerson, Robison, Watt, Rennie, Leslie, Young, Telford, Tredgold, Bevan, Wood, Gordon, M'Neill, &c. &c., have furnished much of the information which this work contains; and occasional extracts have been made from accredited works, but not to such an extent as to diminish their value, or render them unnecessary; the present Dictionary being intended rather as a book for ready consultation, than as containing systematic investigations of the matters which it embraces.

To Mr Frazer, civil engineer, Sweden, the compiler is largely indebted for many rules, and numerous valuable tables, throughout the volume, and from that gentleman's long experience and acknowledged talent as an engineer, these may be employed with implicit reliance. Among these tables may be noticed those on the properties of bodies, the areas of circles, of ellipses, of the diagonals, &c. of various polygons, of the weights of several metals, of screws, chains, and cables, and above all, the very valuable table of the teeth of wheels, the most extensive and correct that has hitherto been published. Various other gentlemen have also furnished valuable original communications, among whom may be more particularly mentioned, Mr George Whitelaw, civil engineer, Glasgow, and Mr James Whitelaw, civil engineer, of the same city.

There are interspersed throughout the volume about 200 wood engravings and diagrams, together with four steel engravings of fixed, locomotive, and marine steam engines, which, together with the elegant portrait of the illustrious Watt, will amply show that the publishers have spared no expense in embellishing the work. From the great care of the printer the accuracy of the tables may be depended upon.

The compiler, in conclusion, has only to express his sincere gratitude to the public for the very favourable manner in which his former publications have been received, and trusts that the present volume will in no way diminish the popularity which he has hitherto enjoyed.

WILLIAM GRIER.

GLASGOW, *November*, 1836.

INTRODUCTION.

In the course of this work many rules for calculation occur, which are expressed by the aid of the common Algebraical signs ; and the reason for so doing has been, that we might, as far as possible, prevent any mistake in the application of these rules. Many who are not acquainted with the use of these signs, are led to believe, that they are employed merely as a parade of mathematical learning, which only serves to make the subject more intricate ; but this is a mistake, for those who are not accustomed to the use of this notation, need only read to the end of this introduction, to be convinced that the invention of these marks of contraction is one of the simplest and most effective means ever contrived by man for the acquisition and communication of scientific knowledge.

$=$ When we wish to state that one quantity or number, is equal to another quantity or number, the sign of *equality* $=$ is employed. Thus 3 added to $2 = 5$, or 3 added to 2 is equal to 5.

$+$ When the sum of two quantities or numbers is to be taken, the sign *plus* $+$ is placed between them. Thus $3 + 2 = 5$; that is, the sum of 3 and 2 is 5. This is the sign of Addition.

$-$ When the difference of two numbers or quantities is to be taken, the sign *minus* $-$ is used, and shows that the latter number or quantity is to be taken from the former. Thus $5 - 2 = 3$. This is the sign of Subtraction.

$\times$ When the product of any two numbers or quantities is to be taken, the sign *into* $\times$ is placed between them. Thus $3 \times 2 = 6$. This is the sign of Multiplication.

$\div$ When we are to take the quotient of two quantities, the sign *by* $\div$ is placed between them, and shows that the former is to be divided by the latter. Thus $6 \div 2 = 3$. This is the sign of Division. But in this work it is seldom employed, the most distinct mode of marking division, being, to place the dividend above a horizontal line, and the divisor below it, in the form of a vulgar fraction, thus :

$$\frac{\text{Dividend}}{\text{Divisor}} = \text{Quotient.} \qquad \frac{6}{2} = 3.$$

When the square of any number or quantity is to be taken, this is denoted by placing a small figure 2 above it to the right. Thus 6^2 shows that the square of 6 is to be taken, and therefore $6^2 = 6 \times 6 = 36$.

When the cube of any number or quantity is to be taken, this is denoted by placing a small figure 3 above it, and a little to the right. Thus, 4^3 shows that the cube of 4 is to be taken, therefore $4^3 = 4 \times 4 \times 4 = 64$.

When we wish to show that the square root of any number or quantity is to be taken, this is denoted by placing the *radical sign* $\surd$ before it. Thus $\surd 36$ shows that the square root of 36 ought to be taken, hence $\surd 36 = 6$.

When we wish to show that the cube root of any number or quantity is to be taken, the sign $^3\surd$ is put before it; thus, $^3\surd 64$ shows that we are to extract the cube root of 64, hence $^3\surd 64 = 4$.

The common marks of proportion are also used, viz., : :: : as 3 : 6 :: 4 : 8, being read 3 is to 6 as 4 is to 8.*

( ) It not unfrequently happens that three, four, or more quantities or numbers are to be taken together or conceived as one, a circumstance which is denoted by a *parenthesis* ( ). Thus, if $3 + 4 + 2 \times 6$, is to be viewed as one number to be multiplied by 5, the whole is written thus, $(3 + 4 + 2 \times 6) \times 5$, which shows that the sum of 3 and 4 is to be added to the product of 2×6, which gives the number $7 + 12 = 19$, which last number is to be multiplied by the 5 without the parentheses, making the whole $= 95$. Now had the parentheses been left out and the numbers stated thus, $3 + 4 + 2 \times 6 \times 5$, the result would have been different, as we have here the sum of 3 and 4 to be added to the product of $2 \times 6 \times 5$, that is $7 + 60 = 67$. In like manner, $\surd 64 + 36$ shows that we are to add the square root of 64, which is 8, to the number 36, and the amount is 44; but if parentheses are used thus, $\surd(64 + 36)$, we must add the numbers 36 and 64, and extract the square root of the sum, and therefore $\surd(64 + 36) = \surd 100 = 10$. It often happens that a dividend consists of several numbers or quantities connected together by the signs $+$, $-$, $\times$, or under the sign $\surd$ or $^3\surd$, as likewise the divisor, in which case the parentheses may be used, as $(6 + 8 + 5 - 2) \div 6 + 2$, which is $17 \div 8 = 2\frac{1}{8}$; but the same thing is more commonly expressed thus,

$$\frac{6 + 8 + 5 - 2}{6 + 2} = \frac{17}{8} = 2\tfrac{1}{8}$$

* These are merely signs to show that these operations ought to be performed according to the rules of Arithmetic, a conspectus of which will be found in the Appendix at the end of the volume.

The application of these signs to the expression of rules is exceedingly simple. Thus, connected with the circle we have the following rules:

1st. The circumference of a circle will be found by multiplying the diameter by 3·1416.

2d. The diameter of a circle may be found by dividing the circumference by 3·1416.

3d. The area of a circle may be found by multiplying the half of the diameter, by the half of the circumference, or by multiplying together the diameter and circumference, and dividing the product by 4, or by squaring the diameter and multiplying by ·7854.

Now all these rules may be thus expressed:

1st. $\text{diameter} \times 3{\cdot}1416 = \text{circumference}.$

2d. $\frac{\text{circumference}}{3{\cdot}1416} = \text{diameter}.$

3d. $\frac{\text{diameter}}{2} \times \frac{\text{circumference}}{2} = \text{area}.$

or, $\frac{\text{diameter} \times \text{circumference}}{4} = \text{area}.$

or, $\text{diameter}^2 \times {\cdot}7854 = \text{area}.$

This latter mode of expressing these rules is evidently the best, as we are enabled to comprehend them by one glance of the eye; and the very form in which they are expressed, shows us at once how the numbers in any particular question are to be arranged for the purpose of solution. It often happens that the rules must be written in a shorter form still, as in this way they will sometimes occupy more than one line. The expedient fallen upon in this case is very simple, one letter being made to stand for a whole word, as in the above rules; *c* for circumference, *d* for diameter, and *a* for area, and they would in this way be written:

1st. $d \times 3{\cdot}1416 = c.$

2d. $\frac{c}{3{\cdot}1416} = d.$

3d. $\frac{d}{2} \times \frac{c}{2} = a.$

or, $\frac{d \times c}{4} = a.$

or, $d^2 \times {\cdot}7854 = a.$

Let us, for the sake of illustration, show the application of these rules to particular examples.

Suppose that the diameter of a circle is 10 inches, then

1st. $10 \times 3{\cdot}1416 = 31{\cdot}416 =$ the circumference.

The circumference being 31·416, then

2d. $\frac{31{\cdot}416}{3{\cdot}1416} = 10 = \text{diameter.}$

3d. $\left.\begin{array}{l} \frac{10}{2} \times \frac{31{\cdot}416}{2} = \\ \text{or,}\quad \frac{10 \times 31{\cdot}416}{4} = \\ \text{or,}\quad 10^2 \times {\cdot}7854 = \end{array}\right\} 78{\cdot}54 = \text{area.}$

Another illustration will make the subject fully understood.

The common rule for determining the power of the steam engine, may be expressed as follows:

Multiply together the square of the diameter of the piston in inches, tho number of strokes per minute, the effective pressure of the steam in lbs. upon each square inch of the piston, the length of the stroke in feet, and the constant number ·0000476; and the product will be the horses' power of the engine: or,

Let d, represent the diameter of piston in inches,

n, the number of strokes per minute,

p, the effective pressure of steam on each square inch,

l, the length of the stroke in feet:

The engine being of the double stroke kind, the rule is $d^2 \times n \times p \times l \times {\cdot}0000476$ = horses' power.

Suppose that the engine is of the high pressure kind, and that the steam has an elastic force of 5 atmospheres, or 75 lbs., this, diminished by $\frac{1}{3}$ to allow for friction and inertia, will give the effective pressure equal to about 50 lbs. to the square inch. Now if the diameter of the cylinder be 20 inches $= d$, the length of stroke $= 3$ feet $= l$, the number of strokes in a minute $= 36 = n$, then putting these numbers in the form of the foregoing rule, instead of their respective letters, we have $20^2 \times 36 \times 50 \times 3 \times {\cdot}0000476 = 102{\cdot}816$ = the horses' power of the engine.

See *Circle* and *Steam Engine*.

MECHANICS' POCKET DICTIONARY.

Abacus, in Architecture, the upper part of the capital of a column. In the Tuscan, Doric, and Ionic orders, the abacus or table is flat and square, but in the rest of the orders, the sides of the abacus are arched inwards, having a *rose* in the centre.

Abscissa, in Geometry signifies a part cut off. See *Curve.*

Abutment, the land pier of a bridge. See *Bridge.*

Accelerated Motion, is that in which the velocity of the moving body is continually increased. When the velocity increases equally in equal intervals of time, the motion of the body is said to be *uniformly* accelerated. An instance of uniformly accelerated motion occurs in the case of bodies falling to the earth by reason of the action of gravity; and as a knowledge of this subject is of extensive use in Mechanics, all our remarks on accelerated motion will be directed to its elucidation.

We observe in the outset, that a uniform motion will take place where the force which urges the body ceases to act after the body has been put in motion, according to Newton's primary laws of motion. (See *Motion.*) For instance, if a ball at A be impelled by a force, in consequence of which it is moved in the direction A B, and with such velocity, that it will pass over the first foot in one second of time, then, if it is not hindered, it will pass over the second foot in the 2nd second of time, the third foot in the 3d second of time, and so on.

A 1 2 3 4 5 6 7 8 B

But if, when the ball arrives at the end of the first foot, it receives another impulse of force in the same direction, and which will impart to it as much more velocity as it had before, then will it move over two feet in the next second of time; for the velocity which the ball had before this new impulse, would have carried it over the second foot in the 2nd second of time, and the second impulse adds to it just as much more velocity; so that it will pass over two feet in the 2nd second of time, and if not obstructed, it would move on with the velocity of two feet in the second. But suppose that at the end of the 2nd second of time, it receives another impulse of the force, this will cause it to move over three feet in the third second of time, and so on, every such succeeding impulse adding to the preceding velocity an increase of one foot in the second. The reader is not to suppose that if a billiard ball, for instance, is struck with a certain force, which causes it to move on the table with a velocity of one foot in the sec. it will move with twice that velocity, after receiving a stroke precisely of the same intensity with the first. The ball when it receives the second stroke is in motion, and, as it were, flies away from the impulse, and consequently a part of it is lost. (See *Collision.*) But it is easy to see that successive impulses, all equal in effect, and repeated at equal intervals of time, and in one direction, will cause the body to move with a velocity which increases with the time: so that in the 3rd second it is three times as great as it was in the 1st; at the 5th, five times; at the 8th, eight times, and so on. In the case we have supposed, the acceleration of the motion or increase of velocity, cannot be said to be absolutely uniform, as it increases by starts separated by intervals of a second of time; but if we suppose that the ball receives a thousand impulses, all equal, and at equal intervals during one second, then these starts will become insensible, and the body will appear to move with a uniformly accelerated motion; and as the increase of velocity must observe the same law as before, it is plain that at the half of the second, the velocity must be half of what it is at the end of the second. Now, it will not be difficult to see, that when a body in motion is uniformly accelerated, the velocity at the middle of the timo is such, that had it been continued uniformly from the beginning to the end of the time, the body would have passed over the same space as it did with the uniformly accelerated motion; for the velocity at the middle, is just the mean between the first and last velocities, and is as much greater than the one, as it is less than the other, so that the increase of velocity after the middle, goes as it were to make up for the deficiency before it.

Let us now turn our attention to the case of falling bodies. They fall to the earth by reason of the action of gravity, which is a force acting constantly. Now it has been found, that heavy bodies falling to the earth in consequence of the action of gravity, do, in the latitude of London, fall through 16·095 feet in the first second of time of their descent. This has been determined by Captain Kater, and may be regarded as more correct than the number usually given, which is 16·0833 feet. It may however be remarked, that for all ordinary purposes the fraction may be neglected altogether, and thus the space through which a body will fall during the first second of time of its descent, may be taken in round numbers at 16 feet. See *Gravity*, and *Pendulum*.

Gravity being a constant force, may be supposed to act on the falling body by impulses repeated in rapid succession after each other, and therefore, from the beginning to the end of the descent of the falling body during the first second of time, its motion will be uniformly accelerated, so that the velocity at the last instant of the time will be greater than at any foregoing instant. It has been stated above, that the body will fall through a space of 16 feet in the first second of time, and the velocity of 16 feet in the second, must be that which the body had at the middle of the second; since, if the body had moved uniformly with the velocity which it had at the middle of the time, it would have passed over the same space as the body did with the uniformly accelerated motion. But the velocity at the end of the time is double of what it was at the middle: it follows, that since the velocity at the middle of the first second is 16 feet in the second, the velocity at the end of the first second must be 32 feet in the second. Were the action of gravity to cease after the first second of time, the falling body would pass through a space of 32 feet per second, uniformly, to the surface of the earth. The action of gravity, however, does not cease, but continues to affect the body during the whole time of its fall; so that in the 2nd second of its descent it will cause it to move through 16 feet more, independent of any former velocity that the body had acquired. We saw before, however, that the body had at the end of the first second acquired such a velocity as would carry it through 32 feet in the 2nd second, and this added to the 16 feet that the body has received from the continued action of gravity in the 2nd second of time, makes the whole space which the body will pass through in the 2nd second to be $32 + 16 = 48$ feet. The space passed over in the 2nd second, is to the space passed over in the first, as $48 : 16$, or as $3 : 1$; and the whole space passed over in the first two seconds is $48 + 16 = 64$; or calling the space passed over in the first second 1, then the second will be 3, and the whole space in the two first seconds 4. Carrying on the same mode of reasoning, we will find that the space passed over in the 3rd second of time is 80 feet, or that it is to the space passed over in the first as 5 to 1. Hence in general it may be inferred, that if the times be as the numbers 1, 2, 3, 4, 5, 6, &c., the spaces passed over from the beginning will be 1, 4, 9, 16, 25, 36, &c., and the space passed over in the successive seconds or intervals of time, will be as the numbers 1, 3, 5, 7, 9, 11, 13, &c.; and the laws of falling bodies may be thus expressed:

The space passed through by a body falling from rest in free space is in proportion to the square of the time of falling, or the time is as the square root of the space.

The velocity acquired by a body falling from rest in free space, is in proportion to the time of falling, or the square root of the space fallen through is in proportion to the velocity acquired.

If a body were to move on uniformly with the velocity which it has acquired at any time, it would pass over twice the space with this velocity in the same time that it did with the accelerated motion.

These laws may be formed into rules for all the circumstances of falling bodies. In these rules it is unnecessary to be troubled with the fraction in the number 16·095, (the space fallen through by a body in the first second of time,) but to consider the number simply as 16 feet, and the rules will be as follow :*

The velocity $= 32 \times \text{time}$

$= \sqrt{(64 \times \text{the space})}$.

The time $= \dfrac{\text{velocity}}{32}$

$= \sqrt{\left(\dfrac{\text{space}}{16}\right)}$

The space $= 16 \times \text{time}^2$

$= \dfrac{\text{velocity}^2}{64}$

Examples.—If a body has fallen through 60 feet, what is the velocity which it has acquired?

By the rule it is $\sqrt{(64 \times 60)} = \sqrt{3840} = 61{\cdot}96$ feet in the second.

In what time did the body fall through that space of 60 feet?

By the rule $\sqrt{\left(\dfrac{60}{16}\right)} = \sqrt{3{\cdot}125} = 1{\cdot}768$ seconds.

What is the space passed through by a body in five seconds, and what is the velocity acquired?

By the rule $16 \times 5^2 = 16 \times 25 = 400$ feet, the space fallen through by the body, and the velocity acquired is $32 \times 5 = 160$ feet in the second.

When a body is projected from the surface of the earth, its motion upwards will be uniformly retarded, since gravity is continually acting in opposition to its ascent, and the body will only rise to a certain height, and then descend. Now the velocity with which it is projected being known, the height to which it will ascend may be found; for the velocity with which it set out, will be such as it would acquire by falling from the height where it stops. Thus, if the body were projected with a velocity of 160 feet in the second, it would rise to the height of 402 feet. See *Projectile*.

To save the trouble of calculation we have added two tables, which will be found of great use in the construction of machines which depend on

* The velocity is that acquired at the end of the time, the space that fallen through from the beginning, and the time is also reckoned from the commencement of the body's fall.

the action of falling bodies. In these tables the number taken as the basis is 16·095, as it is nearer the truth than 16, as given in the rules above.

ACCELERATION OF THE MOTION OF FALLING BODIES.

TABLE A.

The time in seconds of the body's fall.	The space fallen through during each second in feet.	The space fallen through from the beginning in feet.	The velocity acquired in feet.
1	16·095	16·095	32·19
2	48·285	64·380	64 38
3	80·475	144·855	96 57
4	112·665	257·520	128.76
5	144·855	402·375	160 95
6	177·045	579 420	193·14
7	209·235	788·655	225·33
8	241·425	1030·080	257·52
9	273·615	1303·695	289·71
10	305·805	1609·495	321 90
11	337 995	1947·490	354·09
12	370·185	2317·675	386·28
13	402·375	2720·050	418·47
14	434·565	3154·615	450.66
15	466·755	3621·370	482·85
16	498·945	4120 315	515·04
17	531·135	4651·450	547·23
18	563·325	5214·775	579·42
19	595·515	5810·290	611·61
20	627·715	6437·955	643·80
21	659·895	7097·890	675·99
22	692·085	7789·975	708·18
23	724·275	8514·250	740 37
24	756·465	9270·815	772·56
25	788·655	10159·470	864 75
26	820 845	11080·325	896·94
27	853 035	11833·360	929·13
28	885·225	12718·585	961·32
29	917·415	13636·000	993·51
30	949·605	14585·605	1025·70
31	981·795	15567·400	1057 89
32	1013·985	16581·385	1090·08
33	1046·175	17627 560	1122·27
34	1078·365	18705·925	1154·46
35	1110·555	19816 580	1186·65
36	1142·745	20959 325	1218·84
37	1174·935	22134·260	1251·03
38	1207·125	23341·385	1283·22
39	1239·315	24580·700	1265·41
40	1271·505	25852·205	1297·60

TABLE B.

Space through which the body falls in feet.	Time which it requires in seconds to fall through that space.	Velocity acquired at the end of the time.
1	0·2271	7·3103
2	0·3437	12·0637
3	0·4186	13 4165
4	0·4864	15·6562
5	0·5682	18·2903
6	0·5956	19·1725
7	0·6433	20·7078
8	0·6879	22·1435
9	0 7297	23·4890
10	0·7693	23·7647
11	0·8066	25·9628
12	0·8426	27·1232
13	0 8769	28·2264
14	0·9099	29·2786
15	0·9416	30 3601
16	0·9729	31·3176
17	1·0029	32·2833
18	1·0313	33·1975
19	1·0627	34 2083
20	1·0878	35·0066
21	1·1145	35·8757
22	1·1408	36·7223
23	1·1663	37·5431
24	1·1914	38·3511
25	1·2138	39 0722
26	1·2403	39·7252
27	1·2639	40·6849
28	1·2870	41·4285
29	1·3106	42·1882
30	1·3298	42·8966
31	1·3549	43·6042
32	1·3758	44·2770
33	1·3972	44 8558
34	1·4157	45·5613
35	1·4390	46.3214
36	1·4594	46·9777
37	1·4794	47·8111
38	1·4994	48·2656
39	1·5190	48·9276
40	1·5380	49·0826

ACCIDENTAL POINT, in perspective, is that point in the horizontal line, where the projections of parallel lines meet the perspective plane. See *Perspective*.

ACROSTICIA, in architecture, the sharp pinnacles ranged round the tops of flat buildings, with walls and balusters; also small pedestals for supporting statues.

Addition. See Appendix.

Adhesion, a kind of attraction which takes place between the surfaces of bodies; for instance, if two pieces of lead are filed flat on the face, and placed together, so that the flat surfaces touch each other, then it will be found that it requires considerable force to separate them. The force which resists the separation is called *Adhesion*. Adhesion is often confounded with *Cohesion*, but although they are both species of attraction, they are nevertheless distinct from one another. Adhesion is the force which tends to unite the faces of bodies of different kinds together; cohesion, on the other hand, is that force which tends to draw the particles of the same body together. See *Cohesion*.

From experiments it would appear, that the force of adhesion differs in different bodies; for instance, gold and copper adhere to the surface of mercury with forces which are to one another, as 446 to 142; and it would also seem, that the force of adhesion in any two bodies increases with the number of touching points in the adhering surfaces, or on the extent of surface in contact. When two bodies adhere, it is observed that they are most difficult to separate when the force employed for that purpose is made to act at right angles to the plane of the touching surfaces, so that if it takes a force of 132 lbs. to draw asunder two surfaces adhering, when the separating force acts at right angles to the surfaces in contact, 8 or 9 ounces will separate them, when applied in such a direction that they will slide off. It is also remarkable in the adhesion of bodies, that when the force of adhesion is so great that almost no constantly acting force will overcome it, it may be overcome by a slight blow near it. This may be observed every day in the starting of bolts and nails. To know the force of adhesion of nails of different kinds, and in different kinds of wood, is of great moment to the workman, but the only satisfactory source of information on the subject that we are yet possessed of, is derived from the experiments of Mr Bevan. From his experiments the following facts are collected:—Small sprigs, 4560 of which weighed one pound, and the length of each was 44 hundredth parts of an inch, forced in dry Christiana deal to the depth of 0·4 inches in a direction at right angles to the grain of the wood, required 22 lbs. to extract them. Sprigs half an inch long, having 3200 in the pound, and driven into the same kind of deal to the length of 44 hundredth parts of an inch, or nearly half an inch, required 37 lbs. to extract them. Nails, 618 of which make 1 lb., each nail being one and a quarter inch long, when driven half an inch into the same kind of wood, required 58 lbs. to extract them. Nails two inches long, 130 of which were in the lb., when forced one inch into the wood, required a force of 320 lbs. to extract them. Cast iron nails, 380 of which were in the pound, the length of one nail being an inch, when driven half an inch into the wood, required a force of 72 lbs. to draw them. Nails, 73 of which weighed 1 lb., each of which was two inches long, when driven one inch into the deal, required a force of 170 lbs. to extract them, and the same nails when driven an inch and a half, required 327 lbs. to extract them, and when driven two inches, 530 lbs. It was found that the adhesion of a nail driven into Christiana deal at right angles to the grain, was to the force of adhesion when driven with the grain, as 2 to 1, but in elm, as 4 to 3. If the force of adhesion of a nail and Christiana deal be 170, then in similar circumstances the number for green sycamore [plane tree] will be 312; for dry oak, 507; and for dry beech, 667. With regard to the relative adhesion of screws and nails, it was found that a common screw, whose diameter was one fifth of an inch, held with a force three times greater than a nail $2\frac{1}{2}$ inches long, 73 of which made a lb., when both entered the same length into the wood. A half inch iron pin applied in the way of a pin to a tenon in the mortice, the thickness of the board being ·87 of an inch, and the distance of the centre of the hole from the end of the board being 1·05 inches, it required a force of 976 lbs. to extract the pin.

To the same experimenter we are indebted for some important results concerning the adhesion of glue. From his experiments we are led to conclude, that the surfaces of dry ash wood, cemented by newly made glue, in the dry weather of summer, would after 24 hours standing, adhere with a force of 715 lbs. to the square inch. But when the glue has been frequently made, and the cementing effected in wet weather, the force of adhesion is much lower, varying from 360 to 500 lbs. to the square inch. When Scottish fir cut in autumn was tried, the force of adhesion was found to be 562 lbs. to the square inch; from which it would appear, that if this cement be properly used, the strength of the glued part will exceed that of the rest of the wood. In these experiments of Mr Bevan, the force used to draw the surfaces of the wood asunder, was applied perpendicularly to the adhering surfaces, the pressure or weight being applied gradually and allowed to remain for two or three minutes before the adhesion was overcome.

Adit, an entrance or passage; a term frequently employed in talking of mines, to denote the aperture or opening by which they are entered, or by which the minerals or waters are drawn away, and the air shaft also sometimes goes by the name of Adit.

Æolipile, consists of a hollow vessel containing water, from the upper part of which there proceeds a pipe of small bore. When the vessel is placed upon the fire, steam is generated and is impelled through the pipe, the orifice of which is directed to the fire, and the instrument acts as a kind of bellows. On a large scale it is sometimes employed to increase the draught of the steam engine furnace; as a jet of steam of high pressure carries with it a considerable portion of common air, so that when it is directed against the lower ribs of the furnace, the effect of the fire is materially increased.

Aerial Perspective, is that which represents objects diminished in size and weakened in tint in proportion to their distance from the eye, but the term relates principally to the colour. See *Shade*.

Affinity, a term used in chemistry to denote that kind of attraction by which the particles of different bodies unite, and form a compound possessing properties distinct from any of the substances which compose it. Thus, when an acid and alkali combine, a new substance is formed, called a salt, perfectly different in its chemical properties from either an acid or an alkali; and the tendency which these have to unite, is said to be in consequence of affinity. See *Chemistry*.

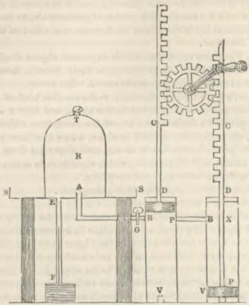
Air, common, or atmospheric. See *Atmospheric*.

Air Furnace. See *Furnace*.

Air Escape, a simple and ingenious contrivance for letting off the air from water pipes. If a range of water pipes be led over a rising ground, it will be found, that air will collect in the higher parts and obstruct the progress of the water, to remedy which inconvenience the Air Escape is employed. A hollow vessel is attached to the upper part of the pipe, in the top of which vessel there is fixed a ball cock, adjusted in such a way, that when any air collects in the pipe, it will ascend into the vessel, and by displacing the water, cause the ball to descend, and thus open the cock, when the air is allowed to escape. No water however can escape, for when that fluid rises in the vessel above a certain height, the ball rises and shuts the cock, new air then collects, displaces the water, lowers the ball, the cock is opened, and it again escapes.

Air Pipes, an invention for clearing the holds of ships and other close places of their foul air. The contrivance is simply this; a long tube open at both ends is placed with one end opening into the apartment to be ventilated, and the other out of it. The air in the outer end of the tube is rarified by heat, and the dense air from the hold comes in to supply the partial vacuum, the escape of the foul air in the hold being supplied by fresh air introduced through an opening above; and this process is carried on until the air becomes everywhere equally elastic.

Air Pump, an instrument invented by Otto de Gucricke, about the year 1654. This instrument has been much improved in form in recent times, but the principle remains the same; its chief use being to extract the air from a vessel, whereby we are said to exhaust it, or to produce a vacuum. The construction and operation of the Air Pump will be understood by a reference to the cut in the next page.



This is a sectional view of the common form of the air pump. Where R is, a bell-shaped glass vessel, open only at the bottom, and whose brim is ground perfectly flat, so that it may rest on every point on a brass plate S S, which is likewise ground to a flat surface, so that when a little hog's lard is rubbed upon the edge of the glass vessel, commonly called the receiver, and then the brim placed, by a kind of circular sliding motion, upon the brass plate, no air can pass in or out of the receiver, between its edge and the plate. Through the centre of the brass plate there is drilled an orifice A, from which orifice there is led a pipe AB, forming a communication between the receiver R and the interior of the cylinder BPV, which communication may be opened or closed by means of a stop-cock at G. The cylinder or barrel BPV is furnished with a piston BP accurately fitted to the cylinder, but capable of free motion up and down, which motion is effected by means of a piston rod DC, which moves through a stuffed or air-tight collar at D. The bottom of the cylinder or barrel is furnished with a valve V opening outwards. This cylinder communicates with another BXPV, constructed and furnished in a similar manner; and the two piston rods are provided with racks CC at the top, the teeth of which are acted upon by those of a wheel placed between them, as may be seen in the figure. Let us now attend to the mode of action. Suppose the stop-cock at G open, and the pistons as they are in the figure. The piston BP being at the top, a free communication is formed between the receiver R and the first cylinder, and the piston being pushed down past the orifice at B, the air contained in the cylinder or barrel will be forced into less space or compressed, and of course its elastic force increased. In consequence of this increased elasticity, the valve at V will be opened, and the air expelled. When the piston is lifted, this valve will be shut by the pressure of the atmospheric air without; thus a portion of the air which was contained in the receiver, communication pipe, and barrel, has been expelled, and that which remains will consequently be less dense; another stroke of the piston will diminish the density still more; and this process may be continued until the density be so diminished, that when compressed by the descent of the piston to the bottom of the barrel, its elastic force is only sufficient to open the valve V. It will be easily seen, that the exhaustion of the air in the receiver depends on the elasticity of the air; for when the piston descends and expells the air contained within the barrel, (which it will do completely, if it go to the bottom,) and then in returning, the valve V being shut, a vacuum will be formed in the barrel until the piston in its ascent passes the orifice B, when the air within the receiver will expand and fill the whole cavity. The operation of the second barrel and piston is precisely similar to that of the first, so that when the one is understood, the other requires no explanation.

The degree of exhaustion will depend upon the workmanship of the pump, the number of strokes of the piston, and the relative capacities of the receiver and barrels; but perhaps in no case can the vacuum in the receiver be made perfect. For the purpose of determining the degree of exhaustion, a mercurial gage is employed, which acts on a similar principle with the common barometer. A glass tube EF, rests in a bason of mercury F, and its upper orifice opens into the brass plate SS. When the exhaustion of the receiver has commenced, the pressure of the air in the receiver must be less than that of the atmosphere without. Wherefore, since the air in the receiver presses the mercury down the tube, and the atmosphere pressing on the mercury in the bason forees it up the tube, with the greater force the mercury will rise in the tube, and it will rise the higher according to the difference of the density, and consequently elastic force of the air in the receiver, and that of the atmosphere.

Air Pump, as applied to the steam engine. See *Condension*.

Air Valve, a valve commonly applied to steam boilers for the purpose of preventing the formation of a vacuum when the steam happens to be condensed within the boiler. The mode of action of these valves is very simple. A valve in the top of the boiler opening inwards, is kept shut by a counterweight at the end of a lever; but whenever the steam in the boiler happens to be condensed, a vacuum is formed, and the air valve is opened by the pressure of the atmosphere, consequently the air enters and destroys the vacuum. The interior of the boiler being allowed to remain in the state of vacuum, the atmospheric pressure from without might cause its sides to collapse, and thus effect the destruction of the boiler. There have been instances of boilers collapsing even though furnished with an air valve, but in this case the counterweight must have been too great, or the valve itself too small; an error which we fear is pretty common, and ought to be avoided.

Air Vessel, a chamber containing air, attached to pumps and other water works, the use of which is to make the discharge constant, where the supply of water is intermittent. In the forcing pump for instance, where the water has to be sent up through a long range of pipes, the discharge from the pump being irregular, the impetus of the water at every stroke would jolt the machinery, which however may be prevented by an air vessel. The ejection pipe of the pump leads into a chamber containing air, and this chamber communicates with the pipes through which the water is to flow, the latter being less in diameter than the former. Now, when water by a stroke of the pump is sent into the air vessel, the air within it will be compressed, and before the pump has made another injection into this vessel, the air will by its elastic power force the water in a constant stream up tho pipes, and thus a continuous stream is kept in the rising main. Air vessels are with great advantage applied to the suction end of a pump. See *Pump*.

Ajutage, a tube fitted to the mouth of a vessel for the purpose of modifying the discharge of water. For an account of the effects of Ajutages of different forms and sizes, see *Discharge*.

Alcove, in architecture, a recess separated from a chamber by a partition of columns.

Algebra, Signs of. See page 1.

Alloy, means generally a baser metal formed by the mixture of a valuable metal, as silver, with one of less value, as copper. In scientific language the value of the metal is not taken into account.

Altitude of a figure, the length of a line drawn perpendicularly from the vertex to the base of a figure.

Altitudes, measurement of. See *Heights*.

Amalgam, a mixture of mercury with any other metal. Thus an amalgam of tin or lead, is a mixture of mercury with tin or lead.

Anchor, a well known instrument for mooring ships. The form of the anchor is so very well known, that it requires no diagram for its illustration in this work, where we will introduce only such subjects connected with ship building as are necessary for the description of steam vessels. The common anchor consists of a long bar of malleable iron, having a ring at one end, and two projecting curved arms at the other. This long bar is called the shank of the anchor, and near the top it passes through a cross piece of oak called the stock, which consists of two pieces strongly bolted together. The arms at the bottom of the shank taper, and form with the shank an angle of 30°., being terminated in broad pointed isosceles triangles, called the flukes of the anchor.

The goodness of the metal will in a great measure determine the quality of the anchor. The shank, arm, and flukes are all forged separately, and then welded or shut together. The general rule for the dimensions of an anchor is, that the length of the anchor should be ·4 of the greatest breadth of the ship; so that if the ship be 30 feet, then the length of the anchor will be $30 \times \cdot 4 = 12 \cdot 0$ feet. The shank is thrice the length of one of the flukes, and half the length of the beam. When the shank is 8 feet long, the two arms are 7 feet, measured with a tape line round the curve from tip to tip. The following tabular view of the lengths and weights of anchors for vessels of various breadths, may serve as a guide. The column B gives the breadth of the ship, L the length of the anchor, and W the weight of the anchor in pounds.

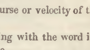
B.	L.	W.	B	L	W.
10	4·0	64	28	11·2	1405
12	4·6	110	30	12·0	1728
14	5·6	175	32	12·8	2097
16	6·0	262	34	13·6	2500
18	7·1	373	36	14·4	2515
20	8·0	512	38	15·2	3512
22	8·6	681	40	16·0	4096
24	9·6	884	42	16·6	4742
26	10·4	1124	44	17·6	5450

The weights of anchors will be as the cubes of their lengths, and from the above table therefore the weight of anchors of all lengths may be determined.

Anemometer, an instrument for measuring the force and velocity of wind. See *Wind*.

Anemoscope, a machine that shows either the course or velocity of the wind. See *Wind*.

Angle, in Geometry, means nearly the same thing with the word inclination; thus, if two lines drawn on a plane surface are so situated, that they meet in a point, or would do so, if long enough, they form an opening which is called an angle. The point where the lines which form the angle meet, is called the angular point; and if on this point as a centre, the one point of a compass be placed, while

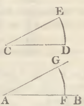


the other is made to describe the arc of a circle, which passes through both of the lines that form the angle, that arc will be the measure of the angle. It is to be observed, however, that it is not the length of the arc which determines the magnitude of the angle, but the number of degrees, minutes, and seconds contained in it, so that if the arc consists of 20° 30′, the angle is said to be one of 20° 30′.

Angles are of various kinds, as Right, Obtuse, and Acute. When one line meets another, or stands upon it, and makes the angles on both sides equal to each other, then these angles are each called a right angle, and in this case the one line is said to be perpendicular to the other. In the common language of workmen, the one line is said to be square with the other; and if the one line be horizontal, as in the figure, the perpendicular is said to be plum to it. The arc which measures a right angle, is the quarter of the whole circumference, or is a quadrant, and contains 90 degrees; any angle measured by an arc less than this, is said to be acute (sharp), and if the arc which measures the angle be greater than a quadrant, the angle is said to be obtuse (blunt).

We may now pass to the common geometrical problem.

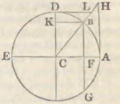
At a given point A, *in a line* AB, *to make an angle equal to a given angle*, C.



The method of performing which is as follows: From the points A and C, describe with the same opening of the compass the arcs DE and FG. Then take the distance DE by the compass, and placing one leg on F mark the same distance FG; join AG, and the required angle will be formed. It is to be observed, that when an angle is denoted by letters, that letter which is at the angular point is always read in the middle, as the angle DCE, or BAG.

The measurement and formation of angles is of extensive application in the mechanical arts, and it is therefore necessary that the artificer should be familiar with the subject. On this account we will introduce in this place an explanation of the various lines employed for that purpose, which lines however are more frequently treated of under the head of Trigonometry; but in the course of this work we will be often concerned with angles, which are not connected with triangles, and we have therefore thought proper to introduce this subject in the present article.

For the division of the circle, we refer to the word circle, where an explanation of the terms, degree, minute, and second, will be found. But it is to be remarked, that as an arc is the measure of an angle, any line which refers to the one, will also be understood to refer to the other; thus the sine of any arc, is also the sine of the angle of which that arc is the measure; so likewise the tangent of any angle, is also the tangent of the arc which measures that angle.



The complement of an arc or angle, is what it wants of a quadrant, or 90°. Thus if AD be a quadrant, AB is the complement of the arc BD, and BD is likewise the complement of AB; and the angles which these arcs measure, that is the angles DCB and BCA, are also complements of each other.

The supplement of an arc or angle is what it wants of a semicircle, or 180°. Thus the arcs AB and BE are supplements of each other, so also are the angles ACB and BCE. Hence the complement of an arc or angle of 50°, will be an arc or angle of 40°; but the supplement will be 130°.

The sine of an arc is the line drawn from one extremity of the arc, perpendicular to the diameter, passing through the other extremity. Thus BF is the sine of the arc AB, and the sine of an angle is the sine of the arc that measures that angle, wherefore BF is the sine of the angle ACB.

The versed sine is that part of the diameter intercepted between the sine and the arc. Thus the versed sine of the arc AB, is FA.

The tangent of an arc is a line touching the circle in one extremity of the arc, and continued from thence to meet a line drawn from the centre of the circle, and passing through the other extremity of the arc. Thus AH is the tangent of the arc AB, or of the angle ACB. The line CH, which is drawn from the centre to meet the extremity of the tangent, is called the Secant.

The sines, tangents, versed sines, and secants of the complements of any arc or angle, are called the co-sines, co-tangents, co-versed sines, and co-secants of that arc or angle. Thus KB is the cosine of AB, DL the cotangent, &c.; co being only a contraction for the word complement.

The chord of an arc is a straight line drawn from one extremity of the arc to the other. See *Chord*.

These definitions being understood, we may proceed to remark that the lines employed for measuring angles bear certain relations to one another, so that if the length of any one or more be known, the lengths of the rest may be determined. It has been usual to take the lengths of these lines in measures of the radius. The radius may be reckoned 1, 10, 100, 1000, or any other number. In the tables of sines and tangents which follow, the radius is taken 1, and the sines and tangents for every five minutes of the quadrant, stated accordingly. In using these tables for calculation, the following rules ought to be attended to:

Any angle being given, to find its sine or tangent in the table; look for the degrees in the horizontal line at the top of the table, and the minutes in the perpendicular column at the left side, and where these two columns meet, the sine or tangent will be found. Thus to find the sine of 14° 15′; in the second division of the table of sines there will be found 14 at the top, and 15 in the left hand column, and where these meet ·24615 will be found, being the sine of the required angle. In the table of tangents we follow a similar method, and the tangentof the same angle will be found to be ·25396.

If it be the cosine or cotangent that we wish to find, we look for the degrees in the bottom line, and the minutes in the column at the right side of the table. Thus the cosine of the angle 14° 15′, will be found to be ·96923; and the cotangent of the same angle 3·93750.

In using the numbers in these tables, it will often be found that the answer is a sine or a tangent, in which case it will be required to find the corresponding angle. It will be easily seen that the numbers in both tables increase from the beginning to the end, and therefore, if the result of our calculation be the sign ·56039, we run our eye along the table of sines, until we come to the exact number, which we find to be the sine of 34° 5′, or the cosine of 55° 55′. When the sine or tangent cannot be found exactly in the table, then the next nearest is taken, and the angle corresponding to it may be regarded as the answer. The table of tangents is used in like manner; but it is to be remembered, that although the points are not put in the tables, that all the sines below 90° are less than units, and therefore are decimals, so likewise all the tangents below 45°.

From these two tables all the other lines which we have noticed above may be found.

Thus for the secant of any angle, divide 1 by the cosine of that angle. Thus the cosine of 21° 30′, is ·93041; therefore,

$$\frac{1}{\cdot 93041} = 1\cdot 07535.$$

To find the cosecant; divide 1 by the sine of the angle; thus the cosecant of the same angle 21° 30′, will be,

$$\frac{1}{\cdot 36650} = 2\cdot 72880.$$

To find the versed sine; subtract the cosine from 1. Thus the versed sine of the angle 21° 30′, will be

$$1 - \cdot 93041 = \cdot 06959.$$

For the coversed sine; subtract the sine of the angle from 1. Thus, for the same angle we have the coversed sine,

$$1 - \cdot 36650 = \cdot 6335.$$

The chord of any angle may be found by taking the sine of half the angle and doubling it. Thus the chord of 21° 30′ will be found.

$$\text{Sine of } \frac{21^\circ\ 30'}{2} = \text{sine of } 10^\circ\ 45' = \cdot 18652.$$

Therefore $\cdot 18652 \times 2 = \cdot 37304 =$ the chord of 21° 30′.

We will have frequent occasion during the course of this work to show the extensive use of these tables in the calculations of the engineer; but in the mean time, the following may be taken as a specimen:

If a body be projected up an inclined plane with a certain force, the constant action of gravity and friction will conspire to check its progress; but leaving friction altogether out of consideration, there will be a certain determinate point to which the body will ascend, and no farther, for then its original velocity will be entirely destroyed by the constant action of gravity. This point may be found by the following rule; the velocity being reckoned in feet per second;

$$\frac{\text{The velocity at the beginning}^2}{64 \times \text{sine of plane's inclination}} = \text{the distance of the point where}$$

the body stops, reckoned from the bottom of the plane.

If a body be projected up a smooth inclined plane, with a velocity at the commencement of 20 feet in the second, the inclination of the plane being 38° 30′, to what height will the body ascend?

By the table of sines it will be found that the sine of 38° 30′, is ·62251, wherefore,

$$\frac{20^2}{64 \times \cdot 62251} = \frac{400}{39 \cdot 84064} = 10 \cdot 015 \text{ feet.}$$

Angle of Application. See *Force*.

Angle of Incidence. See *Collision*.

Angle of Reflection. See *Collision*.

Angle of Traction; the inclination of the traces or line of draught to the roadway, on which a weight is drawn. See *Inclined Plane*.

SINES OF ANGLES.

	0	1	2	3	4	5	6	7	8	9	
0	00000	01745	03489	05233	06975	08715	10452	12186	13917	15643	60
5	00145	01890	03635	05378	07120	08860	10597	12331	14061	15787	55
10	00290	02036	03780	05524	07265	09005	10742	12475	14205	15930	50
15	00436	02181	03926	05669	07410	09150	10886	12619	14349	16074	45
20	00581	02327	04071	05814	07555	09205	11031	12764	14493	16217	40
25	00727	02472	04216	05959	07700	09439	11175	12908	14637	16361	35
30	00872	02617	04361	06104	07845	09584	11320	13052	14780	16504	30
35	01018	02763	04507	06250	07991	09729	11464	13196	14924	16648	25
40	01163	02908	04652	06395	08135	09874	11609	13341	15068	16791	20
45	01309	03053	04797	06540	08280	10018	11753	13485	15212	16935	15
50	01454	03199	04943	06685	08425	10163	11898	13629	15356	17078	10
55	01599	03344	05088	06830	08570	10308	12042	13773	15499	17221	5
	89	88	87	86	85	84	83	82	81	80	

	10	11	12	13	14	15	16	17	18	19	
0	17364	19080	20791	22495	24192	25881	27563	29237	30901	32556	60
5	17508	19223	20933	22636	24333	26022	27703	29376	31040	32694	55
10	17651	19366	21075	22778	24474	26162	27843	29515	31178	32831	50
15	17794	19509	21217	22920	24615	26303	27982	29654	31316	32969	45
20	17837	19651	21359	23061	24756	26443	28122	29793	31454	33106	40
25	18080	19794	21501	23203	24897	26583	28262	29931	31592	33243	35
30	18223	19936	21644	23344	25038	26723	28401	30070	31730	33380	30
35	18366	20079	21785	23485	25178	26864	28541	30209	31868	33517	25
40	18509	20221	21927	23627	25319	27004	28680	30347	32006	33654	20
45	18652	20364	22069	23768	25460	27144	28819	30486	32143	33791	15
50	18795	20506	22211	23909	25600	27284	28958	30624	32281	33928	10
55	18938	20648	22353	24051	25741	27423	29098	30763	32419	34065	5
	79	78	77	76	75	74	73	72	71	70	

	20	21	22	23	24	25	26	27	28	29	
0	34202	35836	37460	39073	40673	42261	43837	45399	46947	48481	60
5	34338	35972	37595	39207	40806	42393	43967	45528	47075	48608	55
10	34475	36108	37730	39340	40939	42525	44096	45658	47203	48735	50
15	34611	36243	37844	39474	41071	42656	44228	45787	47332	48826	45
20	34748	36379	37999	39608	41204	42788	44359	45916	47460	48989	40
25	34884	36514	38133	39741	41336	42919	44489	46045	47588	49115	35
30	35020	36650	38268	39874	41469	43051	44619	46174	47715	49242	30
35	35156	36785	38402	40008	41601	43182	44749	46303	47843	49368	25
40	35293	36920	38536	40141	41733	43313	44879	46432	47971	49495	20
45	35429	37055	38671	40274	41866	43414	45009	46561	48098	49621	15
50	35565	37190	38805	40407	41998	43575	45139	46690	48226	49747	10
55	35701	37325	38939	40540	42130	43706	45269	46818	48353	49874	5
	69	68	67	66	65	64	63	62	61	60	

	30	31	32	33	34	35	36	37	38	39	
0	50000	51503	52991	54463	55919	57357	58778	60181	61566	62932	60
5	50125	51628	53115	54585	56039	57476	58896	60297	61680	63045	55
10	50251	51752	53238	54707	56160	57595	59013	60413	61795	63157	50
15	50377	51877	53361	54829	56280	57714	59131	60529	61909	63270	45
20	50503	52001	53484	54950	56400	57833	59248	60645	62023	63383	40
25	50628	52125	53607	55072	56520	57951	59365	60760	62137	63495	35
30	50753	52249	53730	55193	56640	58070	59482	60876	62251	63607	30
35	50879	52373	53852	55314	56768	58188	59590	60991	62365	63720	25
40	51004	52497	53975	55436	56880	58306	59715	61106	62478	63832	20
45	51129	52621	54097	55557	56999	58425	59832	61221	62592	63943	15
50	51254	52745	54219	55677	57119	58542	59948	61336	62705	64955	10
55	51379	52868	54341	55797	57238	58660	60065	61451	62818	64167	5
	59	58	57	56	55	54	53	52	51	50	

	40	41	42	43	44	45	46	47	48	49	
0	64278	65605	66913	68199	69465	70710	71934	73135	74314	75471	60
5	64390	65715	67021	68306	69570	70813	72034	73234	74411	75566	55
10	64501	65825	67128	68412	69674	70916	72135	73333	74508	75661	50
15	64612	65934	67236	68518	69779	71018	72236	73432	74605	75756	45
20	64723	66043	67344	68624	69883	71120	72336	73530	74702	75851	40
25	64834	66153	67451	68729	69987	71223	72437	73629	74799	75946	35
30	64944	66262	67559	68835	70090	71325	72537	73727	74805	76040	30
35	65055	66370	67666	68940	70194	71426	72637	73825	74991	76135	25
40	65165	66479	67773	69046	70298	71528	72737	73923	75088	76229	20
45	65276	66588	67880	69151	70401	71630	72837	74021	75184	76323	15
50	65386	66696	67986	69256	70504	71731	72936	74119	75279	76417	10
55	65496	66804	68093	69361	70607	71832	73036	74217	75375	76510	5
	49	48	47	46	45	44	43	42	41	40	

	50	51	52	53	54	55	56	57	58	59	
0	76604	77714	78801	79863	80901	81915	82903	83867	84804	85716	60
5	76697	77806	78890	79951	80987	81998	82985	83946	84881	85791	55
10	76791	77897	78979	80038	81072	82081	83066	84025	84958	85866	50
15	76884	77988	79069	80125	81157	82164	83147	84103	85035	85940	45
20	76977	78074	79157	80212	81242	82247	83227	84183	85111	86014	40
25	77069	78170	79246	80299	81327	82330	83308	84260	85187	86089	35
30	77162	78260	79335	80385	81411	82412	83388	84339	85264	86162	30
35	77254	78351	79423	80472	81495	82494	83468	84417	85339	86236	25
40	77347	78441	79512	80558	81580	82577	83548	84495	85415	86310	20
45	77439	78531	79600	80644	81664	82659	83628	84572	85491	86383	15
50	77531	78621	79688	80730	81748	82740	83708	84650	85566	86456	10
55	77623	78711	79775	80816	81837	82822	83787	84727	85641	86529	5
	39	38	37	36	35	34	33	32	31	30	
	60	61	62	63	64	65	66	67	68	69	
0	86602	87462	88294	89100	89879	90630	91354	92050	92718	93358	60
5	86675	87532	88362	89166	89943	90692	91413	92107	92772	93410	55
10	86747	87602	88430	89232	90006	90753	91472	92163	92827	93461	50
15	86819	87672	88498	89297	90069	90814	91531	92220	92881	93513	45
20	86892	87742	88566	89363	90132	90875	91589	92276	92934	93565	40
25	86963	87812	88633	89428	90195	90935	91647	92332	92988	93616	35
30	87035	87881	88701	89493	90258	90996	91706	92388	93041	93667	30
35	87107	87951	88768	89558	90321	91056	91763	92443	93095	93718	25
40	87178	88020	88835	89622	90383	91116	91821	92498	93148	93768	20
45	87249	88089	88901	89687	90445	91176	91879	92554	93200	93819	15
50	87320	88157	88968	89751	90507	91235	91936	92609	93253	93869	10
55	87391	88226	89034	89815	90569	91295	91993	92663	93305	93919	5
	29	28	27	26	25	24	23	22	21	20	
	70	71	72	73	74	75	76	77	78	79	
0	93969	94551	95105	95630	96126	96592	97029	97437	97814	98162	60
5	94018	94599	95150	95672	96166	96630	97064	97460	97844	98190	55
10	94068	94646	95195	95715	96205	96665	97099	97502	97874	98217	50
15	94117	94693	95239	95757	96245	96704	97134	97534	97904	98245	45
20	94166	94739	95283	95799	96284	96741	97168	97566	97934	98272	40
25	94215	94786	95327	95840	96324	96778	97202	97598	97963	98298	35
30	94264	94832	95371	95882	96363	96814	97237	97628	97992	98325	30
35	94312	94878	95415	95923	96401	96851	97270	97661	98021	98351	25
40	94360	94924	95458	95968	96440	96887	97304	97692	98050	98378	20
45	94408	94969	95502	96005	96478	96923	97337	97723	98078	98404	15
50	94456	95015	95545	96045	96516	96958	97371	97753	98106	98429	10
55	94504	95060	95587	96086	96554	96994	97404	97784	98134	98455	5
	19	18	17	16	15	14	13	12	11	10	
	80	81	82	83	84	85	86	87	88	89	
0	98480	98768	99026	99254	99452	99619	99756	99863	99939	99984	60
5	98505	98791	99046	99272	99467	99632	99766	99870	99944	99987	55
10	98530	98813	99066	99289	99482	99644	99776	99877	99948	99989	50
15	98555	98836	99086	99306	99496	99655	99785	99884	99953	99991	45
20	98580	98858	99106	99323	99511	99668	99795	99891	99957	99993	40
25	98604	98880	99125	99340	99525	99680	99804	99898	99961	99994	35
30	98628	98901	99144	99357	99539	99691	99813	99904	99965	99995	30
35	98652	98923	99163	99373	99553	99703	99822	99911	99969	99996	25
40	98676	98944	99182	99389	69597	99714	99830	99917	99972	99997	20
45	98699	98965	99200	99405	99580	99725	99839	99922	99976	99998	15
50	98722	98985	99218	99421	99593	99735	99847	99928	99979	99999	10
55	98746	99006	99236	99436	99606	99746	99855	99933	99982	99999	5
	9	8	7	6	5	4	3	2	1	0	

	0	1	2	3	4	5	6	7	8	9	
0	00000	01745	03492	05240	06992	08748	10510	12278	14054	15838	60
5	00145	01891	03637	05286	07138	08895	10657	12426	14202	15987	55
10	00290	02036	03783	05532	07285	09042	10804	12873	14350	16136	50
15	00436	02182	03929	05678	07431	09188	10951	12721	14199	16286	45
20	00581	02327	04074	05824	07577	09335	11099	12869	14647	16435	40
25	00727	02473	04220	05970	07723	09482	11246	13017	14796	16584	35
30	00872	02618	04366	06116	07870	09628	11393	13169	14945	16734	30
35	01018	02764	04511	06262	08016	09775	11540	13313	15093	16883	25
40	01163	02909	04657	06408	08162	09922	11688	13461	15242	17033	20
45	01309	03055	04803	06554	08309	10069	11835	13609	15391	17183	15
50	01454	03200	04949	06700	08455	10216	11983	13757	15540	17332	10
55	01600	03346	05094	06846	08602	10363	12130	13905	15689	17482	5
	89	88	87	86	85	84	83	82	81	80	
	10	11	12	13	14	15	16	17	18	19	
0	17632	19438	21255	23086	24932	26794	28674	30573	32492	34432	60
5	17782	19589	21407	23240	25087	26950	28832	30732	32652	34595	55
10	17932	19740	21559	23393	25242	27106	28909	30891	32813	34758	50
15	18033	19891	21712	23546	25396	27263	29147	31050	32975	34921	45
20	18233	20042	21864	23700	25551	27419	29305	31210	33136	35084	40
25	18383	20193	22016	23854	25706	27575	29463	31370	33297	35248	35
30	18533	20345	22169	24007	25861	27732	29621	31529	33459	35411	30
35	18681	20456	22322	24161	26017	27889	29779	31689	33621	35575	25
40	18835	20648	22474	24315	26172	28046	29938	31850	33783	35739	20
45	18985	20800	22627	24469	26327	28202	30096	32010	33945	35903	15
50	19136	20951	22780	24624	26483	28360	30255	32170	34107	36068	10
55	19287	21103	22903	24778	26639	28517	30414	32331	34270	36232	5
	79	78	77	76	75	74	73	72	71	70	
	20	21	22	23	24	25	26	27	28	29	
0	36397	38386	40402	42447	44522	46630	48773	50952	53170	55430	60
5	36561	38553	40571	42619	44697	46808	48953	51135	53357	55621	55
10	36726	38720	40741	42791	44871	46985	49133	51319	53544	55811	50
15	36892	38887	40911	42983	45046	47163	49314	51503	53731	56002	45
20	37057	39055	41081	43135	45221	47341	49495	51687	53919	56193	40
25	37222	39223	41251	43308	45397	47519	49679	51872	54107	56385	35
30	37388	39391	41421	43481	45572	47697	49858	52056	54295	56577	30
35	37554	39559	41591	43654	45748	47878	50039	52241	54484	56769	25
40	37720	39727	41762	43827	45924	48053	50221	52427	54672	56961	20
45	37886	39896	41933	44001	46100	48234	50404	52612	54861	57154	15
50	38053	40064	42104	44174	46277	48413	50586	52798	55051	57347	10
55	38219	40233	42275	44348	46453	48593	50769	52984	55240	57541	5
	69	68	67	66	65	64	63	62	61	60	
	30	31	32	33	34	35	36	37	38	39	
0	57735	60086	62486	64940	67450	70020	72654	75355	78128	80978	60
5	57929	60284	62689	65147	67662	70237	72876	75583	78363	81219	55
10	58123	60482	62892	65355	67874	70455	73099	75812	78598	81461	50
15	58318	60681	63095	65562	68087	70673	73323	76041	78833	81703	45
20	58513	60880	63298	65771	68300	70891	73546	76271	79069	81946	40
25	58708	61080	63502	65979	68514	71110	73771	76501	79806	82189	35
30	58904	61280	63707	66188	68728	71329	73996	76732	79543	82433	30
35	59100	61480	63911	66397	68942	71543	74221	76964	79281	82678	25
40	59297	61680	64116	66607	69157	71769	74447	77195	80019	82923	20
45	59493	61881	64322	66817	69372	71989	74673	77428	80258	83169	15
50	59690	62083	64528	67028	69588	72210	74900	77661	80497	83415	10
55	59888	62284	64734	67239	69804	72432	75127	77894	80737	83662	5
	59	58	57	56	55	54	53	52	51	50	

	40	41	42	43	44	45	46	47	
0	83910	86928	90040	93251	96568	1·00000	1·03553	1·07236	60
5	84158	87184	90304	93523	96850	1·00291	1·03854	1·07550	55
10	84406	87440	90568	93796	97132	1·00583	1·04157	1·07864	50
15	84656	87697	90833	94070	97415	1·00876	1·04461	1·08179	45
20	84906	87955	91099	94345	97699	1·01170	1·04766	1·08495	40
25	85156	88213	91365	94620	97984	1·01465	1·05071	1·08812	35
30	85408	88472	91633	94896	98269	1·01760	1·05378	1·09130	30
35	85659	88732	91901	95173	98556	1·02057	1·05685	1·09450	25
40	85912	88992	92169	95450	98843	1·02354	1·05993	1·09770	20
45	86165	89253	92439	95729	99131	1·02652	1·06303	1·10091	15
50	86419	89515	92709	96008	99419	1·02952	1·06613	1·10413	10
55	86673	89777	92980	96288	99709	1·03252	1·06924	1·10736	5
	49	48	47	46	45	44	43	42	

	48	49	50	51	52	53	54	55	
0	1·11061	1·15036	1·19175	1·23489	1·27994	1·32704	1·37638	1·42814	60
5	1·11386	1·15375	1·19528	1·23857	1·28378	1·33106	1·38060	1·43257	55
10	1·11713	1·15715	1·19881	1·24226	1·28764	1·33510	1·38483	1·43702	50
15	1·12040	1·16055	1·20236	1·24597	1·29151	1·33916	1·38908	1·44149	45
20	1·12369	1·16307	1·20593	1·24969	1·29540	1·34323	1·39335	1·44598	40
25	1·12698	1·16740	1·20950	1·25342	1·29930	1·34732	1·39764	1·45048	35
30	1 13029	1·17085	1·21309	1·25717	1·30322	1·35142	1·40134	1·45500	30
35	1·13361	1·17430	1·21669	1·26093	1·30719	1·35554	1·40627	1·45955	25
40	1·13694	1·17777	1·22031	1·26470	1·31110	1·35967	1·41061	1·46411	20
45	1·14028	1·18124	1·22393	1·26849	1·31506	1·36382	1·41496	1·46869	15
50	1·14363	1·18473	1·22757	1·27229	1·31904	1·36799	1·41934	1·47329	10
55	1·14699	1·18824	1·23123	1·27611	1·32333	1·37218	1·42373	1 47792	5
	41	40	39	38	37	36	35	34	

	56	57	58	59	60	61	62	63	
0	1·48256	1·53986	1·60033	1·66428	1·73205	1·80404	1·88072	1·96261	60
5	1·48722	1·54477	1·60552	1·66977	1·73788	1·81025	1·88734	1·96968	55
10	1·49190	1·54971	1·61074	1·67529	1·74374	1·81648	1·89399	1·97680	50
15	1·49660	1·55467	1·61598	1·68084	1·74963	1·82275	1·90068	1·98396	45
20	1·50132	1·55965	1·62124	1·68642	1·75555	1·82906	1·90741	1·99116	40
25	1·50607	1·56465	1·62653	1·69203	1·76151	1·83540	1·91417	1·99849	35
30	1·51083	1·56968	1·63185	1·69766	1·76749	1·84177	1·92098	2·00569	30
35	1·51562	1·57473	1·63719	1·70332	1·77350	1·84817	1·92782	2·01301	25
40	1·52042	1·57980	1·64255	1·70901	1·77955	1·85461	1·93470	2·02038	20
45	1·52525	1·58490	1·64794	1·71428	1·78562	1.86109	1·94162	2·02779	15
50	1·53010	1·59002	1·65336	1·72047	1 79173	1·86760	1·94857	2·03524	10
55	1·53497	1·59516	1·65881	1·72624	1·79787	1·87414	1·95557	2·04275	5
	33	32	31	30	29	28	27	26	

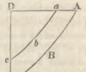
	64	65	66	67	68	69	70	71	
0	2·05030	2·14450	2·24603	2·35585	2·47508	2·60508	2·74747	2·90421	60
5	2·05789	2·15267	2·25485	2·36541	2·48548	2·61645	2·75996	2·91799	55
10	2·06553	2·16089	2·26373	2·37503	2·49596	2·62791	2·77254	2·93188	50
15	2·07321	2·16916	2·27267	2·38472	2·50652	2·63945	2·78523	2·94590	45
20	3·08094	2·17749	2·28166	2·39448	2·51715	2·65108	2·79802	2·96004	40
25	2·08872	2·18586	2·29072	2·40431	2·52786	2·66280	2·81091	2·97430	35
30	2·09654	2·19430	2·29984	2·41421	2·53864	2·67462	2·82391	2·98868	30
35	2·10441	2·20278	2·30902	2·42418	2·54951	2·68652	2·83702	3·00319	25
40	2·11233	2·21132	2·31826	2·43421	2·56046	2·69852	2·85023	3·01783	20
45	2·12030	2·21991	2·32756	2·44432	2·57149	2·71061	2·86356	3·03259	15
50	2·12832	2·22856	2·33692	2·45450	2·58260	2·72280	2·87699	3·04749	10
55	2·13638	2·23727	2·34635	2·46476	2·59380	2·73509	2·89054	3·06252	5
	25	24	23	22	21	20	19	18	

	72	73	74	75	76	77	78	
0	3·07768	3·27085	3·48741	3·73205	4·01078	4·33147	4·70463	60
5	3·09298	3·28794	3·50665	3·75388	4·03577	4·36040	4·73850	55
10	3·10842	3·30520	3·52609	3·77595	4·06107	4·38969	4·77285	50
15	3·12399	3·32263	3·54573	3·79826	4·08666	4·41936	4·80768	45
20	3·13971	3·34023	3·56557	3·82082	4·11256	4·44941	4·84300	40
25	3·15558	3·35800	3·58562	3·84364	4·13877	4·47986	4·87882	35
30	3·17159	3·37594	3·60588	3·86671	4·16530	4·51070	4·91515	30
35	3·18775	3·39406	3·62635	3·89004	4·19215	4·54196	4·95201	25
40	3·20406	3·41236	3·64704	3·91364	4·21933	4·57362	4·98940	20
45	3·22052	3·43084	3·66795	3·93750	4·24684	4·60572	5·02734	15
50	3·23714	3·44951	3·68909	3·96162	4·27470	4·63824	5·06583	10
55	3·25391	3·46836	3·71045	3·98607	4·30291	4·67121	5·10490	5
	17	16	15	14	13	12	11	

	79	80	81	82	83	84	85	
0	5·14455	5·67128	6·31375	7·11537	8·14434	9·51436	11·4300	60
5	5·18480	5·71991	6·37373	7·19124	8·24344	9·64934	11·6247	55
10	5·22565	5·76986	6·43484	7·26872	8·34495	9·78817	11·8261	50
15	5·26715	5·81965	6·49710	7·34786	8·44895	9·93100	12·0346	45
20	5·30927	5·87080	6·56055	7·42870	8·55554	10·0780	12·2505	40
25	5·35206	5·92283	6·62522	7·51131	8·66482	10·2294	12·4742	35
30	5·39551	5·97576	6·69115	7·59575	8·77688	10·3854	12·7062	30
35	5·43965	6·02962	6·75838	7·68207	8·89185	10·5461	12·9469	25
40	5·48450	6·08443	6·82694	7·77035	9·00982	10·7119	13·1968	20
45	5·53007	6·14023	6·89688	7·86064	9·13093	10·8829	13·4566	15
50	5·57637	6·19702	6·96823	7·95302	9·25530	11·0594	13·7267	10
55	5·62344	6·25485	7·04104	8·04756	9·38306	11·2417	14·0076	5
	10	9	8	7	6	5	4	

	86	87	88	89	
0	14·3006	19·0811	28·6362	57·2899	60
5	14·6059	19·6273	29·8823	62·4991	55
10	14·9244	20·2055	31·2415	68·7500	50
15	15·2570	20·8188	32·7302	76·3900	45
20	15·6047	21·4704	34·3677	85·9397	40
25	15·9686	22·1639	36·1776	98·2179	35
30	16·3498	22·9037	38·1884	114·588	30
35	16·7496	23·6945	40·4358	137·507	25
40	17·1693	24·5417	42·9640	171·885	20
45	17·6105	25·4517	45·8293	229·181	15
50	18·0749	26·4316	49·1038	343·773	10
55	18·5644	27·4898	52·8821	687·548	5
	3	2	1	0	

ANGLES, VERTICALLY OPPOSITE; are formed by two lines which cross each other. At each crossing there are two pairs of such angles; those of each pair are equal, and the supplements of the other pair. *Alternate Angles*, are those made on the opposite sides of a line cutting two other lines; and if these two lines are parallel, the alternate angles are equal. *Exterior Angles*, are those formed by the sides of any right-lined figure, and the adjacent sides produced; they are the supplements of the interior angles; which are the angles within a figure, formed by the meeting of each two adjacent sides.



Angular Motion. When a body moves in the arc of a circle, its velocity is commonly measured not by the space over which it passes in a given time, but by the number of degrees and minutes over which it passes; so that two bodies may have the same angular velocity, whose actual velocities are very different. There are two arcs, AC, *ac*, having the same centre, D, but different radii, D*a*, DA. They contain each 90°, yet the lengths of these arcs must be different. Now if a body moves from A to C in the one, while another body moves from *a* to *c* in the other, they have passed through 90 degrees in the same time, and their angular velocity is the same, but the radius of the one arc, is to that of the other, as 2 to 3; therefore the actual velocity of the body moving in the arc *ac*, is two-thirds of that moving on AC.

Animal Strength. Of all the first movers of machinery, the force derived from the strength of man or other animals, was first used; and notwithstanding the great power to be obtained from water, wind, steam, heated air, &c., the strength of animals continues in a multitude of cases not only to be the most convenient, but the only applicable source of power. As horses were formerly employed for the same purposes as water-wheels, wind-mills, and steam-engines now are, it has become usual to calculate the effect of these machines as equivalent to so many horses; and animal strength becomes thus a sort of measure of mechanical force. From these circumstances it is desirable, that a correct estimate should be had of the real strength of these animals, employed for mechanical purposes; but from the nature of animal organization, and from the variety of circumstances in which the living being may be placed in the exertion of its strength, it is impossible to come to any invariable standard; and all that is left for us to do, is therefore to collect together the results of many experiments, and take the average of the whole. We will here present to our readers, a condensed account of all that is yet known on this subject.

When an animal is at rest, and exerts its strength against any obstacle, then the force of the animal is greatest, or the animal when standing still, will support the greatest load. If the animal begins to move, then it cannot support so great a load, because a part of its strength must be employed to effect the motion, and the greater the speed with which the animal moves, the less will be the force exerted on the obstacle, or the less will be the load which it is able to carry, for the greater will be the portion of its strength directed to the movement of its own body; and there will be a speed with which the animal can move and carry no load, but where the whole of its strength is employed in keeping up its velocity.

It is clear that in the first and last of these cases, the useful effect of the animal is nothing, in a mechanical point of view. There must however be a certain relation between the load and speed of the animal, in which the useful effect is a maximum. It has been found that the mechanical effect of any animal at work during a given time, is greatest when the animal moves with one-third of the greatest velocity with which it can move unloaded, and the load which it bears is four-ninths of that which it can only move. Thus if a man can move through $7\frac{1}{2}$ feet in the second, for ten hours a day, when he is unloaded, and if the weight which he is just able to move be 336 lbs., then the greatest mechanical effect will be obtained when he moves at the rate of $2\frac{1}{2}$ feet per second, which is $\frac{1}{3}$ of $7\frac{1}{2}$, and when he carries a load of $149\frac{1}{3}$ lbs., which is $\frac{4}{9}$ of 336 lbs. The mechanical effect of any animal depends upon the load which it carries, and the speed with which it moves, conjointly; and thus to find the mechanical effect of an animal, we have only to multiply the load by the speed; hence the mechanical effect of a man carrying a load of 60 lbs., and moving at the rate of 3 feet in the second, is the same as that of a man who moves with a velocity of 2 feet in the second, and carries a load of 90 lbs., for $3 \times 60 = 2 \times 90 = 180$.

We have a few scattered hints on the subject of animal strength, from Smeaton, Euler, Desaguliers, and others, but it is to the labours of Coulomb that we are principally indebted; and the more important of his results we shall therefore present to the reader.

If the average weight of a man be taken at 150 lbs., the quantity of action which he furnishes in going up a stair will be 2560 lbs., raised one yard in one minute, and a man will with convenience carry up a stair 480 lbs., through 1000 yards. In this kind of exertion it was found that the quantity of action of a man loaded, was to one unloaded, as one to two. It must be remembered, however, that quantity of action is a very different thing from useful effect. When a man goes up a stair unloaded, his quantity of action is the greatest possible, but his useful effect is nothing. When he is loaded his quantity of action is less, but his useful effect is more than formerly. In fact, it was found by Coulomb, that the greatest useful effect was produced when the weight which the man bore was 0·756, or $\frac{3}{4}$ of his weight; or assuming the weight of the man to be 150 lbs. as before, the load would be $113\frac{1}{2}$ lbs.

When a man travels unloaded on a level road for several days, he can hardly walk more than 31 miles a day, which gives for the quantity of a man's action in this way 7700 lbs., carried 1094 yards. The quantity of action of a man walking up a stair, is to that when he walks on a level road, as 1 to 17.

The strength of men according to different authors, is very different, as the following tables will show.

Number of pounds raised.	Height to which the weight is raised	Time in which it is raised.	Duration of the work.	Authors.
1000	180 feet.	60 minutes.		Euler.
60 (French.)	1 (French.)	1 second.	8 hours.	Bernouilli.
25 (French.)	220 (French.)	145 do.		Amenton.
170 (French.)	1 (French.)	1 do.	half an hour.	Coulomb.
1000	330	60 minutes		Desaguliers.
1000	225	do.		Smeaton.
30	$3\frac{1}{2}$	1 second.	10 hours.	Emerson.
30	2·43	do.		Schulze.

These discrepancies are what might be expected in experimenting on a subject of this variable nature, where there are such differences in original constitution, and in habit. Climate seems to have a decided influence on the strength of man, as may be learned from the statements of Regnier, according to whom,

Nations.	With the hands. lbs.	oz.	With the reins. lbs.	oz.
Savages of Van Diemen's Land.	30	6	0	0
New Zealand. .	51	8	14	8
Zimer. . .	58	7	16	2
Civilized men of France . .	69	2	22	1
England . .	71	4	23	8

According to Robertson Buchanan, the effective strengths of men in working a pump, in turning a winch, in ringing a bell, and rowing a boat, are as the numbers 100, 167, 227, and 248. According to Mr Bevan, an ordinary workman is able to use the undernamed tools for a short time, with the forces marked against them.

	lbs.
A drawing knife, with a force of . . .	100
An augur with two hands, ...	100
A screw driver, one hand, ...	84
A common bench vice handle	72
A chisel and awl, vertically, ...	72
A windlass handle, turning, . . .	66
Pincers and pliers, compression, ...	60
A hand plane, horizontally, ...	50
A hand or thumb vice, ...	45
A hand saw, ...	36
A stock bit, revolving, ...	16
Small screw drivers, or twisting by the thumb or fingers only,	14

The horse was formerly much employed in the propelling of machinery, and continues still to be so; on which account it is necessary to direct our attention to the measure of the average force of this animal. Of tho strength of the horse there is about as much difference of opinion, as of that of man. Desaguliers and Smeaton state the strength of a horse to be equivalent to five men; whereas the French writers make it seven. Probably the truth lies somewhere between, and we may with Dr Gregory estimate the strength of one horse, as equivalent to six men. Gregory estimates the strength of a horse to be about 420 lbs., at a dead pull. It is however to be remarked in comparing the strength of a horse with that of a man, that the most advantageous way to apply the strength of the one, is the least advantageous to the other. The worst way to apply the strength of a horse, is to make him carry a weight up a steep hill, while the structure of man fits him very well for that purpose; wherefore three men, each bearing a load of 100 lbs., will proceed faster up a hill, than one horse with 300 lbs.

The best way of applying the weight of a horse, is to make him draw a loaded carriage. A horse put into harness and endeavouring to draw, bends himself forward, and inclines his legs, bringing his breast nearer the earth, and this he will do the more, the greater the effort he makes. In this way it is obvious that the effect will depend in some measure upon his own weight, and also upon the weight he has on his back. It is therefore useful to load the back of a horse when in draught, although at first sight it might appear a hindrance; and the more skilful of those who manage draught horses, being aware of this fact, adjust the load upon the cart, or carriage, so that the shafts throw a portion of the weight upon the horses back, which portion operates with the weight of the animal in diminishing the exertion of strength necessary for draught, which more than compensates for the burden on the back. The best disposition of the traces while the horse is drawing, is to be perpendicular to the plane of the collar upon his breast and shoulders. When the horse is standing still, the position of the traces is rather inclined upwards, from the direction of the road, but when the horse leans forward to draw the load, the traces should become nearly parallel to the road. If the horse be employed in drawing a sledge or any other thing without wheels, the inclination of the traces to the road, will vary with the proportion of the friction compared with the pressure. Thus if the friction be one third of the pressure, the inclination of the traces to the road, will be according to the table, (see *Inclined Plane*,) $18\frac{1}{2}°$, and the same table will give the angle for other proportions of friction to pressure.

When a horse is employed in a gin, as is often practised in grinding and thrashing mills, it is desirable to give as great a diameter as possible to the circle in which the animal walks. It is clear that since a rectilinear motion is easiest for the horse, and that with the same velocity the centrifugal force will be less in a large circle, than in a small, which will proportionately lessen the friction in the cylindrical trunions, that it is advantageous to have the diameter of the gin circle large.

In practice it may be stated, that the diameter of the gin walk ought not to be less than 25 or 30 feet.

Mr Tredgold gives the following view of a horse's daily labour, and maximum velocity unloaded.

Direction of labour in hours.	Maximum velocity in miles per hour, unloaded.	Direction of labour in hours.	Maximum velocity in miles per hour, unloaded.
1	14·7	6	6·0
2	10·4	7	5·5
3	8·5	8	5·2
4	7·3	9	4·9
5	6·6	10	4·6

Taking the hours of labour at 6 per day; the same author assigns 125 lbs. as the maximum of useful effect, moving at the rate of 3 miles an hour; and regarding the expense of carriage in that case as 1, he gives:

Miles per hour.	Proportional expense.	Moving force.
2	1·125	166
3	1	125
3½	1·0282	104
4	1·125	83
4½	1·333	62·5
5	1·8	41·66
5½	2	36·5.

Mr Tredgold states, that a horse working 6 hours, will raise 2250 lbs. one mile. Mr Bevan makes the number 2080.

According to Desaguliers, a horse's power is equivalent to 44000 lbs. raised one foot high in one minute of time. Smeaton makes the number 22916. Hachette, 28000; and Watt, 33000.

For other particulars concerning animal strength, see the articles *Dynamical Unit*, and *Power*.

Annealing. Glass, cast iron, and steel, together with other substances, when heated, and then allowed suddenly to cool, become hard and brittle, a circumstance which often renders them unfit for the purposes for which they are intended. To obviate this inconvenience, these bodies are, when heated, allowed gradually to cool, and this process is called annealing. Glass vessels after having been blown, are placed in an oven called the *leer*, which is situated immediately over the great furnace, where they are allowed to remain gradually cooling for a greater or less time, according to their thickness. The best way of annealing steel, is to render it red hot in a charcoal fire, taking care that the metal be completely covered, and then allowing the fire to go gradually out of its own accord. Cast iron cannot be managed in this way, as being bulky, the expense of charcoal would be enormous; it is therefore usual to employ turf or cinders, the process being otherwise conducted the same way as with steel. In annealing cast iron, it is not desirable that the metal should be brought to any more than a red heat, as otherwise the smaller pieces, and thin bars might not only bend, but even melt. In annealing cast iron when the pieces are numerous, and the fire too small, or, when it is suspected that the heat of the fire when left to itself may become too great, the pieces are when red hot, buried in dry saw dust, and in that state allowed to anneal. One great advantage of annealing cast iron, is, that if it is afterwards subjected to a partial heating, it is less liable to warp than it would otherwise be. The character of cast iron is not in any way altered by annealing, except that it is rendered more malleable. Cast iron when employed in cutlery, is commonly bedded in some poor iron ore, or some substances which give out oxygen, and kept in a state little short of fusion for twenty-four hours; it is then found to be in a state not unfit for some kinds of edge tools and nails, and to retain a considerable portion of that malleability imparted to it by annealing. It is remarkable, that annealing makes copper hard and brittle, and that sudden cooling has the contrary effect. See *Iron*.

Anvil, a table on which smiths hammer their work. The anvil is a solid mass of iron, of a peculiar form, being a kind of table, to the upper surface of which a plate of steel is firmly welded, and so hard that it can withstand the blow of a hammer, or the action of a file. When designed for forging iron upon, the anvil is commonly made with one or two projecting arms, useful in giving the requisite shape to certain kinds of work, which may require to be bent or curved. Should there be only one arm on an anvil, workmen prefer it of a conical shape, but if two arms, the second is made pyramidical. Each of these arms is fixed to the body of the anvil a little below the surface, and they are so formed that they rise a little towards the point. Clock makers use very small anvils, which when using they fix in the vice. Tin plate workers have anvils of various forms and sizes, having concavities and convexities upon them, by means of which the proper form is more easily given to the work. Anvils, or break-irons as they are frequently called, may sometimes require to be placed in some upper story of a house, in which case it will be advantageous that they should be placed on beds of sand, which goes far to prevent the vibration and noise.

Apparatus, the appendages belonging to machines, various detached parts necessary for experiments, or putting machines in motion.

Aqueduct; a structure for leading water over valleys, or uneven ground, whereby the level is always preserved. See *Bridge*.

Arc, in Geometry; part of the circumference of a circle, or any other curve, lying between two points. It is often required to find the length of the arc of a circle containing a given number of degrees, and for this purpose the following table will be found serviceable:

Degrees.	Degrees.	Minutes.	Minutes.
1.— ·01745329	10.— ·17453293	1.—·00029089	10.—·00290888
2.— ·03490659	20.— ·34906585	2.—·00058078	15.—·00436332
3.— ·05235988	30.— ·52359878	3.—·00087266	20.—·00581776
4.— ·06981317	40.— ·69813170	4.—·00116455	30.—·00872665
5.— ·08726646	50.— .87266463	5.—·00145444	40.—·01163553
6.— ·10471976	60.—1·04719755	6.—·00174533	45.—·01308997
7.— ·12217305	70.—1·22173048	7.—·00203622	50.—·01454441
8.— ·13962634	80.—1·39626340	8.—·00232711	55.—·01599885
9.— ·15707963	90.—1·57079633	9.—·00261799	

In the above table the radius of the circle is supposed to be 1, and therefore when the circle has any other radius, it will be necessary to multiply the numbers in the table by it, as will be shown in the following example:

It is required to find the length of an arc of 48° 13′, the radius of the circle being 15 inches.

By the table we find that the length of an arc of 40° is ·69813170; that for 8°, is ·13962634; that for 10′, is ·00290888; and for 3′, ·00087266; all which numbers added together give ·84153958 as the length of an arc of 48° 13′ of a circle whose radius is 1, hence $\cdot 74153958 \times 15 = 12\cdot 6230937$ inches, as the length of an arc of the same number of degrees and minutes, the radius being 15 inches.

Arcs whose lengths are required, are not always to be found to degrees and minutes; for instance, it might be required to find the length of the arc of a circular segment, there being 18 segments in the whole circle, and the radius of the circle being 16 inches. In such cases the easiest method will be to take the whole circumference, and divide it by the number of segments required to complete the circle. In the case given we will find, that the entire circumference of a circle, 16 inches in radius, is 100·53096; (see *Circle*) which number divided by 18, gives

$$\frac{100\cdot 53096}{18} = 5\cdot 5840 \text{ inches.}$$

In the erection of bridges and similar arched structures, it is often required to find the length of an arc, where the base or span, and height are given. For this purpose the following rule and table may be employed:

$\frac{\text{Height of given arc,}}{\text{Base, or span}}$ = a number which will be found in the column Height of arc, in the table, against which in the column Length of arc, will be found a number such, that when multiplied into the base of the given arc, will give the length of the arc required. Thus,

In Southwark bridge, (London,) the arches are circular; the span of the middle arch is 240, and height 24 feet. Find the length of the arc.

$$\frac{24}{240} = \cdot 100$$

A number which in the table, column of heights, stands opposite to 1·02645 in the column of lengths; wherefore,

1·02645 × 240 = 246·348 feet, the length required.

Rules and tables for the lengths of arcs of other curves, will be found under the respective articles, *Catenary*, *Cycloid*, *Ellipse*, &c.

The lines called sines, tangents, chords, &c. &c., are common to arcs and angles. See *Angle*, and *Chord*.

TABLE OF THE LENGTHS OF CIRCULAR ARCS.

Hght. of Arc.	Length of Arc.	Hght. of Arc.	Length of Arc.	Hght. of Arc.	Length of Arc.	Hght. of Arc.	Length of Arc.	Hght. of Arc.	Length of Arc.
·100	1·02645	·132	1·04584	·164	1·07025	·196	1·09949	·228	1·13331
·101	1·02698	·133	1·04652	·165	1·07109	·197	1·10048	·229	1·13444
·102	1·02752	·134	1·04722	·166	1·07194	·198	1·10147	·230	1·13557
·103	1·02806	·135	1·04792	·167	1·07279	·199	1·10247	·231	1·13671
·104	1·02860	·136	1·04862	·168	1·07365	·200	1·10348	·232	1·13786
·105	1·02914	·137	1·04932	·169	1·07451	·201	1·10447	·233	1·13903
·106	1·02970	·138	1·05003	·170	1·07537	·202	1·10548	·234	1·14020
·107	1·03026	·139	1·05075	·171	1·07624	·203	1·10650	·235	1·14136
·108	1·03082	·140	1·05147	·172	1·07711	·204	1·10752	·236	1·14247
·109	1·03139	·141	1·05220	·173	1·07799	·205	1·10855	·237	1·14363
·110	1·03196	·142	1·05293	·174	1·07888	·206	1·10958	·238	1·14480
·111	1·03254	·143	1·05367	·175	1·07977	·207	1·11062	·239	1·14597
·112	1·03312	·144	1·05441	·176	1·08066	·208	1·11165	·240	1·14714
·113	1·03371	·145	1·05516	·177	1·08156	·209	1·11269	·241	1·14831
·114	1·03430	·146	1·05591	·178	1·08246	·210	1·11374	·242	1·14949
·115	1·03490	·147	1·05667	·179	1·08337	·211	1·11479	·243	1·15067
·116	1·03551	·148	1·05743	·180	1·08428	·212	1·11584	·244	1·15186
·117	1·03611	·149	1·05819	·181	1·08519	·213	1·11692	·245	1·15308
·118	1·03672	·150	1·05896	·182	1·08611	·214	1·11796	·246	1·15429
·119	1·03734	·151	1·05973	·183	1·08704	·215	1·11904	·247	1·15549
·120	1·03797	·152	1·06051	·184	1·08797	·216	1·12011	·248	1·15670
·121	1·03860	·153	1·06130	·185	1·08890	·217	1·12118	·249	1·15791
·122	1·03923	·154	1·06209	·186	1·08984	·218	1·12225	·250	1·15912
·123	1·03987	·155	1·06288	·187	1·09079	·219	1·12334	·251	1·16033
·124	1·04051	·156	1·06368	·188	1·09174	·220	1·12445	·252	1·16157
·125	1·04116	·157	1·06449	·189	1·09269	·221	1·12556	·253	1·16279
·126	1·04181	·158	1·06530	·190	1·09365	·222	1·12663	·254	1·16402
·127	1·04247	·159	1·06611	·191	1·09461	·223	1·12774	·255	1·16526
·128	1·04313	·160	1·06693	·192	1·09557	·224	1·12885	·256	1·16649
·129	1·04380	·161	1·06775	·193	1·09654	·225	1·12997	·257	1·16774
·130	1·04447	·162	1·06858	·194	1·09752	·226	1·13108	·258	1·16899
·131	1·04515	·163	1·06941	·195	1·09850	·227	1·13219	·259	1·17024

Hght. of Arc.	Length of Arc.	Hght. of Arc.	Length of Arc.	Hght. of Arc.	Length of Arc.	Hght. of Arc.	Length of Arc.	Hght. of Arc.	Length of Arc.
·260	1·17150	·309	1·23780	·357	1·31115	·405	1·39196	·453	1·47942
·261	1·17275	·310	1·23925	·358	1·31276	·406	1·39372	·454	1·48131
·262	1·17401	·311	1·24070	·359	1·31437	·407	1·39548	·455	1·48320
·263	1·17527	·312	1·24216	·360	1·31599	·408	1·39724	·456	1·48509
·264	1·17655	·313	1·24360	·361	1·31761	·409	1·39900	·457	1·48699
·265	1·17784	·314	1·24506	·362	1·31923	·410	1·40077	·458	1·48889
·266	1·17912	·315	1·24654	·363	1·32086	·411	1·40254	·459	1·49079
·267	1·18040	·316	1·24801	·364	1·32249	·412	1·40432	·460	1·49269
·268	1·18162	·317	1·24946	·365	1·32413	·413	1·40610	·461	1·49460
·269	1·18294	·318	1·25095	·366	1·32577	·414	1·40788	·462	1·49651
·270	1·18428	·319	1·25243	·367	1·32741	·415	1·40966	·463	1·49842
·271	1·18557	·320	1·25391	·368	1·32905	·416	1·41145	·464	1·50033
·272	1·18688	·321	1·25539	·369	1·33069	·417	1·41324	·465	1·50224
·273	1·18819	·322	1·25686	·370	1·33234	·418	1·41503	·466	1·50416
·274	1·18969	·323	1·25836	·371	1·33399	·419	1·41682	·467	1·50608
·275	1·19082	·324	1·25987	·372	1·33564	·420	1·41861	·468	1·50800
·276	1·19214	·325	1·26137	·373	1·33730	·421	1·42041	·469	1·50992
·277	1·19345	·326	1·26286	·374	1·33896	·422	1·42222	·470	1·51185
·278	1·19477	·327	1·26437	·375	1·34063	·423	1·42402	·471	1·51378
·279	1·19610	·328	1·26588	·376	1·34229	·424	1·42583	·472	1·51571
·280	1·19743	·329	1·26740	·377	1·34396	·425	1·42764	·473	1·51764
·281	1·19887	·330	1·26892	·378	1·34563	·426	1·42945	·474	1·51958
·282	1·20011	·331	1·27044	·379	1·34731	·427	1·43127	·475	1·52152
·283	1·20146	·332	1·27196	·380	1·34899	·428	1·43309	·476	1·52346
·284	1·20282	·333	1·27349	·381	1·35068	·429	1·43491	·477	1·52541
·285	1·20419	·334	1·27502	·382	1·35237	·430	1·43673	·478	1·52736
·286	1·20558	·335	1·27656	·383	1·35406	·431	1·43856	·479	1·52931
·287	1·20696	·336	1·27810	·384	1·35575	·432	1·44039	·480	1·53126
·288	1·20828	·337	1·27864	·385	1·35744	·433	1·44222	·481	1·53322
·289	1·20967	·338	1·28118	·386	1·35914	·434	1·44405	·482	1·53518
·290	1·21202	·339	1·28273	·387	1·36084	·435	1·44589	·483	1·53714
·291	1·21239	·340	1·28428	·388	1·36254	·436	1·44773	·484	1·53910
·292	1·21381	·341	1·28583	·389	1·36425	·437	1·44957	·485	1·54106
·293	1·21520	·242	1·28739	·390	1·36596	·438	1·45142	·486	1·54302
·294	1·21658	·343	1·28895	·391	1·36767	·439	1·45327	·487	1·54499
·295	1·21794	·344	1·29052	·392	1·36939	·440	1·45512	·488	1·54696
·296	1·21926	·345	1·29209	·393	1·37111	·441	1·45697	·489	1·54893
·297	1·22061	·346	1·29366	·394	1·37283	·442	1·45883	·490	1·55090
·298	1·22203	·347	1·29523	·395	1·37455	·443	1·46069	·491	1·55288
·299	1·22347	·348	1·29681	·396	1·37628	·444	1·46255	·492	1·55486
·300	1·22495	·349	1·29839	·397	1·37801	·445	1·46441	·493	1·55685
·301	1·22635	·350	1·29997	·398	1·37974	·446	1·46628	·494	1·55884
·302	1·22776	·351	1·30156	·399	1·38148	·447	1·46815	·495	1·56083
·303	1·22918	·352	1·30315	·400	1·38322	·448	1·47002	·496	1·56282
·304	1·23061	·353	1·30474	·401	1·38496	·449	1·47189	·497	1·56481
·305	1·23205	·354	1·30634	·402	1·38671	·450	1·47377	·498	1·56680
·306	1·23349	·355	1·30794	·403	1·38846	·451	1·47565	·499	1·56879
·307	1·23494	·356	1·30954	·404	1·39021	·452	1·47753	·500	1·57079
·308	1·23636								

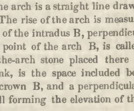
ARCH, in Geometry, is any portion of the circumference of a circle not exceeding a semicircle.

ARCH; a term used in architecture, to denote an arrangement of separate stones, bricks, or other hard, non-elastic bodies, over any opening, as a gate-way, or water course, so that the structure shall be capablo of resisting a limited pressure. Arches, as the name implies, are most commonly in the form of a curve, but sometimes they are straight, as is the case in the portico of that beautiful specimen of architecture, St Andrew's church, Glasgow. The wood-cut below will give a clear notion of the circular arch.

The supports of an arch are pillars, or walls, called abutments, butments, or piers. FGA the first stone which rises from the abutment to form the curved part of the arch, is called the spring or rein, as A. The impost or platband, is the upper part of the abutment at A. The stones ranged in the curved line forming the arch, are called arch-stones or vousoirs, and the concave surface which they form, that is the curve line ABM, is called the intradus, or not unfrequently the soffet, the extradus being the curve formed by the upper, or opposite surface of the arch-stones. The span of the arch is a straight line drawn from the one impost A, to the other M. The rise of the arch is measured by a line drawn from the highest point of the intradus B, perpendicular to the line of span, AM. The highest point of the arch B, is called the vertex, or sometimes the crown, and the-arch stone placed there is called the key-stone. The haunch or flank, is the space included between a horizontal line drawn from the crown B, and a perpendicular drawn from the spring A. The outer wall forming the elevation of the arch, is called the spandril.

Various other particulars in the description of arches might be here given, but they will be better introduced under the article *Bridge*, to which we refer, and terminate this with the following problem.

To draw the plan of a circular segment arch, the space and rise being given.



This like all other plans ought to be drawn to a certain scale; say in the present instance, that the span of the arch is 50 feet, and the rise 30, and that the plan is to be drawn to a scale, in which 1-16th of an inch represents a foot. Take by the compass from a common foot rule, the distance AB = 50 sixteenths of an inch, and draw the line AB, bisect it in S, and raise the perpendicular SR, whose length is 30 sixteenths. It only now remains to draw the arc of a circle, which shall pass through the three given points ARB; join the points A and B with R, and bisect the lines AR and

BR, in M and N, from which raise the perpendicular MO and NO, the point O being the centre, from which with the distance O A as radius, the arc AR B may be described. The figure will also show the method of drawing the arch stones, when the curve is circular ; and the method of drawing these vousoirs, when the curve is not a circle, will be found under the name of the curve, as Ellipse, Parabola, &c.

ARCHITECTURE ; the art of building, considered both as an ornamental and useful art. In this work there will be found definitions of such terms in architecture, as are useful to the engineer in understanding the principles on which bridges and edifices to contain machinery ought to be built, &c.

ARCHITECTURAL ORDERS. See *Order*.

ARCHITRAVE ; that part of a column which lies immediately upon the capital, being the lowest member of the entablature. The architrave of a fire-place, is the mantle piece.

AREA, of any plane figure in geometry, is the measure of the space contained within its boundaries, without any regard to thickness. The area of any plane figure is estimated by the number of little square spaces, that may be contained in it, each of these squares being of a certain size; as an inch, a foot, or a yard long in the side. Workmen call this square measure. See *Mensuration*.

ASH, is a very useful wood, as it possesses great elasticity, toughness, and considerable hardness. Ash answers well for instruments of husbandry, and for buildings where it is not much exposed to the weather; also, for handles of such tools as axes, adzes, hammers, &c. It is remarkable of this wood, that it is equally good, whether cut young or at maturity.

ATMOSPHERE ; that gaseous fluid which surrounds tho earth, and which we breathe. The air which composes the atmosphere, was for a long time by all, and is at present by many, supposed to be destitute of weight, but this is not the case, for the exact weight of air has been determined by experiment. If a bottle whose content is one cubic foot, be weighed when full of common air, and then weighed when the air is taken out of it by means of an air pump, (see that article,) the bottle will be found to weigh heavier in the former case, than in the latter, by 1·222 ounces; from which we are led to infer the specific gravity of atmospheric air at the surface of the earth, and at the common temperature. Dr Prout states that 100 cubic inches of atmospheric air, at the surface of the earth, when the barometer stands at 30 inches, and at a temperature of 60 Fahrenheit, weighs 31·0117 grains, being thus about 815 times lighter than water, and 11,065 times lighter than mercury. Since the air of the atmosphere is possessed of weight, it must be evident, that a cubic foot of air at the surface of the earth, has to support the weight of all the air directly above it, and that therefore the higher we ascend up in the atmosphere, the lighter will be the cubic foot of air; or in other words, the farther from the surface of the earth, the less will be the density of the air. This may be easily inferred to be the case, from the nature of aeriform fluids, (see *Pneumatics*,) but it is verified by experiment. At the height of three and a half miles, it was found that the atmospheric air was only half as dense as it was at the surface of the earth. It may be proved that if altitudes are taken in arithmetical progression, the rarities of the air will be in geometrical progression. Now since the air at the height of three and a half miles, be twice as rare as the air at the surface of the earth; it follows from the above law, that at the height of seven miles the air will be four times rarer than at the surface of the earth; at the height of fourteen miles the rarity will be 16; and by continuing the same calculation, it will be found that at the height of 49 miles the rarity of the air is 16,384 times greater than at the surface of the earth. In this manner it might be shown, that at the height of 500 miles, one cubic inch of the air which we breathe, would be so much expanded by rarefaction, that it would fill a hollow globe equal in diameter to the orbit of Saturn. This fact is sufficient to prove that the limit of the atmosphere is far within the height of 500 miles; in fact, from the researches of Dr Wollaston, we may conclude that the height is at least 40 miles, and from observations on the duration of twilight it may be inferred that the height of the atmosphere does not extend beyond 49 or 50. This subject is perhaps more curious than useful, and its consideration must therefore give place to others with which the mechanic is more immediately concerned.

From the nature of fluids, it follows, that the air of the atmosphere presses against any body which comes into contact with it; because fluids exert pressure in all directions, upwards, downwards, sidewise, and oblique. From the nature of fluids it also follows, that the pressure on any point is equal to the weight of all the particles of the fluid in a perpendicular line between the point in contact, and the surface of the fluid. The amount of pressure of a column of air, whose base is one square foot, and altitude the height of the atmosphere, has been found to be 2156 pounds avoirdupois, or very nearly 15 pounds of pressure on every square inch. It is common to state the pressure of the atmosphere as equal to 15 lbs. on the square inch; and this ought to be remembered by the mechanic, as it is often an important element in the calculation of the effects of machinery. If any gaseous body or vapour, such as steam, exert a pressure equivalent to 15 lbs. on the square inch, then the force of that vapour is said to be equal to one atmosphere; if the vapour be equal to 30 pounds on every square inch, then it is equal to two atmospheres; if the pressure be 45 pounds to the square inch, then its force is equal to three atmospheres, and so on. That the pressure of the atmosphere is equal to about

15 lbs. to the square inch, may be proved by the Torricellian experiment. Take a glass tube which is at least 30 inches long, being closed at one end, and open at the other. This tube being filled with mercury, and placed in a perpendicular direction, with the open end downwards, and resting in a basin of mercury; it might be thought that the mercury would by its weight fall out of the tube, but it is to be remembered that the atmosphere presses on the surface of the mercury at the open end of the tube, and forces it up the tube, and if the weight of the mercury in the tube is greater than the pressure of the atmosphere, it is clear that a portion of the quicksilver will flow out of the tube, so that it will only be at rest when the weight of the mercury in the tube is equal to the pressure of the atmosphere. Supposing the bore of the tube to be one square inch, in the cross section, then it will be found that every two inches of mercury in the tube will weigh one pound; and consequently, if the height of the mercury in the tube be thirty inches, then will its weight be 15 pounds. Now the atmospheric pressure is capable of supporting about thirty inches of mercury, and we therefore infer that the atmospheric pressure is equal to about 15 pounds on the square inch. A column of water 34 feet high, and one inch in base, is also found to weigh about 15 lbs., and it is found that the pressure of the atmosphere is sufficient to support a column of water of this height.

The pressure of the atmosphere is not constant even at the same place; at the equator, the pressure is nearly constant, but it is subject to greater change as we approach the high latitudes. In this country the pressure of the atmosphere varies so much, as to support a column of mercury some times so low as 28 inches, and at other times so high as 31, the mean being 29·5. This would make the average pressure between 14 and 15 pounds on the square inch. Throughout this work, and indeed in scientific books generally, the pressure is understood in round numbers to be 15 lbs., so that when we say a pressure is exerted equal to one, two, three, four, &c. atmospheres, we mean such a pressure as would support 30, 60, 90, 120, &c. inches of mercury in a perpendicular column, or 15, 30, 45, 60, &c. pounds on every square inch. The higher we ascend in the atmosphere, the shorter will be the perpendicular column of air, and consequently the less will be the pressure; a fact which has been advantageously applied to the measurement of altitudes. See *Heights.*

The elasticity of the atmosphere is every where equal to the force which compresses it, that is to say, to the weight of the column of air which is above it. If a copper vessel be filled with common air, at the surface of the earth, and then sealed, the pressure on the inside will just be equal to the pressure on the outside, and be the vessel ever so thin, it will sustain no injury from the pressure of the atmosphere; but if it be placed in the receiver of an air pump, and the air exhausted from about it, (the air in the inside remaining unchanged,) it will be found that, unless the copper has sufficient strength to overcome a pressure of 15 lbs. to the square inch, the vessel will burst, which follows in consequence of the elastic force of the air within. Had the air in the vessel been compressed by any means into half its original bulk, then its elastic force would have been doubled; in which case the pressure arising from the elasticity in the inside of the vessel would be 30 lbs. to the square inch, when the vessel is placed in an exhausted receiver; but when placed in the open air, the effective pressure would only be 15 lbs., because the atmosphere presses on the outer surface with a force of 15 lbs., which pressure being directly opposed to that arising from the elasticity of the air within the vessel, will destroy 15 lbs. of the pressure from within, and reduce it to 15 lbs., or one atmosphere.

The air of the atmosphere was long supposed to be an elementary substance, but Dr Priestley determined it to be a compound. Various philosophers have subjected atmospheric air to analysis, and have arrived at different results. The latest, and that on which we may most implicitly depend, is as follows:

Oxygen . .	20
Nitrogen . .	80
	100

In 10,000 parts of common air, there is found about 4·9 of carbonic acid gas. Water in the form of vapour, is also found in the atmosphere, in small and variable quantities. The chemical properties of the atmospheric air are interesting to the mechanic, principally on account of the effects of the oxygen that it contains, which supports combustion, and corrodes metals.

The following table will enable the reader to find a column of Mercury or Water, equivalent to the pressure of steam over the atmosphere; from 1 to 50 pounds on the square inch.

Pressure on the square inch in lbs.	Height of the gauge in inches.	Height of a column of Mercury in inches.	Height of a column of water in feet.
1	1·01	2·03	2·30
1 5	1·52	3·04	3·45
2	2·03	4·06	4·60
2·5	2·54	5·08	5·76
3	3·04	6·09	6·91
3·5	3·55	7·11	8·06
4	4·06	8·13	9·21
4·5	4·57	9·14	10·36
5	5·08	10·16	11·52

Pressure on square inch in lbs.	Height of the guage in inches.	Height of a column of mercury in inches.	Height of a column of water in feet.
5·5	5·59	11·18	12·67
6	6·09	12·19	13·82
6·5	6·60	13·21	14·97
7	7·11	14·23	16·12
7·5	7·62	15·24	17·28
8	8·13	16·26	18·43
8·5	8·64	17·28	19·58
9	9·14	18·29	20·73
9·5	9·65	19·31	21·88
10	10·16	20·33	23·04
11	11·18	22·36	25·34
12	12·19	24·39	27·64
13	13·21	26·42	29·95
14	14·23	28·46	32·25
15	15·24	30·19	34·56
16	16·26	32·52	36·86
17	17·27	34·55	39·16
18	18·29	36·58	41·47
19	19·31	38·62	43·77
20	20·32	40·65	46·08
25	25·40	50·81	57·60
30	30·49	60·98	69·12
35	35·57	71·14	80·64
40	40·65	81·30	92·16
45	45·73	91·46	103·68
50	50·80	101·60	115·20

Atmospheric Engine. This form of the steam engine was the joint invention of Newcomen, an ironmonger, and Cowley, a glazier, both of Dartmouth, in Devonshire; the former of whom is commonly considered as the inventor, in consequence of which it is not unfrequently called Newcomen's engine. The individuals above mentioned, had for some years been employed in an endeavour to improve the engine of Savary, the invention of the atmospheric steam engine was the result; and the year 1712, in which this machine was first constructed, forms a most important epoch in the history of the employment of steam, as a mover of machinery. The principles of this engine are sufficiently simple. It consists of a hollow cylinder, in which a piston is placed, similar to that of a common pump; the end of the rod of the piston is attached to a long lever, moving vertically, to the other end of which the pump rod is attached; the machine being commonly used for pumping water. The weight of the pump rod and geering attached, must be sufficient to draw down that end of the beam, and consequently raise the piston to the top of the cylinder, in which case steam is admitted into the cylinder, below the piston, and then cold water injected which condenses the steam within the cylinder, producing a vacuum; when this takes place, the atmospheric air pressing on the upper surface of the piston, forces down the piston to the bottom of the cylinder, the steam is again admitted, and again condensed, and the reciprocating motion of the engine is thus produced. The injection of the steam, and likewise of the cold water, is performed by valves or stop-cocks, at the proper time, which is done by particular appendages to the machinery. In the article steam engine there will be found a particular description of the atmospheric engine, which though vastly inferior to those of more recent invention, still continues in many places to be employed in draining mines, &c.

With regard to the proportions of the different parts of this species of the steam engine, the following general remarks may guide. The length of the cylinder ought to be twice its diameter; and $98 \times \sqrt{(\text{the length of the stroke in feet})}$ = the velocity of the piston in feet per minute, which may be called V, and,

$$\frac{V \times \text{area of cylinder}}{4800} = \text{area of steam passage.}$$

Wherefore if the diameter of the cylinder be 72 inches, the length of the stroke is $72 \times 2 = 144$ inches $= 12$ feet, and $98 \times \sqrt{12} = 98 \times \sqrt{3{\cdot}4641}$ $= 339{\cdot}4818$ feet per minute, which is V in the foregoing rule, and the area of the cylinder will be found to be 4071·504, hence,

$$\frac{339{\cdot}4818 \times 4071{\cdot}504}{4800} = 288 \text{ square inches } \textit{nearly} = \text{the}$$

area of the steam passage. The quantity of water necessary for condensation, is about twelve times that necessary for the formation of the steam, and a knowledge of this fact, will of course regulate the size of the orifice for the injection of the cold water; the height of the cistern should be about three times the height of the cylinder, and the jet aperture being made square, its side should be about 1-22nd part of the diameter of the cylinder. The conducting pipe should be four times the diameter of the jet.

To determine the power of the atmospheric engine, the rule is, the square of the diameter of the cylinder in inches, $\times \frac{1}{2}$ the velocity of the piston in feet per minute $\times 5{\cdot}9$ = the weight in lbs. which the engine will raise one foot high in a minute.

In 1775, Smeaton designed the Chess-Water Engine, having a cylinder 72 inches in diameter, the length of the stroke was 9 feet, and 9 strokes were made in the minute. Required the power of this engine according to the foregoing rule; $72^2 \times 9 \times 9 \times 5{\cdot}9 = 2477433{\cdot}6$ raised one foot high per minute; consequently estimating the horses' power according to Watt at 33000, we have,

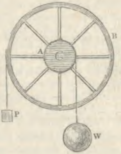
$$\frac{2477433{\cdot}6}{33000,} = 75 \text{ horses, the power of the engine.}$$

Attraction. This is a general term which applies to several classes of phenomena in mechanics and chemistry, and its true extent of meaning, will, like that of most other technical terms, be best understood by a reference to the facts which it is intended to classify. In the solar system it appears, that each planet has a tendency to every other planet, and that all have a tendency to the sun; and, on our globe, bodies when unobstructed will fall to the earth. These phenomena are said to occur in consequence of a common property of matter, called the attraction of gravitation. When we pour any liquid, as water, into a vessel, we may not only fill the vessel to the brim, but more than this, so that the vessel will appear to be heaped. Now the particles of fluids are so easily moved among themselves, that they will be drawn by the action of gravity to the lowest point, and if there was not some power keeping the particles of the fluid above the brim together, the fluid would flow over the brim, until the surface became perfectly level with the edge of the vessel. There appears then to be a tendency in the particles of the fluid to keep together, which tendency is observed in all bodies, being greatest in solids, less in liquids, and least in gases, or aeriform fluids. This is the property by which bodies resist being broken, and is called the attraction of cohesion. (See *Cohesion.*) This kind of attraction is only exerted between the particles of the same body, but it is often confounded with another kind of attraction, which is exerted between the surfaces of different bodies. Take two pieces of lead, and file a flat face on each, then bring these two surfaces into contact, it will be found that it requires a considerable force to draw them asunder. (See *Adhesion.*) When tubes of small bore are immersed in any liquid, the liquid will be found to rise in the tube above its common level, and there thus appears to be a tendency in the tube to draw up the water, which tendency is called capillary attraction. (See *Capillary Attraction.*) If a stick of sealing wax be rubbed briskly with a woollen cloth, and then brought near to light substances, as bits of paper, they will fly to the sealing wax, and the attraction of electricity is said to be exerted between them. If a common magnetic needle, or loadstone, be brought near a piece of iron, a mutual tendency to draw together takes place, which is called magnetic attraction. If acetic acid, that is common vinegar, and soda, are mixed together, then the particles of these two substances will unite with each other, and form a new substance, called a salt, whose properties are entirely different from the properties of either of the two substances which formed it, and it requires some superior power to separate the particles of the two substances which compose the salt. The attraction here exerted is sometimes called affinity or chemical attraction. See *Chemistry.*

Those kinds of attractions which act at sensible distances, seem all to observe one general law; viz., that their power increases inversely with the square of the distance; that is, let the power of attraction at any distance be reckoned unity, then at twice the distance, the power will be one-fourth; at three times the distance, one-ninth. This is the case in the attraction of gravitation; and the same law would seem to hold good in electricity and magnetism, which has led many to suppose, that these three kinds of attractions are only different modifications of the same power.

Axis, in Geometry; the straight line in a plane figure, about which it revolves to generate a solid. Thus, if a circle be described on a surface, and that surface made to turn round the diameter, the figure of a sphere would be described. In a yet more general sense, the axis of any figure is a straight line drawn from the vertex to the middle of the base.

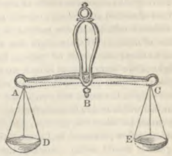
Axis, in Mechanics; the line about which a body turns. See *Ellipse*, *Parabola*, *Curve*, &c.



Axis, in Peritrochio, or, the Wheel and Axle; one of the simple mechanical powers, which may be considered to be a kind of perpetual lever. In the accompanying cut, A is an axle and B a wheel firmly fixed together, but capable of motion round the centre C. A cord passes round the circumference of the wheel, from which is suspended the power P, another cord passes round the axis, from which the weight W is suspended. Now in the simple machine, there will be an equilibrium when the weight W, is to the power P, inversely, as their horizontal distances from the centre of motion; that is P : W :: AC : CB. Wherefore the rules are the same as for the lever. (See *Lever*.) If the power acts at the end of a handspike fixed in the rim of the wheel, then this increases the leverage of the power, by the length of the handspike. If a weight of 36 lbs. is to be raised by an axle 3 inches diameter; what must be the power applied at the end of a handspike 4 inches long, fixed in the rim of the wheel connected with the axle, the wheel being 6 inches diameter? Here the handspike will increase the distance of the power from the fulcrum, and will add to the diameter of the wheel twice its own length; therefore, $8 + 6 = 14$;—hence, 14 : 3 :: 36 : 7·71, the power required to keep the weight in equilibrio.

Axle, or Axle-Tree; a piece of timber, or bar of iron fitted into the holes or naves of wheels, round which they turn. See *Gudgeon*, *Shaft*, *Wheel*, *Friction*, and *Centre*.

B



Balance; a well-known modification of the first order of levers, commonly called the beam and scales. When the balance is properly constructed, the fulcrum is in the middle, between the two extremities, and consists of an edge first ground sharp, and then rounded a little with a hone. The two scales are hung upon edges of the same kind, which are commonly called knife-edge centres, and are employed to diminish friction, where the body which moves upon them does not require to make an entire revolution. In this cut A and C are the points of suspension, B the fulcrum, D and E the scales.

In the construction of balances, three conditions must be satisfied before they can be pronounced perfect.—1st, That when equal weights lie in the scales, the beam ought to be level, or rest in a horizontal position.—2nd, The beam ought to be easily disturbed by small weights put into either scale, which property is called the sensibility of the balance.—3rd, That when the beam is drawn out of its horizonal position by any small addition of weight to either scale, it should quickly resume the horizontal position, which property is called the stability of the balance. The means of satisfying these requisites of a good balance, may be learned from what follows.

If the centre of motion, the centre of gravity, and the centres of suspension be all in the same straight line, the beam will have no tendency to remain in a horizontal position in preference to any other, in which case the stability of the balance will be destroyed. On the other hand, if the centre of gravity be immediately above the fulcrum, the sensibility of the balance will be very great, but it will have no stability; for in that case when the slightest additional weight is put into one scale, the balance will overset, for the centre of gravity will fall below the centre of motion, and this will follow the more quickly, the higher the centre of gravity is above the centre of motion, and the less the centres of suspension are loaded. But if the centre of gravity of the beam, be immediately below the centre of motion, it will remain, if undisturbed, in a horizontal position, and if disturbed in this position, and then left at liberty, it will vibrate, and at last come to rest in the level. The lower the centre of gravity is below the fulcrum, the quicker will be the vibration of the beam, and the greater will be its stability. This effect will also be the greater, the less the load upon the centres of suspension.

Having thus stated the effects of the different relative positions of the centres of motion and gravity, we will now proceed to examine the effects of different relations of the centres of suspension, and the fulcrum, or centre of motion. If the straight line which joins the centres of suspension, be above the centre of motion, the beam will overset, unless the weight of the beam prevent it by a tendency to restore it to the horizontal position. In this case, small weights will equilibrate, and with a certain exact weight, the beam will rest in any position; but all greater weights than this will cause the beam to overset. If the line joining the points of suspension be below the fulcrum, the beam will assume the horizontal position, unless prevented by its own weight. If the fulcrum and centre of gravity should nearly coincide, the vibrations of the beam will be nearly isochronous, and when the weights are very small, they will be very slow. The higher the fulcrum is, the tendency of the beam to the horizontal position is the stronger and the vibrations the quicker.

If the arms of the balance be unequal in length, false indications will be given, because then the weights though equal, will act at unequal distances from the fulcrum. But although equality in the length of the arms of a balance be necessary to the perfection of that instrument, yet a balance with unequal arms may be made to give correct weights; for we have only to weigh the body first in one scale, and then in the other, and multiply the one by the other. The square root of this product will be the true weight of the body. Thus if a body weigh in one scale, 4 ounces 2 drams, and in the other 4 ounces 3 drams, then we have

4 oz. 2 drams = 4 2-16th oz. = 4·125 oz., and,

4 oz. 3 drams = 4 3-16th oz. = 4·1875 oz.; wherefore,

$\sqrt{(4{\cdot}125 \times 4{\cdot}1875)} = \sqrt{17{\cdot}2735} = 4{\cdot}156$ oz. = 4 oz. 2·496 drams,

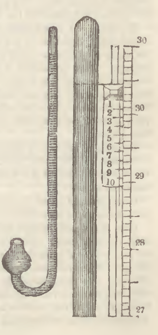
the true weight of the body.

In the construction of balances, the artificer ought to keep the following observations in view :—That the fulcrum and centres of suspension be all in one straight line—That the arms of the beam be of equal length from the fulcrum—That the arms be as long as possible with convenience—That there be as little friction as possible—That the centre of gravity of the beam be a very little below the centre of motion—That the scales be in equilibrium when empty.

There have been various contrivances to rectify the balance when deficient in sensibility or stability. Thus for the purpose of raising or lowering the centre of gravity, a simple appendage to the balance has been resorted to. On the index, or tongue, that slender stem rising perpendicularly from the beam, and which serves to indicate the beam's inclination from the horizontal position, there is affixed a small weight, capable of being shifted up or down, by the motion of which the centre of gravity may be raised or lowered at pleasure. For the purpose of equalizing the length of the arms, there is sometimes a screw affixed to the end of the beam, by means of which the centre of suspension of that scale which is attached to it, may be moved to or from the fulcrum. The exact difference in the length of the arms of a balance may be determined on the following grounds. The weight which counterpoises an ounce when suspended from the longer arm of a balance, when added to the weight which counterpoises an ounce suspended from the shorter arm, will make a sum greater than two ounces. The difference between this sum and two ounces, when expressed as the fraction of an ounce, will give us in the numerator, the square of the difference of the arms, and the denominator the product of the lengths of these arms.

BALUSTER; a small column or pilaster; and a collection of these, joined by a rail, is called a balustrade.

BAROMETER; an instrument used for determining the pressure and elasticity of the atmosphere. To construct this instrument, procure a glass tube, having a bore of not less than one third of an inch in diameter, and which is perfectly clear and free from flaws, and at least thirty-three inches in length. Let this tube be hermetically sealed at one end, that is to say, closed by fusing the glass with a blowpipe, and then with the open end uppermost, holding the tube in a vertical position, fill it with purified mercury. In this state the finger is placed on the orifice at the open end, to prevent the mercury from falling out, and the tube is inverted, the open end being placed in a basin of mercury. Now the air of the atmosphere presses on the surface of the mercury in the basin, and tends to force it up the tube, but the mercury in the tube tends by its weight to descend into the basin; and in this state



of things it is evident, that the pressure of the atmosphere on the surface of the mercury in the basin, must be equal to the pressure arising from the weight of the mercury in the tube, otherwise there cannot be an equilibrium. From the laws of the pressure of fluids, it follows, that there will be supported in the tube a column of mercury of such height as will exert by its weight a pressure on its base, equal to that of a column of air of the same area of base, and of a height reaching to the top of the atmosphere. Now it will be found that the height of the mercury in the tube will be in ordinary circumstances about 30 inches, from which circumstance we may determine the amount of the pressure of the atmosphere. To render this as simple as possible, let us suppose the base of the tube to be one inch in area, as the width of the tube's bore cannot, from the laws of the pressure of fluids, alter the height of the mercury. We know from the specific gravity of mercury, that two cubic inches of it weigh about one pound avoirdupois; and as the column of mercury in the tube is 30 inches long, and has a bore of one square inch, its whole contents will be 30 cubic inches. But since two cubic inches weigh one pound, the whole weight of the column will be 15 lbs.; and this is the pressure upon the base. The pressure of the atmosphere may, therefore, be inferred to be about 15 lbs. to the square inch.

The barometer is commonly employed for the purpose of determining approaching variations in the weather; and the rules for applying its indications in this respect, may be found under *Barometer*, Popular Encyclopedia. This instrument is more scientifically used for measuring altitudes, for which, see *Heights*. There are various modifications of the barometer, as the Diagonal, Horizontal, Marine, Pendant, Reduced, and Wheel Barometer, all modifications of the same instrument, the common form of which, with the scale attached, will be seen in the cut above. See *Atmosphere*.

Baroscope, the same as barometer; a weather-glass.

Barrel of a Wheel, is the axle, or cylindrical body, about which the rope goes.—*Barrel of a Pump*, is the hollow part of the pump where the piston works.

Bars; straight pieces of timber or metal, that run across from one part of a machine to another.

Base of a figure, denotes the lowest part of its perimeter; in which sense the base stands opposed to the vertex, which denotes the highest part.—Base of a right-angled triangle, is properly the hypothenuse, though it is generally used to denote one of the sides about the right angle, the other side being called the perpendicular. That side on which a solid body stands is called the base of the solid.—Base of a conic section, is a right line in the parabola and hyperbola, formed by the common intersection of the cutting plane and the base of the cone.

Basil; that angle the edge of a tool is ground to.

Batten; a piece of timber three or four inches broad, and one thick.

To **Batter**; to lean backward.

Bauk; a long piece of timber.

Beak; the crooked end of a piece of iron, to hold any thing fast.

Beam; a large piece of timber lying across any place. For the proportion of the working beam of the steam engine, see *Working Beam.*

Beech; a kind of timber very extensively used by artificers; while young, it possesses great toughness, and is of a white colour. The cohesive strength of this wood is, according to Sir John Leslie, 12,225, that is, this is the number of pounds weight which will tear asunder a piece of this timber one inch square. But great as its strength is, it is nevertheless unfit for many purposes, as it is liable to be worm-eaten when exposed in the open air, and warps in moist weather. Beech is chiefly useful for furniture work, but is sometimes employed in buildings. One great objection to the use of this wood is, that it is liable to be consumed by a worm which seems to feed upon its sap; and therefore with a view of preserving the wood, different methods are employed to extract the sap from it. When the scantling of beech is large, it is soaked in a pond of water for several weeks, the time required being longer or shorter according to the size of the scantling, or the heat of the season; the requisite time being shorter, the smaller the scantling, and hotter the weather. In general, beams and thick planks require six; joists and rafters, three; and thin boards about two months' soaking in the water. When taken out they are left to dry gradually in the shade; they ought also to be protected from the rain, and laid down with laths between them to prevent their contact, and pressed by a considerable weight, all which precautions are taken, so that the timber may not warp. When beech is used for building, the ends of the wood which touch the brick work ought to be covered with a thick coating of pitch. Beech is often used for handles of saws, plane-blocks, and small articles to be turned in the lathe; previous to which it is recommended to boil the pieces for two or three hours, which process renders the wood much more easily wrought, and in every respect better fitted for the purpose to which it is to be applied.

Beetle; a wooden instrument, or mallet, for driving piles.

Bellows; a well known instrument used for supplying a blast of air to the fire. In a smith's forge, the best position for the bellows, is in a level with the fire; but for the purpose of giving more room near the floor, they are frequently placed higher, and the blast is then communicated through a tube bent downwards. The nose of the bellows passes through the back of the forge, where it is fixed in a strong iron plate, called a *true* iron or patent back, which arrangement preserves the bellows, and also the back of the forge from injury.

Bending of Timber. This becomes an object of very considerable importance to the millwright, who has often to purchase wood having a curved form, at a very high price. Wood which is curved naturally, is often very imperfect from its inequalities, and consequently ill adapted for mechanical purposes; but this may be avoided if the artificial mode of bending wood be attended to, for then the best pieces may be selected, dressed in a straight form, and afterwards bent to the curve required. The process of bending wood to any required curve depends on the property of heat, for its presence increases the elasticity of the wood; thus thin planks of wood, such as pipe staves, and the planks for the sides of boats, are heated in the part where the curve is required, and they are gradually bent as they become hot. Wood, of whatever kind it may be, is a bad conductor of caloric, and therefore the heat applied at one part of a plank will not readily be communicated to another; and thus there will be an inequality of elasticity, and consequently of curvature, and not unfrequently cracks in the interior, and splinters off the exterior surface of the wood will be the consequence. The heat is sometimes given to the wood intended to be curved by placing it in an oven, or stove heated gradually, which obviates the inconvenience above alluded to. The risk of injuring timber by the application of dry heat, however equal, is very considerable; as wood contains in its ordinary state more or less moisture, which dry heat has a tendency to dispel, a circumstance that ought to be avoided, since there cannot be any doubt that the elasticity of wood depends upon the quantity of moisture which it contains, no less than upon its temperature. This then is a general law, that of two pieces of wood of the same kind, and containing the same quantity of water, that will be the more elastic which is the warmer, and if they be both of the same temperature, that will be the more elastic which contains the greater quantity of water. To take advantage of this law in its fullest extent, it was for a long time usual to boil the pieces of wood to be bent, but this process was found very injurious, as it not only diminished the strength of the wood, but caused it to shrink, and become when dry and cold, less elastic than ever. The vapour stove was next employed. It consisted of a chest formed of thick planks firmly jointed together, and of a sufficient capacity to contain the wood to be curved, which was laid upon supports placed in the interior of the chest; steam was introduced into the chest by means of a pipe led from a boiler. The wood being thus subjected to the action of the steam for some time, is rendered fit for bending, but if the planks or pieces are of considerable thickness, this method of increasing elasticity by imparting heat and moisture can be of no effect, since the temperature cannot be raised higher than that of boiling water. When the timber is not very thick, the vapour stove will answer exceedingly well, as it is not expensive, and requires little attendance. The deficiency of this latter method is supplied by the employment of the sand stove. This stove is an imitation of the sand bath so extensively employed in chemical operations. It is formed of four walls of stone, or brick, having in the middle two fire places that communicate with several circular flues, to convey the heated air and smoke to the two chimneys at each end. Over these flues are laid the plates of metal, forming the bottom of the chest, in which the sand is placed. The wood is introduced lengthwise into the stove by either end, and placed upon gratings, then covered with sand. The sand it is well known may be heated to a great degree, and thus the temperature of the wood raised far above that of boiling water; and if the wood were kept dry, it might thus be converted into charcoal; to prevent which occurrence, two boilers containing water are placed in the sand chamber, and the steam thus generated impregnates the sand with moisture, and supplies the wood with its watery principle, which is continually flying away from the action of the heated sand. If the wood be removed when it is sufficiently hot, and no more, it will be found to have sustained very little injury. The wood being thus prepared for bending, it must when hot, be moulded upon a surface, which gives it the curve required; which may be effected by the application of any sufficient force, by means of cords, pulleys, or capstans. If the pieces are not large, heavy weights, or the force of men may be employed, but in all cases it is necessary to keep the force in action, until the wood be cold and dry.

Bevel; any angle except one of 90 degrees. The term bevel is also applied to an instrument for drawing angles, in general use among workmen. In construction, it somewhat resembles the common square, with this difference, that the blade is movable about a centre in the stock, so that it can be set at various angles. The joint of the bevel should be stiff, otherwise no dependence can be put in the instrument, that it will remain as it has been set; indeed, it would be advisable that the mill-wright should take the precaution usually adopted by stone masons, of fixing the blade at the required angle, by means of a thumb screw.

Bevel Geer, in mechanics, denotes a species of wheel-work, where the axis or shaft of the leader or driver forms an angle with the axis or shaft of the follower or the driven. The wheels in this species of geering are not unfrequently called conical wheels, as they may be regarded as the frustums of fluted cones. The nature of the action of these wheels will be understood from the cut, fig. 1.

In order to determine the relative size of the wheels for changing a motion into a direction inclined 45°, for example, to its first direction, and in which the new axle shall move with four times the velocity of the first,—Let AB (Fig. 2) be the original direction of the motion; through

Fig. 1.

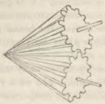
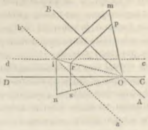


Fig. 2.



any point O draw COD, inclined 45°, to AB; then since the axle CD is to move four times more rapidly than AB, the wheel which it carries must have one-fourth the number of teeth, and one-fourth the diameter. Draw cd at any convenient distance from CD, and parallel to it, and draw ab parallel to AB, so that $Aa = Bb = 4\ Cc = 4\ Dd$, and join the points of intersection i and O. Draw Om, so that the angle BOm = BOi, and draw On, so that DOn = DOi, and these lines will mark out the size and situation of the cones of which the wheels are to be portions. By attending to the preceding construction, it is obvious that it is nothing more than to divide the angle BOD into two angles, whose sines are to one another as the number of the revolutions of the one wheel is to the number of revolutions of the other. For further particulars regarding bevel geer, see *Wheel Work*.

Bird's Eye View; a phrase used among draughtsmen to designate the picture of any machine, building, &c., where the spectator is supposed to look from above. The plane of such a picture is parallel to the horizon.

Bisection; dividing into two equal parts.

Block; a lump of wood.

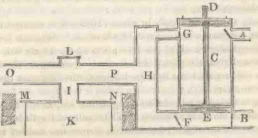
Blocks; pieces of wood in which the sheevers or pullies run, and through which the ropes go.

Blowing; the projection of air into a furnace in a strong and rapid current, for the purpose of increasing combustion. Whether bellows or a pumping cylinder be employed for this purpose, the air will be projected into the furnace in puffs, unless some regulation of the blast be employed. To regulate and equalize the blast, three different contrivances have been adopted.

The first is what has been called a regulating cylinder. In this contrivance, the air which is propelled from the pumping cylinder, or large bellows, is carried through a pipe called the tuyère, into another cylinder, in which a piston loaded with a pressure of at least three pounds to the square inch, is fitted. The air from the pumping cylinder or bellows passes through the tuyère into the regulating cylinder, and having no means of escape, presses up the piston in the regulating cylinder. Another tuyère opens from the regulating cylinder into the furnace, and thus by the constant pressure of the piston, the blast is in a great measure equalized. This machine, however, is not by any means perfectly adapted to the purpose intended.

The second way of regulating the blast, is by means of an air vault. The operation of the air vault may be easily understood. It is merely a vault connected with the pumping cylinder by a pipe, with a valve opening into the vault, so that the air will not return to the pumping cylinder. If the content of the pumping cylinder be the one hundredth part of that of the air vault, and the nose-pipe of the air vault which leads into the furnace be stopped, then after the engine has made 25 strokes, and forced into the air vault 25 cylinders of air, the air vault will then contain 25 cylinders of air in a state of condensation, and having a force of three pounds upon the square inch above its original pressure. Let the nose-pipe opening into the furnace be now opened, and with such a bore as to allow the same quantity of air to be sent in blast from the air vault as is supplied by the pumping cylinder, then the blast will be nearly equal to the elasticity of the condensed air, acting as a regulator.

The best form of the machine is represented in the cut below. Where C is a hollow cylinder furnished with a piston E, similar to that of a common steam engine. The piston-rod D, works through a stuffing box at the top of the cylinder, also similarly formed with that of the steam engine. A and B are pipes leading into the cylinder, and furnished with valves opening inwards. On the opposite side of the cylinder are two valves F and G, opening outwards from the cylinder into two pipes which lead into the large upright pipe H. From this pipe, which is closed both at bottom and top, there proceeds a pipe PO, a branch of which leads off



at I, into the iron chest K, which has no bottom, but rests in a cistern of water, a part of the stone work of the sides of which is seen at M and N. Above this branch there is a valve L opening upwards. The figure will now be completely understood by following the operation. When the piston is at the bottom of the cylinder, and is then raised, the valve A will shut, and all the air will in a condensed state be forced through the valve G into the pipe H. During the ascent of the piston, a vacuum would be formed in the cylinder below the piston, in consequence of which the valve F would be shut, and the valve B open, which last admits the air into the cylinder C. When the piston begins to descend, the condensation of the air within the cylinder will cause the valve B to shut and F to open, so that the condensed air will rush into the pipe H; and thus, by the alternate ascent and descent of the piston, the air in a compressed state is sent into the pipe H. The compressed air proceeds along the pipe PO, but as the branch I allows it a passage into the chest K, it will press upon the surface of the water in the cistern, and of course cause it to rise on the outside of the chest. The pressure of the condensed air in the chest is often so great, as to raise the water in the outside of the chest, 6, 7, or 8 feet above the level of the water in the chest. By this contrivance, should there be any intermission in the intensity of the blast, the column of water in the cistern will press up the air in the chest, and thus equalize the current above. The valve at L is loaded with a certain pressure, so that when the engine is going too quick, and the supply of air too rapid, the valve will be forced open. Two branches are led from the horizontal pipe at O, one to each side of the furnace. If the diameter of the cylinder is 5 feet 2 inches, stroke 7 feet, making 6 strokes per minute, the engine will supply one furnace. The water cistern is then 47 feet long, 14 deep, and 19 broad, the chest being 40 long, 12 broad, and 12 deep. Such an engine is wrought with a steam engine of 35 horses' power, the diameter of cylinder being 32 inches, and length of stroke 7 feet. It has been found that the same bulk of air at 32°, has ten per cent. more oxygen than at 85° when dry, and if saturated with moisture, twelve per cent.; wherefore, if 1500 cubic feet per minute be a sufficient supply in winter, 1625 will be required in summer, to have the same effect. From this it was inferred, that the colder the blast, the greater would be the effect; but at the Clyde iron works, and other founderies, the pipe which conducts the compressed air from the chest to the furnace is made to pass through the fire, and the air is thus heated to a very high temperature before it acts upon the fuel. This has caused great economy in the smelting of the ore, as will be seen by statements under the article *Furnace*. The density of the air is regulated by a constant pressure of from 4 to 6 inches of mercury, that is 2 to 3 lbs. on the square inch. The quantity of air required per minute varies from

1200 to 3000 cubic feet, and it may be assumed that the chest should contain ten times the quantity discharged during one stroke of the piston. See *Combustion*, *Furnace*, and *Smelting*.

Body, or Solid, in Geometry, has three dimensions, viz. length, breadth, and thickness. Body, in mechanical science, is a solid, extended, palpable substance; of itself merely passive, and indifferent either to motion or rest, but capable of any sort of motion, and all figures and forms.

Bodies are either *hard*, *soft*, or *elastic*. A *hard body* is that whose parts do not yield to any stroke or percussion, but which retains its figure unaltered. A *soft body* is that whose parts yield to the stroke or impression, without restoring themselves again. An *elastic body* is that whose parts yield to any stroke, but immediately restore themselves again, and the body retains the same figure as at first. We know not, however, of any bodies that are perfectly hard, soft, or elastic; but all possess these properties in a greater or less degree. Bodies are also either *solid* or *fluid*. A *solid body* is that in which the attractive power of the particles of which it is composed exceed their repulsive power, and, consequently, they are not readily moved one among another; and, therefore, the body will retain any figure that is given to it. A *fluid body* is that in which the attractive and repulsive powers of the particles are in exact equilibrio, and therefore yields to the slightest impression. Fluid bodies are also distinguished into non-elastic and elastic, or fluids properly so called, and aeriform fluids or gases.* Regular bodies, or Platonic bodies, are those which have all their sides, angles, and planes, similar and equal, of which there are only five, viz.

1. Tetraedron, contained under 4 equilateral triangles.
2. Hexaedron, . . 6 squares.
3. Octaedron, . . . 8 triangles.
4. Dodecaedron, . . 12 pentagons.
5. Icosaedron, . . . 20 triangles.

Boiler; the name generally applied to the vessel in which steam is generated for the supply of steam engines. These vessels have been constructed of various forms and materials, with a view to economy of fuel, strength, compactness, or durability. No one form will, however, ensure all these advantages; for if we wish the greatest possible strength, the boiler would be nearly of a spherical form, but this is the worst form for the economizing of fuel, as the spheric will expose less surface in proportion to its contents, than any other figure whatever. It was a remark of Watt, that his chief object in the construction of boilers, was

* The Table of the Proportions of Bodies in the next page will be found highly useful for reference.

as much as possible to economize the fuel; which effect was produced mainly by making the boilers of such a shape, that the air which passed through the fire should be robbed of almost all its heat, before it was allowed to escape. This great engineer made his boilers of a rectangular form, being curved at the top. Boilers for fixed engines are most commonly made in this manner, and they seem well adapted for low pressure steam; but when steam is required of high pressure, the cylindrical form seems best. Boilers have also been formed of tubes for the supply of locomotive engines. It is desirable in the construction of boilers, that

TABLE OF THE PROPORTIONS OF BODIES.

Names of Bodies.	Specific gravity.	Weight in lbs. of a square inch bar, one foot long.	Weight in lbs. of a cubic foot.	Bears in lbs. on a square inch without permanent alteration.	Cohesive force in lbs. of a sq. inch.	Crushed by a force in lbs. on a sq. inch.	Absorbs of its weight of water.	Compared with cast iron as 1, its strength is	Expands in length by one degree of heat Fahrenheit.	Melts at Fahrenheit.
Air..............	0·0012	0·000523	0·0753						1·480	
Ash	0·76	0·33	47·5	3540	16000			·23		
Beech...........	0·696	0·315	45·3	2360	6300			·15		
Bismuth, cast..	9·822	4·26	614							476°
Brass, cast.....	8·37	3·63	523·	6700	18000			·435	1·9380	1869°
Brick...........	1·841	0·8	115·		275	562	1·15			
Clay	2	0·868	125·							
Coal, Newcastle	1·269	0·516	79·31							
Copper	8·75	3·81	549·	10000	33000				1·105900	2548°
Elm	0·544	0·236	34·	3240				·21		
Fir, red or yel..	0·557	0·242	34·8	4290	12000			·3		
Do. white......	0·47	0·204	29·3	3630				·23		
Gold, pure	19·351	8·4	1210·06							2590°
Granite, Aber..	2·625	1·138	164·			10910				
Gun-metal, cast	8·153	3·54	509·5	10000	34000			65	1·99090	
Iron, cast.......	7·207	3·2	450·	15300	44600	93000			1·16200	3479°
Do. malleable..	7·6	3·3	475·	17800	60000			1·12	1·143000	
Larch fir........	0·560	0·243	35·	2065				·136		
Lead............	11·352	4·94	709·5	1500				·096	1·62800	612°
Mahogany......	0·56	0·213	35·	3800	8000			·24		
Marble, white..	2·706	1·17	169·		1811	6060				
Mercury........	13·568	5·888	348·						1·9990	
Oak, English..	0·83	0·36	52·	3960	10000			·25		
Pine, Amer. yel.	0·46	0·186	26·75	3900				·25		
Silver	10·474	4·54	654·62							2233°
Steel, cast	7·84	3·4	490·	40000	130000				1·157200	
Stone, Bath.....	1·975	0·85	123·4		478		1·13			
Do. Craigleith	2·362	1·02	147·6		772	5490	1·63			
Do. Dundee..	2·621	1·13	163·8		2661	6630	1511			
Do. Portland.	2·113	0·92	132·		857	3729	1·16			
Tin, cast........	7·291	3·165	455·7	2880				·182	1·72510	442°
Water, river...	1	0·434	62·5						1·3858	
Do. sea......	1·0271	0·445	64·2							
Whalebone	1·3	0·562	81·	5600						
Zinc, cast.......	7·028	3·05	439·25	5700				·365	1·61200	648°

they should expose as great a surface as possible to the action of the fire, and that this be done in as small a space as possible; but whatever the form of the boiler may be, there must be a determinate quantity of water always contained within it, and likewise a proportionate space for steam, otherwise the engine will not be regularly supplied; and beyond the requisite dimensions it would be injudicious to go. The proper dimensions of a boiler may be found by the table of the proportions of boilers. It may be remarked, that Watt and Boulton usually allowed five feet of bottom surface for each horse's power in land engine boilers, but only three feet for those of steam boats, as in these, economy of space is a matter of great consequence. Large boilers require proportionally less water, than small ones, as will be seen by an inspection of the table, and a satisfactory reason can be given for this; for a great quantity of water will take a longer time to arrive at a given temperature, than a less quantity, and will fall in temperature much slower when exposed to cold. Now, since the influx of steam from the boiler is intermittent, there must be a variation in the pressure on the surface of the water, consequently the temperature will rise, or tend to rise, and this tendency will be inversely as the quantity of water. To find the depth of water in the boiler, if it be of the common rectangular form, with a semi-cylindrical top, the rule is, to divide the quantity of water contained in the boiler, by the bottom surface, which quantities will be both found in the table. Thus, for a 12 horse engine boiler, we have,

$$\frac{146{\cdot}4}{60} = 2{\cdot}44 = \text{the depth of water in the boiler}$$

in feet; and for the whole depth of the boiler of the above form, we may take twice the depth of water, added to one-tenth of that depth; thus for the same boiler we have,

$$(2 \times 2{\cdot}44) + {\cdot}244 = 4{\cdot}88 + {\cdot}244 = 5{\cdot}124 \text{ feet} =$$

the whole depth of the boiler. For the length and breadth of the boiler, we have,

$$\frac{\text{bottom surface} \times \text{side surface}}{\text{quantity of water in the boiler} - \text{bottom surface}} = \text{length, and}$$

$$\frac{\text{bottom surface}}{\text{length}} = \text{breadth of boiler, wherefore in the}$$

boiler for a twelve horse engine, we have bottom surface, 60, side surface 58·8 or 59, and the quantity of water being 146·4, we have,

$$\frac{60 \times 59}{(2 \times 146{\cdot}4) - 60} = \frac{3540}{232{\cdot}8} = 15 = \text{the length, and } \frac{60}{15} = 4 = \text{the}$$

breadth. These rules by Tredgold give the capacity nearly the same as the boilers commonly used, but the extent of surface for heat is increased, and they seem not only more effective, but also stronger.

A TABLE OF THE PROPORTIONS, &c. OF BOILERS FOR LOW PRESSURE ENGINES, FROM 1 TO 40 HORSES' POWER.

Horses' power of the engine to be supplied.	Bottom surface for the whole boiler in feet.	Bottom surface for each horse's power in feet.	Side surface for the whole boiler in feet.	Side surface for each horse's power in feet.	Quantity of water in cubic feet, in the boiler with common fuel.	Quantity of water in cubic feet in the boiler with common fuel, for each horse's power.	Cubic feet of water required per hour, to supply the boiler, the engine working expansively.	Lbs. of coals consumed per hour, the engine working expansively.	Cubic feet of steam lost for each horse's power.
1	8·8	8·8	8·5	8·5	22	22	·8	15	2·16
2	14·2	7·1	13·8	6·9	34	17	1·57	23	1·73
3	19·2	6·4	18·6	6·2	48	16	2·36	30½	1·56
4	24	6	23·2	5·8	60	15	3·13	38	1·46
5	28·5	5·7	27·5	5·5	70	14	3·92	45	1·39
6	33·6	5·6	32·4	5·4	81·6	13·6	4·7	53	1·35
7	37·8	5·4	37·1	5·3	92·4	13·2	5·5	60	1·32
8	42·4	5·3	41·6	5·2	104	13	6·3	67	1·29
9	46·8	5·2	45·9	5·1	112·5	12·6	7	73	1·26
10	51	5·1	50	5	125	12·5	7·82	80	1·25
12	60	5	58·8	4·9	146·4	12·2	9·4	95	1·22
14	68·6	4·9	67·8	4·8	168	12	11	109	1·20
16	76·8	4·8	75·2	4·7	192	12	12·6	122	1·18
18	86·4	4·8	84·6	4·7	216	12	14·1	135	1·17
20	95	4·75	92	4·6	240	12	15·7	149	1·16
25	115	4·6	112·5	4·5	275	11	20	189	1·13
30	138	4·6	135	4·5	330	11	23·5	216	1·12
40	180	4·5	176	4·4	440	11	31·4	283	1·1

For the proportions of cylindrical boilers, various rules have been given, but we are inclined to think that they can be of little service to the practical engineer. By Tredgold's rules, a cylindrical boiler, whose ends are the segments of spheres, and capable of converting seven cubic feet of water into steam of four atmospheres' pressure per hour, should be 2·03 feet in diameter, and 18·6 in length; and one to boil off 24 cubic feet at three atmospheres, would be 2·6 feet in diameter, and 50 in length. To produce the same effect, two boilers of the same diameter, and each 25 feet long, would be preferable.

With regard to the strength of boilers, it is to be observed in the outset, that the pressure tending to separate a boiler, is about proportional to the load on the safety valve; and the tendency to crush it together, is equal to the pressure of the atmosphere. Against the last of these pressures it will be easy to provide, for it will always be constant; but the former may be varied, and if any thing should go wrong with the valves, a considerable excess of pressure may arise from the elasticity of the steam, against which it is necessary to provide. From experience we are led to conclude, that a boiler ought to be enabled to bear from two to three times the pressure that is generally put on the safety valve in the working state. This may serve as a guide for the excess of strength of low pressure engines; but for high pressure engines, the excess of strength would require to be more. For boilers of a rectangular shape, and formed of wrought iron plates, this rule may be employed. The load in pounds per circular inch on the safety valve, multiplied by the greatest diagonal of the section of the boiler in inches, will give a dividend; and for a divisor, multiply the cubic content of the boiler per horse's power by 120, perform the division, and the quotient will be the thickness of the plate in inches. For copper, use 72 instead of 120. Thus, the greatest diagonal of a boiler is 8 feet $= 96$ inches, the load on the safety valve 3·5 lbs. per circular inch, and the space for steam being 16 feet per horse's power, here by the rule,

$$\frac{3{\cdot}5 \times 96}{120 \times 16} = {\cdot}173 \text{ inch for iron.}$$

and for copper,

$$\frac{3{\cdot}5 \times 96}{72 \times 16} = {\cdot}282 \text{ inch.}$$

These results come very near to the practice of the best boiler makers, so far as the top plates are concerned, as it is usual to make the top plates about a quarter of an inch in thickness, and the bottom ones about three eighths; it is generally thought advisable to make the plates acted upon by the fire, a great deal thicker, with a view to make them last longer. This however would appear to be a mistaken notion, not only from observation, but also from a very simple consideration. When the metal which is subjected to the immediate action of the fire is very thick, the heat is a considerable time in passing from the exterior to the interior surface, and it is plain that the interior surface (in contact with the water), cannot acquire a temperature greater than 212, while the outer surface may have acquired a temperature much higher; and thus the bottom surface of the boiler soon becomes burnt, and a crust of carbonaceous matter is presented to the action of the fire, and the plate of solid metal at the bottom has become as thin as any other part of the boiler. Besides, carbon is a bad conductor of heat, and so a loss of fuel is sustained, which it is the wish of the intelligent engineer always to avoid. If the plate had been thin, this would have taken place much slower, and to a far less extent. As to the comparative utility of copper and malleable iron plates for boilers, we give our opinion decidedly in favour of the former. Copper is a better conductor of heat than iron, and although its tenacity is not so great, yet when a copper boiler bursts there is only a tear, whereas, when an iron boiler bursts, it is often blown to pieces, destroying every thing in its way—the copper boiler doing less damage, and being easily repaired. The prime cost of iron is only 1-6th of that of copper, but when a copper boiler is done, the metal will sell for 1-6th less than its prime cost, whereas the iron will not pay the expense of removal. The bursting of vessels exposed to heat is frequently owing to the unequal expansion, and therefore, as we see in glass vessels, the thicker they are the more liable are they to break; cast iron boilers often burst from the same cause, wrought iron ones being better conductors of heat, burst less frequently, and for a similar reason, copper boilers are preferable to those of malleable iron. Other particulars regarding boilers of various forms, will be found under *Steam*, and *Locomotive Engine*; and we will conclude this article by describing the accompanying cuts of a rectangular boiler of the common form, with all its appendages. Fig. 1, is a longitudinal, and Fig. 2, a cross section, and the same letters are used for the same parts in both. *aa* is the boiler, surrounded by the flues *bb*, *c* is the chimney, *d* is the ash-pit, and *e* is a space for holding any ashes that may be carried over the division behind the furnace bars, this space being cleaned out through the opening *f*, which is built up when the boiler is in action, so that no air can be admitted into the flues. *g* is a space in the top of the division behind the furnace, to allow the flame and smoke to pass over; *h* is the furnace mouth, and *i* the bars; *k* is a plate behind the bars, furnished with a handle *l*, with which when it is drawn out, the danders may be forced into the ash-pit. On the top of the man-hole *m*, a valve is shown, which opens inwards, in order to prevent the sides of the boiler from being crushed in when the steam in the interior happens to be condensed, (see *Air Valve*); *n* is the steam pipe and safety valve (see *Safety Valve*); *o* shows the gauge cocks for ascertaining

FIG. 1.

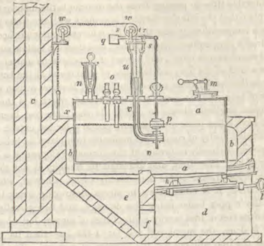
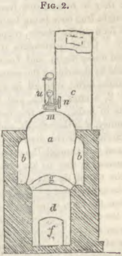


FIG. 2.



the height of the water in the boiler, (the surface of the water is shown by the dotted line). The stone float *p* is partly balanced by the weight *q*, which is hollow, in order, if required, to hold additional weights for regulating the float; *r* is the fulcrum on which the lever *ss* turns, and *t* is the centre of the lever which works the small valve fixed in the bottom of the top part of the feed-pipe, which admits the water into the boiler. This water flows into the top of the feed pipe from the hot water pump. When the water in the boiler becomes less by evaporation, the level of the surface will be lowered, and consequently the stone float will descend, and the other end of the lever which works the valve in the feed-pipe will be raised, and the valve opened, and water admitted until the float rises to the proper level, (see *Feeding Apparatus.*) The feed-pipe *u* ought to be so high, that there cannot be a possibility of the water in the boiler being forced out through it by the pressure of the steam. When the steam gets very strong, the water in the boiler is by the increased pressure forced through the pipe *vv* up into the feed-pipe, and acts upon a float which is connected by a chain passing over the pulleys *ww*, to the damper *x*, which damper passes into the flue and damps the fire, (see *Damper.*) In the bottom of the top part of the feed-pipe, there is fixed a small pipe to allow the chain of the damper to work through the bottom, and not allow any water to pass into the boiler which does not pass by the feed-valve. There is attached to the top of the feed-pipe, a small pipe for the purpose of carrying off the surplus water which is supplied by the hot-water pump, but is not required for the boiler. The feed-pipe is shown broken in the end section.

Boiling, or Ebullition ; the agitation of fluids, arising from the action of fire, &c. All fluidity is the effect of a quantity of caloric, or the matter of heat, absorbed by a body in passing from a solid to a fluid state ; and boiling is the act of a body passing from a fluid state to that of vapour, by a further absorption of the caloric. If the heat is applied to the bottom of the vessel, after the whole liquid has acquired a certain temperature, those particles next the bottom become elastic, and ascend as they are formed through the liquid like air-bubbles, and throw the whole into violent agitation. The liquid is then said to boil. Every liquid has a fixed point at which boiling commences, and this is called its boiling point. Thus under the ordinary pressure of the atmosphere, water begins to boil when heated to 212 degrees. After a liquid has begun to boil, it will not become hotter, however much the fire may be increased. A strong heat, indeed, makes it boil more rapidly, but does not increase its temperature. This was first observed by Dr Hooke.—The following table contains the boiling point of a number of liquids, at the ordinary pressure of the atmosphere:

Bodies.	Boiling point.
Ether,	98
Ammonia .	140
Alcohol,	176
Water,	212
Nitric acid,	248
Sulphuric acid,	590
Oil of turpentine,	560
Sulphur,	570
Linseed oil,	600
Mercury,	660

Bolts, large iron pins.

Bond, the fastening several pieces of timber together, either by mortise and tenon, dove-tailing, &c.

Boring. Much of the excellence of our modern steam engines depends on the improved methods of boring their cylinders. The cylinders of steam engines are cast hollow; and it is a well known fact among founders, that although the mould be ever so correct, and the casting managed with the utmost care of the most skillful workmen, yet there is every likelihood that the cylinder will be drawn out of the sand untrue. The cylinder to be bored is firmly fixed with its axis parallel to the direction in which the borer is to move. The cutting apparatus moves along a bar of iron, accurately turned to a cylindrical form, having a polished surface. Two opposite and parallel grooves are cut on this cylinder, from one end to the other. A socket of cast iron, which is bored and ground so as exactly to fit this cylinder, and to slide along it without the slightest shaking, is then put on. Its external part is made conical, having five or six studs upon the base to receive the cutter block, which is fastened to it. The bore of this socket is furnished with fillets, which fit the groves cut in the cylinder, so that the socket may easily slide lengthwise on the cylinder, but can only revolve on its axis with it. The cutter block is wedged tight into the socket. The cutter block is a ring of metal somewhat less in diameter than the cylinder to be bored, and having on its circumference eight notches to receive the cutters, which are fastened with wedges. To give a progressive motion to the cutting head, (including the socket, and cutter block,) while the cylindrical guide is revolving upon its axis, a collar of metal is fitted to the socket, which collar is connected with two racks of sufficient length to reach through the cylinder to be bored, which racks communicate with a pair of pinions, acted upon by two levers loaded with a sufficient weight to overcome all obstacles while the operation is going on.

The cutter should pass through 72 inches in the minute, so that the diameter of the cylinder to be bored, will determine the number of revolutions of the shaft in a given time. If the circumference of the cylinder be 72 inches, then the shaft carrying the cutters will just make one turn in the minute, and the number of turns for any other cylinder will be found by dividing the circumference in inches, by 72.

Some of these boring machines are so adjusted, that the cylinder is in a perpendicular direction, and this seems to be an improvement. See *Drilling*.

The largest of the boring tools for wood, is the auger. The oldest construction of the auger, which is yet in common use, in various parts of the country, cannot be wrought till a small excavation has been made, which is mostly done with a gouge, at the place where the hole is to be;

and until the auger arrives at a considerable depth, its motion is very unsteady. This old auger is shaped like a gimblet, except at the point, which is like that of a nose-bit. An improved construction of the auger, by Phineas Cooke, appeared to possess so much merit, that the Society for the Encouragement of Arts, presented thirty guineas to the inventor. This is called the spiral auger, for it consists of a rectangular bar of steel, twisted in the shape of a bottle-screw, terminating in a short taper screw, with a double worm like a gimblet. The upper part, like that of the common auger, is formed into a large ring, in which the handle is inserted, at right angles to the length of the auger. That part of the screw adjoining the spiral, presents an edge which cuts the wood. This auger is not very commonly used, but it pierces the wood much truer than the common one; no picking is necessary before it can be wrought, nor does it require to be drawn out to discharge the chip. It is, however, better adapted to the boring of soft wood than hard. Its use being on this account more limited than workmen like; besides, its not being cheap in its first purchase, and if not made of good metal and very carefully tempered, easily changing its form, it will probably not retain the character it once acquired. The latest construction of the auger has been found to answer so well, that it will probably supersede the use of the spiral and common auger. Like the spiral one it terminates with a gimblet-screw, which draws it down into the wood, while the workman turns it round and presses upon it; and another peculiar advantage of which is, that its point can be set precisely upon the centre marked for the perforation, the proper direction of which there is then a good chance of preserving, while the broad-ended auger is apt to deviate considerably at its very commencement. Immediately above the spiral screw, it is, for a short length, rather of a prismoidal shape, tapering a little upwards, like the socket chisel below the conical part. The prismoidal part has one cutting edge which cuts the sides of the hole, and another which cuts the bottom. The core rises as the act of boring goes on, in the form of a spiral shaving. Above the prismoidal part, the shaft may be of any shape at pleasure, that possesses sufficient strength, taking the obvious precaution of making its diameter less than that of the bore. The general disadvantage of augers with gimblet points, is, that when they encounter knots or hard places in the wood, they are apt to break. Every one who makes use of an auger in the usual way by hand, knows by experience that he never can so completely exert his strength in this operation, as when he bores down perpendicularly, with his body leaning over his work; and it is very evident, that by every degree of the auger's elevation from this situation, his power is of less effect, consequently his labour is increased, and his work so much retarded, that in the former position he can bore four holes for one in the latter. In hand boring, also, the unsteady and irregular motion of the auger, (particularly when the common old-shaped one is used,) at its first entrance into the wood, occasions the holes to be bored very crooked, often larger without than within, and very wide of the direction aimed at, espceially if the wood proves hard and knotty, and the holes are deep. Regarding the prevention of these disadvantages, as a matter of considerable consequence to ship-builders, and a variety of other artists, the Society for the Encouragement of Arts, &c. presented the sum of fifty pounds to William Bailey, for his invention of a machine for boring auger-holes, by the use of which the force of the workman, and consequently the despatch of his operations, are equally exerted in all directions. It is unavoidable, also, in the usual way of boring, for the action of the auger to be discontinued twice in every revolution; but with the machine the motion is continued with equal force and velocity, till the auger has bored to the depth required. A description of this machine, illustrated by a plate, may be seen in Bailey's Advancement of Arts; our limits will not allow us the further notice of it here, but the fact of such a contrivance having been executed, being mentioned, the ingenious mechanic will not perhaps find it very difficult to contrive one for himself.

The contrivance for boring next entitled to notice, is the stock, which is in effect a crank, not unlike the hand-drill, and frequently made of iron, though generally of wood, defended by brass, at the parts most subject to wear. Where the crank terminates, two short limbs project from it, in a line with each other, and parallel with that part of it by which it is revolved. In the end of one of these limbs, which is called the pad, the piece of steel by which the boring is performed, is inserted; the other limb is connected with a broad head, rather convex externally, which head is placed against the breast, and is stationary while all the other parts are revolved.

The piece of steel inserted in the stock is called the bit; as it can readily be taken out or put in, the same stock serves for bits of all sizes. They are differently shaped, according to their use. The gouge-bit is best adapted for boring small holes in soft wood; it is shaped nearly like the turner's gouge, but is rather more pointed like a spoon at the extremity; the basil is made in the inside, and the sides are brought to a cutting edge like those of a gimblet. The centre-bit has a small conical point projecting from the lower end; this point entering the wood first, keeps the tooth of the bit from wandering out of its proper course, and the hole is bored straight with great ease. The taper shell-bit is used for widening holes; it differs from the gouge-bit chiefly in tapering gradually from the pad to the lower extremity.

The bit for widening the upper part of a hole, to admit the head of a screw, is called a countersink. The head of the countersink is conical, and the cutting edge is single when made for wood alone, and stands out a little from the side of the cone. Joiners and cabinet-makers, however, are generally provided with countersinks for brass ; and these, which have ten or a dozen teeth on the surface, running slantwise from the base up the sides of the cone, they frequently make use of for wood, especially when it is hard, and they are anxious to avoid tearing it ; for the teeth of the brass countersink act like those of a file.

The gimblet is a boring implement too well known to require any explanation of its construction ; but with respect to its management, it may not be wholly useless to remind the novice, that like other boring tools of a similar conformation, it requires to be withdrawn to remove the core as often as the cup or groove is filled, and this will be sooner or later, not only in proportion to the depth penetrated, but the density of the wood. Indeed, in boring such wood as lignum-vitæ, which clogs the tool, it is advisable to withdraw the gimblet, to clear away the core, before the cup is full. The auger gives warning of the time to stop, by the difficulty of turning it, when overcharged with shavings, and is too strong a tool to be in danger of being twisted ; but the smallness of the gimblet renders it liable to be twisted and broken before the workman is aware, if not often enough withdrawn and emptied. Gimblets which are broken-pointed, or blunted on the arris of the screw, are generally thrown aside, it being tedious and laborious when they are large, to work with them in such a state ; but we may observe, that though the grindstone cannot be employed to sharpen the worm, a file may, so that a few minutes' labour will render them fit for use again.

The smallest sort of boring tool is a kind of bodkin, called the brad-awl, or sprig-bit, as it is chiefly used in making the perforation to admit those small slender nails, which have no head except a trifling projection on one side, and are called brads in some parts of the country, and sprigs in other parts. The sprig-bit is generally made with a shoulder where the tang terminates ; below the shoulder it is cylindrical, to within a short distance of the extremity, which is flattened, and thereby made rather broader than the diameter of the cylindrical part ; but so thin at the same time towards the end as to form an edge. Unlike other boring tools, the sprig-bit takes away no part of the substance of the wood, nor is it turned entirely round in making a hole, but merely wrought backwards and forwards about half round before the motion is reversed.

Bow Compass, for drawing arches of very large circles ; it consists of a beam of wood or brass, with three long screws that bend a lath of wood or steel to any arch. The term is also sometimes used to denote very small compasses employed in describing arcs, too small to be accurately drawn by the common compasses.

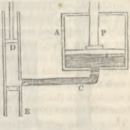
Bow-drill. See *Drill.*

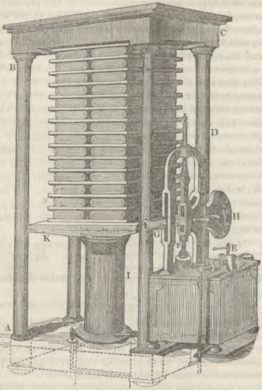
Brace; a piece of timber fixed obliquely into others, to stay them from moving any way.

Brackets; the cheeks of the carriage of a mortar. A cramping iron to stay timber work; also stays set under a shelf to support it.

Brads; nails having no broad heads.

Bramah's Press, or the hydrostatic press, is one of the most valuable of all the machines ever invented by man, dependent on the action of water. The first idea of the construction of this machine was given by Pascal, about the middle of the 17th century, but we have no proof of its ever having been put in practice, until Mr Bramah, about the year 1800, without any knowledge of the discovery of Pascal, constructed the press which now goes by his name. The action of this press depends upon the well known principle in hydrostatics, that fluids press equally in all directions (see *Hydrostatics*); and the application of this theorem to the machine under consideration, will be easily understood from this cut. Here AB is the section of a hollow cylinder, into which a piston P is fitted. Into the bottom of this cylinder there is introduced a pipe C leading from the forcing pump D; water is supplied to this pump by a cistern below, from which the pipe E is led, being furnished with a valve opening upwards where it is joined to the pump barrel. Where the pipe C enters into the pump barrel there is also a valve opening outwards into the pipe; consequently, when the piston D rises, this valve shuts, and the valve at the cistern pipe opens, and the fluid rises into the pump barrel. When the piston begins to descend, the cistern valve shuts, and the water is forced through the pipe C into the large cylinder AB, and by the law of fluids before alluded to, whatever pressure be exerted by the piston D on the surface of the water in the pump, will be repeated on the piston of the large cylinder AB as many times as the area of the small piston D is contained in the area of the large piston AB; that is, if the area of the pump-piston were one square inch, and that of the cylinder 100 inches, and if the piston were forced down with a pressure of 10 lbs., then the whole pressure on the bottom of the piston AB will bo 10 times 100, that is 1,000 lbs. The accompanying wood engraving will give a correct idea of the most improved construction of the press. ABCD is a strong iron frame, at one side of which is the cistern containing the water for the supply of the force pump F, wrought by means of a lever which fits into the tube G, at the other end of which is the counterweight H. At the beginning of the operation little power is required, but a great





quantity of water, and therefore the fulcrum of the bar is placed far back, in order that the pump may have a longer stroke; but as the pumping advances, more pressure becomes necessary, and therefore the stroke is shortened by moving the fulcrum forward. The water is forced in the manner before described into the bottom of the large cylinder I, and the piston being pressed up, the board K supporting the material to be pressed, is raised, and the goods are compressed between this board and the top of the press. To prevent the machine from bursting, a safety valve, capable of overcoming a given pressure is employed; and for the purpose of admitting the water or drawing it from the large cylinder, the press is furnished with stop-cocks at E. From the facility of operating with this machine, and its great power, it is applied to many purposes. When the page which is now before the reader was taken wet off the types, it was all deeply indented in consequence of the pressure of the printing press; but after being dried, it was subjected to the action of Bramah's press, by which process, as will be seen, these indentations have been nearly obliterated. In the press by which this has been accomplished, the pump has a bore of $\frac{3}{4}$ of an inch in diameter, and the cylinder one of 8 inches, their areas are therefore to one another, as 9 16ths to 64 (the squares of the diameters), that is, as 1 is to 136; hence if the pressure upon the pump-cylinder be 56 lbs., (which can be easily effected by boys,) the pressure upon the piston of the large cylinder will be 56 × 136, that is, 7,616 lbs. This astonishing power has also been employed in the construction of cranes. To find the thickness of metal necessary for the cylinder of Bramah's press, multiply the pressure per square inch by the radius of the cylinder, and divide the product by the difference between the cohesive power of the metal per square inch, and the pressure per square inch; and the quotient will be the thickness sought. Wherefore, in two presses, each 12 inches in diameter, in one of which the pressure is $1\frac{1}{2}$ tons, and in the other 3 tons, per circular inch,—the cohesive force of cast iron being 18,000 lbs. per square inch—

$1\frac{1}{2}$ tons per circular inch = 4,278 lbs. per square inch.
3 tons do. = 8,556 lbs. do.

Whence, by the rule, $\frac{4{,}278 \times 6}{18{,}000 - 4{,}278} = 1\cdot87$ inches thickness.

And, $\frac{8{,}556 \times 6}{18{,}000 - 8{,}556} = 5\cdot43$ inches thickness.

Brass; an alloy of copper and zinc. Of all the alloys of copper, this is the most useful, being more malleable than copper when cold, and less liable to tarnish from the action of the atmosphere. The malleability of brass is however destroyed by heating, so that at a low red heat, it crumbles under the hammer. Brass is composed of

Copper, 3 parts,
Carbonate of zinc, 1.

The carbonate of zinc is found commonly combined with a small portion of lead, and is called calamine.

In the formation of brass, the calamine is first pounded in a stamping mill, and afterwards washed and sifted in order to free it from the lead with which it is mixed. It is then placed on a broad shallow brick hearth, over an oven, heated to redness, and thus it is calcined for several hours, being frequently stirred during the process. Sometimes the calcination is carried on in another way. Alternate layers of calamine and charcoal are placed in a kiln, which is fired from the bottom. When the calcination of the calamine has been completod; it is then taken to a mill and ground. It is then mixed with a third or fourth part of charcoal, and being put into crucibles, with the proper proportion of grain copper, or old copper of any kind, and then covered with charcoal, and the whole luted over with a composition of clay and horse dung, is set in a furnace. The temperature of the furnace is for some time kept below that which is necessary to fuse copper, but after some time it is raised to this pitch, and the brass being thus formed is run off into bars.

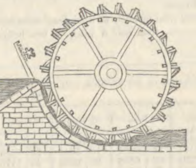
Brass varies in the proportion of zinc which it contains, there being seldom less than one-ninth, or more than one-fourth of zinc. That brass is softer and easier wrought, which contains the least quantity of zinc; but even with so large a proportion of zinc as one-fourth, brass is still perfectly malleable when cold. Hammering increases, or indeed creates elasticity in brass, destroys its flexibility, adds considerably to its durability, and imparts magnetic power.

TABLE FOR COMPOSITIONS OF BRASS, &c.

2 parts copper,	0 tin,	1 zinc,	Yellow brass.
3	0	1	Spelter.
4	1	$0\frac{1}{4}$	For lathe bushes.
4	1	$0\frac{3}{4}$	Still harder.
6	1	0	Fit for bearings of shafts.
5	1	$0\frac{1}{2}$	For harder bearings.
7	1	0	Fit for pulley blocks.
8	1	0	Fit for wheels.
9	1	0	Gun-metal.

Breast Wheel; a form of the water wheel, in which the water is delivered to the float boards, at a point somewhere between the bottom and top. The water in this form of the water wheel, is commonly delivered to the float boards a little below the level of the axis, but sometimes even above it. Buckets are never employed on breast wheels, but the float boards are fitted accurately in the mill course, so as to have little play, and thus the water after having acted upon the float boards by impulse, is retained between them and the mill course, acting by its weight until it arrives at the lowest part of the wheel. The effect of a breast wheel, is equal to that of an undershot whose head of water is equal to the difference of level between the surface of water in the reservoir, and the part where it strikes the wheel, added to that of an overshot, whose height is equal to the part where it strikes the wheel, and the level of the tail water. When the fall is between four and ten feet, and there be a sufficient supply of water, the breast wheel ought to be erected. It is also recommended that when the fall exceeds ten feet, it ought to be divided into two, and two breast wheels employed. The following table is calculated according to the data of Lambert:

	Breadth of the float-boards.	Depth of the float-boards.	Radius of water-wheel, reckoned from the extremity of float-boards.	Velocity of the wheel in a second.	Time in which the wheel performs one revolution.	Turns of the mill-stones for one of the wheels.	Force of the water upon the float-boards.	Water required in a second to turn the wheel.
	Feet.	Feet.	Feet.	Feet.	Sec.	....	Lbs. Av.	Cub c ft.
1	0·17	198·6	0·75	2·18	1·92	4·80	1536	74·30
2	0·34	35·1	1·50	3·09	2·72	6·80	1084	37·15
3	0·51	12·7	2·26	3·78	3·33	8·32	886	24·77
4	0·69	6 2	3 01	4·36	3 84	9·60	762	18·57
5	0·86	3·57	3·76	4·88	4·28	10·70	686	14·86
6	1·03	2·25	4·51	5 35	4 70	11·76	626	12·38
7	1·20	1·53	5·26	5·77	5·08	12·70	581	10·61
8	1·37	1·10	6·02	6·17	5·43	13·58	543	9 29
9	1·54	0·81	6·77	6·55	5·76	14·40	512	8 26
10	1·71	0·77	7·52	6·90	6·07	15·18	486	7·43



Brick; earth formed into long squares by a wooden mould, and then baked in a kiln, or burnt in the sun. The principal are compass-bricks of a circular form, used in steyning of walls; concave or hollow bricks used for conveyance of water; feather-edged, which are thinner, used for penning up brick panels in timber buildings; cogging bricks are used for making the indented works under the coping of walls built with great bricks; coping-bricks are for coping of walls; Dutch or Flemish bricks, for paving yards, soap-boilers' vaults, &c.; clinkers are bricks glazed by the heat of fire; sandal or samel bricks are those which are not thoroughly burnt, but soft and useless; great bricks are for fence walls; plaster or buttress-bricks have a notch at one end, and their use is to bind the work built of great bricks. Statute, or small common bricks, ought to be nine inches long, four broad, and two and a half thick. Bricks may be made of pure clay, or of clay mixed with sand or ashes. The clay is first tempered with water to render it fit for moulding. The brick-makers are called a gang, each consisting of one or two men, a woman, and two children. When the bricks are dry they are burnt in a kiln. A kind of bricks, called fire bricks, are made from slate-clay, which are very hard, heavy, and contain a large proportion of sand. These are chiefly used in the construction of furnaces for steam-engines, or other large works, and in lining the ovens of glass-houses, as they will stand any degree of heat. Indeed, they should always be employed where fires of any intensity are required.

One stock brick is $8\frac{3}{4}$ inches long, $4\frac{1}{4}$ inches wide, and $2\frac{1}{2}$ inches thick, and weighs about 4 lbs. 15 oz. 16 bricks to each foot of reduced brick-work; 7 bricks to each foot superficial of marle facing, laid Flemish bond; and 10 bricks to each foot superficial of gauged arches. 272 superficial feet, or 306 cubic feet, make 1 rod of reduced brick-work of the standard of $1\frac{1}{2}$ brick thick. To reduce cubic feet to the standard thickness, multiply by 8, and divide by 9. 450 stock bricks weigh 1 ton, and 1 rod of brick-work weighs 13 tons.

Table showing what quantity of bricks are necessary to construct any piece of brick-work, from half a brick to two bricks and a half in thickness.

Area of the face of the wall.	THE NUMBER OF BRICKS THICK AND THE QUANTITY REQUIRED.									
	½ Brick.		1 Brick.		1½ Brick.		2 Bricks.		2½ Bricks.	
	Bcks.	Decimals	Bcks.	Decimals	Bcks.	Decimals	Bcks.	Decimals	Bcks.	Decimals
1	5	5147	11	0294	16	5441	22	0588	27	5735
2	11	0294	22	0588	33	0882	44	1176	55	1470
3	16	5441	33	0882	49	6323	66	1764	82	7205
4	22	0588	44	1176	66	1764	88	2352	110	2940
5	27	5735	55	1470	82	7205	110	2940	137	8675
6	33	0882	66	1764	99	2646	132	3528	165	4410
7	38	6029	77	2058	115	8087	154	4116	193	0145
8	44	1176	88	2352	132	3528	176	4704	220	5880
9	49	6323	99	2646	148	8969	198	5292	248	1615

This table is at the rate of 4500 bricks to the rod of reduced brick-work, including waste. The left-hand column contains the number of superficial feet contained in the wall to be built: the adjacent columns show the number of bricks required to build a wall of the different thicknesses of $\frac{1}{2}$, 1, $1\frac{1}{2}$, 2, and $2\frac{1}{2}$ bricks.

Although the left-hand column only exhibits the number for units, the number for tens, hundreds, and thousands may be found by bringing forward as many of the decimals to the whole number of bricks as the number required to be found is removed from the unit's place.

Example 1.—Required the number of bricks necessary to build a wall 1 brick thick, containing an area of 5760 feet.

5000	will require	55147
700		7720
60		661
5760		63528, Ans.

Example 2.—Required the number of bricks necessary to build a wall 2 bricks thick, containing an area of 9 feet.

9 will require 198, Ans.

Bridge; an erection to facilitate conveyance from one point of space to another. There are few subjects of greater interest to the civil engineer, than the erection of bridges; in this article, therefore, we will endeavour to give a short, but perspicuous view of the principles and mode of procedure employed in these erections.

Convenience, beauty, and durability should be the characteristics of a bridge, as well as of every other structure. To preserve all which qualities is often a difficult task for the architect, who has seldom the choice of the situation, and thus it becomes his first concern to consider well the local circumstances.

A bridge should always be constructed at right angles to the current, and where a choice can be made, the widest part of the stream should be selected, as the velocity of the water will there be the least, and therefore it will have the less power in affecting the foundation. For the same reason, every possible means of preventing the current from being narrowed ought to be taken, as the narrowing the current must always increase its velocity. If the piers are unnecessarily large or numerous, they will contract the stream, and thus prove injurious. It is likewise to be observed, that the arches of a bridge ought to be 1, 3, 5, 7, or some odd number; as in this case the middle of the stream, which has the greatest velocity, will flow through the opening of the centre arch, which ought to have the greatest span. With regard to the proper curve for the arch of a bridge, great variety of opinion prevails both among architects and mathematicians. Some have contended that semicircular arches ought to be preferred, because they press more perpendicularly upon the piers, than smaller portions of circles, and in proportion to their number, will diminish the pressure on the abutments. The elliptical arch has been preferred to others, where the arches are large, and few in number; because, in this way, the roadway would not be so much raised, as if circular arches were employed. Much has been said of the arch of equilibrium, (see *Catenary*,) but the arches of a stone bridge could not be made of this form; for although the mathematical reasoning on the properties of this curve be perfectly just, yet it applies with strict propriety only to homogeneous materials, and to structures acted on by no force, but that of gravitation; so that whenever a waggon, or any load acted upon this arch, it would no longer be an arch of equilibrium, but would be as liable to fall as any other. Bridges have been built, having arches which were not of the equilibrate kind, and yet these have stood the test of centuries, and are likely to stand, until the materials of which they are composed, crumble into dust. We are therefore warranted to build similar bridges when they suit our convenience. Arches which are parts of circles, have all their stones of one form, and they can therefore be made with great exactness; but this is not the case with arches having other curves, and hence, especially in the catenary, errors will arise, which will materially injure the structure. Next to circular curves, ellipses admit of the stones which compose them being formed in the most certain and satisfactory manner. Semi-elliptical approximate very nearly to the equilibrate arch, as their contour is not only very graceful, but in navigable rivers especially, very convenient, from the elevation of their haunches; as they can be made also to so great a variety of heights on the same span. To the semi-elliptic arch, then, we give our decided preference, especially for large works; and a table of elliptic arches, will be found under *Ellipse*; and the manner of forming the arch-stones will be found under the different curves, as *Circle*, *Ellipse*, &c.

Autumn is the most favourable time to lay the foundations of a bridge, as it is commonly the driest season of the year, and the consequent lowness of the water is favourable to the work. The simplest mode of overcoming the inconvenience of the water, in laying the foundations of piers, consists in turning the river out of its course, above the place designed for the bridge; but this plan is seldom expedient, the use of the coffer-dam, or enclosure to keep off the water, being much more common. By the coffer-dam, a part only at a time of the bed of the river is enclosed from the water, which flows in a free current along the unenclosed parts of its bed. An account of the method employed in laying the foundations of Essex Bridge, in Dublin, will illustrate this subject. Round the place where the intended pier was to be built, two rows of strong piles were driven, about 30 inches from each other, and which were left at low-water-mark. These piles were lined with planks between which was rammed a quantity of clay, and thereby the wall of the coffer-dam was formed. Within this wall were driven a row of piles, dove-tailed at their edges, so as to receive each other, and which formed the extremities of the plan of the piers at the level of the bed of the river. After having dug to a fine stratum of sand, about four feet lower, within these a great number of other piles were driven as deep as they could possibly be made to penetrate. The intervals of these piles were filled up, and in order to produce a solid foundation, the first course was laid with mortar made of roach lime and sharp gravel, and on this large flat stones were rammed to about a foot in thickness. On this first course was laid a thick coat of dry lime and gravel of the same quality, on which were again laid stones and the mortar as at first; and so on alternately, until the pier arrived at a level with the piles. Three beams, stretching the whole length of the pier, from sterling to sterling, were fastened down to the ends of these piles, and their intervals filled up with masonry. On this platform, which was 4½ feet under low-water mark, was laid the first course of stones for the pier, cramped together, and jointed with terras mortar as usual; courses of stones were laid in this manner, until the piers were on a level with the water at ebb-tide.—The caisson is a contrivance of still more extended utility than the coffer-dam, being better suited to very deep and rapid streams. The most considerable work where caissons have been employed, was in the building of Westminster bridge. Each of the caissons contained 150 loads of fir timber, and was of greater tonnage than a frigate of forty guns; their size was nearly 80 feet from point to point, and 30 feet in breadth; the sides, which were 10 feet in height, were formed of timbers laid horizontally over one another, pinned with oak trunnels, and framed together at all the corners, except the salient angles, where they were secured by proper iron-work, which being unscrewed, would permit the sides of the caisson, had it been found necessary, to divide into two parts. These sides were planked across the timbers, inside and outside, with three-inch planks in a vertical position. The thickness of the sides was 18 inches at the bottom, and 15 inches at the top; and every angle, except the two points, had three oaken knee timbers, properly bolted and secured. These sides, when finished, were fastened to the bottom or grating, by 28 pieces of timber on the outside, and 18 within, called straps, about 8 inches broad and 3 inches thick, and reaching and lapping over the tops of the sides. The lower part of these straps were dove-tailed to the outer curb of the grating, and kept in their places by iron wedges, which were used when the pier was built up sufficiently high above low-water-mark, to render the caisson no longer necessary for the masons to work in, the wedges being drawn up, gave liberty to clear the straps from the mortises, in consequence of which the sides rose by their own buoyancy, leaving the grating under the foundation of the pier. The pressure of the water upon the sides of the caisson, was resisted by means of a ground timber or ribbon, 14 inches wide, and 7 inches thick, pinned upon the upper row of timbers of the grating; and the top of the sides was secured by a sufficient number of beams laid across, which also served to support a floor on which the labourers stood to hoist the stones out of the lighters, and to lower them into the caisson. The caisson was provided with a sluice to admit the water. The method of working was as follows: a pit being dug and levelled in the proper situation for the pier, of the same shape as the caisson, and about five feet wider all around, the caisson was brought to its position, a few of the lower courses of the pier were built in it, and it was sunk once or twice to prove the level of the foundation; then, being finally fixed, the masons worked in the usual method of tide-work. About two hours before low water, the sluice of the caisson—kept open till then, lest the water, flowing to the height of many more feet on the outside than the inside, should float the caisson and all the stone-work out of its true place—was shut down, and the water pumped low enough, without waiting for the lowest ebb of the tide, for the masons to set and cramp the stone-work of the succeeding courses. Then, when the tide had risen to a considerable height, the sluice was opened again, and the water admitted; and as the caisson was purposely built but ten feet high to save useless expense, the high tides flowed some feet above the sides, but without any damage or inconvenience to the works. In this manner the work proceeded, till the pier rose to the surface of the caisson, when the sides were floated away, to serve the same purpose at another pier.

General Bentham proposes the construction of hollow masses of masonry, brickwork, &c. which he would afterwards float to, and sink at the place desired. He observes, that these masses, if filled with casks, might be floated without having themselves any bottom; and directs a calculation to be made of the weight which any of them will have to bear when employed as piers, or for any other purpose, so that vessels properly loaded may be grounded upon them, and by that means sink them, when the tide retires, as low as they would otherwise have been ultimately sunk by the weight they are to sustain, and thus prevent their sinking after the structure is finished. J. I. Hawkins would build his piers on shore, in some situation where they might be launched like a ship; he would cramp the outside stones strongly with iron, and would make the walls of such a thickness that they might float in water. He would have a valve in the wall, to admit water whenever it might be proper to sink the pier, and a pipe fixed through the top, communicating with the lower part of the inside, on which pipe a pump must be fixed, for drawing the water out, should that measure be necessary.

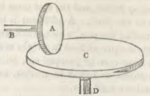
To form a good foundation, a space in the bed of the river, rather larger than the base of the pier, must be excavated and levelled by the means used in taking up ballast, and the spot must be piled, if necessary, as on other occasions of the kind. A platform is to be made over the place intended for erecting the pier, which, when sunk, must have bricks or stones let down into it equal at least in weight to the water required to sink it. The water must then be pumped out, when the workmen may descend, to lay the stones or bricks in mortar, and fill up the whole interior; thus he obtains a solid pier.

In situations where, from the state of navigation, or any other cause, it may be inconvenient to erect centering in the customary way, he would not hesitate to adopt suspending chains; since the weight of an arch of any given dimensions is easily calculated, and the suspending power of iron is known; and no arch can be so heavy, but that a sufficient number of chains may be provided to bear more than the weight. The chains may be advantageously composed of long bars of iron, merely turned up at the ends, so that when done with, they may have these ends cut off and be sold as bar iron again.

That the piers of bridges may be built hollow, and rendered perfectly manageable in or under water, at a considerable depth, is put beyond a doubt by an experiment of J. I. Hawkins. Two hollow cylinders of brickwork, upwards of 11 feet diameter, and 25 long each, were sunk through 30 feet of water in the river Thames, and bedded precisely at the spot proposed. These cylinders were built in a barge, in October and November, 1810, and launched into the water, where they remained floating all winter, and were sunk in the river in the spring of 1811. They were under such perfect command, that from a stage erected on the bed of the river, and supplied with suitable windlasses, pulleys, ropes, &c., they were lowered, raised, or moved, in any lateral direction without difficulty. These experiments left not a doubt, that masses of masonry, of large dimensions, might be fixed through the water, in the bottom of a river or harbour, to the depth, if requisite, of 120 feet.

Bridge, any horizontal beam, &c., that is to support something.

Brush Wheel. In light machinery, wheels often turn each other by means of bristles or brushes fixed in their circumference. Sometimes they are brought into contact acting by friction, the rims being formed by the end surfaces of wood, or by being covered with hempen belts, or that kind of belt worn by soldiers. A very good method of changing velocity at any given rate may be effected by means of brush wheels.—Thus let the wheel A turn with the horizontal spindle B, having its rim in contact with the face of the wheel C turning on the upright spindle D. The face of the wheel C and the rim of A are made rough, so that the one may turn the other by friction, and the wheel A is made capable of being moved on its spindle so as to be placed near to, or farther from, tho



centre of the wheel C, and as is evident there will be produced a corresponding change in the relative velocities of the two wheels.

Bronze, a compound metal, made from six to twelve parts of tin, and one hundred parts of copper. It is used for cannon and for medals.

Bull's Eye; a small oval block of hard wood, withoutsheaves, having a groove round the out-side, and a hole in the middle. The bull's eye spindle or under spindle of the air pump rod in the common parallel motion of a steam engine, so called, because the air pump rod must pass through a hole in it, called the bull's eye.

Bush; a piece of metal fitted into the plummet block of a shaft in which the journal turns. The guide of a sliding rod also goes by the same name. Bushes are most commonly made of hard brass, and are not unfrequently denominated pillows, and the plummet blocks in which they are fixed, are called pillow blocks.

Building, may be defined the art which comprises all the mechanical operations necessary to carry into effect the designs of the architect. The engineer should make himself conversant with the principles of building, at least, so far as regards the erection of edifices for containing machinery. He ought to know the strength, durability, and other properties of the materials employed, and the best possible arrangement for the purpose required. It would be perfectly inconsistent with the plan of our work to enter here into details concerning the practice of building. Under various articles, such as *Brick*, *Bridge*, *Cement*, *Engine-house*, *Mill*, &c., will be found several of the more important practical details useful to mechanics.

Butments, those supports on which the feet of arches stand.

Buttress, a piece of strong wall that stands on the outside of another wall to support it.

C

Cable; a thick rope made of hemp. To determine the ultimate strength of a cable,

$$\frac{\text{girth in inches}^2}{5} = \text{the utmost strength in tons that the cable will}$$

bear; wherefore, if the circumference of the cable be 4 inches,

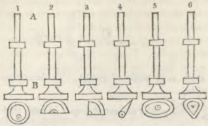
$$\frac{4^2}{5} = \frac{16}{5} = 3{\cdot}2 \text{ tons, the utmost that it can bear.}$$

Caisson; a frame used in laying the foundation of the piers of a bridge. See *Bridge*.

Caliber, or Caliper; properly denotes the diameter of any round or cylindrical body. Calipers, or caliper compasses, is the name given to a kind of compass for measuring the thickness of articles—chiefly employed by turners.

Caloric. See *Heat*.

Cams. If the axis of a wheel be situated in any other point than its centre, the wheel, thus rendered *eccentric*, may produce by its revolution an alternate motion in any part exposed to its action. Circles, hearts, ellipses, parts of circles, and projecting parts of various forms, are made to produce alternate motion, by continually altering the distance of some movable part of the machine, from the axis about which they revolve. Such projecting parts are called *cams.* In the various forms which are shown in the figures, the part removed by the cam is supposed to return by its own gravity, or by some other power, so as to keep up the alternate motion. In the circular eccentric cam, or wheel, Fig. 1, the sliding or reciprocating part, AB, will ascend and descend with an easy motion, being never at rest unless at the instant of changing its direction. In the semicircular cam, Fig. 2, the reciprocating part will remain at rest on the periphery of the cam during half the revolution, but in the remaining half it will approach the axis and return. In the quadrant cam, Fig. 3, the reciprocating part will remain at rest on the periphery during the first quarter of the revolution: during the second it will descend to the axis; during the third it will be at rest upon the axis, and during the fourth it will return to its original situation. The narrow cam, Fig. 4, causes the reciprocating part to rise and fall in one half the revolution and to remain at rest on the axis during the other half. In these figures, the angles of the cams are made sharp, for the sake of demonstration, but in practice they are generally rounded, to produce more gradual changes



of motion. The elliptical cam, Fig. 5, causes two alternate movements for each revolution. A cam in the form of a heart, called a *heart wheel*, Fig. 6, is much used in cotton mills, to cause a regular ascent and descent of the rail on which the spindles are situated.

When an easy motion is desired, as in most large machinery, the acting outline of the cam should be curved; but to produce a sudden stroke it should be straight. The number of cams may be indefinitely multiplied, if a rapid, or vibrating movement is required. This is in effect done, when the teeth of a wheel act upon a spring or weight, as in a watchman's rattle, or in the feeder of a grist-mill.

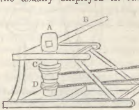
CAPILLARY TUBES; pipes whose canals or bores are exceedingly narrow, being so called from their resemblance to a hair in size. If several of these tubes, open at both ends, are immersed into water, the fluid will rise in them to heights which are inversely as their diameters, the height of the water in the tube of the smallest (*practicable*) bore being about 20 inches. It is also a law of capillary attraction, that different fluids rise to different heights in the same tube; thus, in a tube of ·061 inch bore,

Water will rise	·587 inches.
Hot do. .	·537
Oil of turpentine	·351
Whisky .	·327
Sulphuric acid	·20

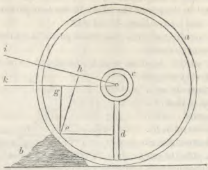
It is remarkable, that mercury forms a prominent exception to the general law, for, instead of rising in a capillary tube, it falls below the level of the fluid in the bason, and the smaller the bore of the tube, the greater will be the depression. Many conjectures have been made as to the cause of capillary attraction. Some insist that the matter of the tube acts upon the upper surface of the fluids; while others maintain that the rise is caused by the diminished pressure of the air in the tube, on the surface of the fluids. The following explanation, however, may be regarded as more satisfactory. Since a force impressed upon a fluid in any one direction is distributed in every other, the tendency of the fluid to adhere to the matter of the tube will cause it to spread over the internal cavity, and consequently it will rise.

Capital; in architecture, the uppermost part of a column or pilaster, serving as the head or crown.

Capstan; a simple machine usually employed in ships to weigh anchors, &c. A very simple and effective form of this machine is represented by the accompanying cut; where A D is a barrel composed of two cylinders, differing in diameter. On the extremity of the cylinder at D, the rope C E D is fixed, passing round the pulley E, which is attached to the weight to be lifted by means of the hook F, the rope being coiled round the larger cylinder, so that while the bar B urges the barrel round, the rope untwines itself from the smaller barrel, and passes round the larger one. To ascertain the power of the capstan, let us suppose the diameter of the barrel C is 21 inches, those of the under cylinder and pulley each 20 inches. Since the diameters of the two barrels are to one another, as 21 to 20, the circumferences will be in round numbers, as 63 to 60, therefore there will be $63 - 60 = 3$ inches of rope coiled more than was uncoiled, and the half of this, or $1\frac{1}{2}$ inches, will be the space through which the weight has been raised; and, knowing the length of the bar, it is easy to determine through what space the power moves; and as this is greater than the space through which the weight has moved, so will the power of the capstan be. The great advantage of this form of the machine, which seems to be of Chinese origin, is that it has no recoil.



Carriage Wheels. Call *a* a wheel, *b* an obstacle, *c* the axle of the wheel, *d* the spoke which at present sustains the weight. A line drawn from the nearest part of the horizontal line of draught *ck* to the fulcrum or obstacle at *e*, will form the acting part of a lever *ge*; and another line *ed* being drawn from the fulcrum *e* to the nearest part of the spoke *d*, will form the resisting part of the same lever. Now, as the acting and resisting arms of the lever are of equal lengths, it becomes like a scale-beam, and a draught in the line *gk* must be equal to the weight of the wheel and all that it sustains, besides the friction; for if *ged* be a crooked lever, a pull at *g* must be equal to all the weight supported by *d*. But when a horse draws agreeably to the shape of his shoulders, in the line *ih*, the acting part of the lever *he* is lengthened nearly one-fourth; so that, if it would require a pull at *g* equal to four hundred weight, a power ap-



plied at *h* will draw the wheel over the obstacle *b* with three hundred weight. To those unacquainted with the principles of mechanics, this truth may be easily proved by an ordinary scale-beam. The horse himself considered as a lever, has in this inclined draught a manifest advantage over obstacles, in comparison of a horizontal draught. Single-horse carts are better than teams, because in a team, all but the shaft horse must draw horizontally, and in a manner inconsistent with the established laws of mechanics. Waggon wheels are generally made with the extremities of the axle inclined downwards; thus is forfeited the advantage of their being formed in a lathe; and the ends are seldom inclined in the same angle or exactly opposite each other, consequently the tendency of the motions of the wheels is in different directions, which mischief is increased by bevelling the wheels. Let a bevelled wheel be rolled by itself, it will soon be seen that it will not proceed in a straight line, but in a curve. Another disadvantage of a waggon arises from the sluggishness of its motion. This will be readily understood and allowed, when it is considered how small a force will continue the motion of a heavy body, moving with a certain degree of rapidity, in comparison with what is required to impel it from a state of rest; but if the motion of the body be extremely slow, the force necessary to keep it up must be nearly equal to that which moved it at first. A sledge, in sliding over a plane, suffers a friction equivalent to the distance through which it moves; but if we apply wheels, the circumference of which is only six inches, it is plain, that while the carriage moves eighteen feet over the plane, the wheels make but one revolution; and as there is no sliding of parts between the plane and the wheels, but only a mere change of surface, no friction takes place there, the whole being transferred to the nave acting on the axle; so that the only sliding of parts has been betwixt the inside of the nave and the axle, which, if they fit one another exactly, is no more than six inches; hence the friction is reduced in the proportion of six inches to eighteen feet, that is, as thirty-six to one. In all cases, by applying wheels, the friction is thus lessened, in the proportion of the diameter of the axles to that of the wheels. Another advantage is also gained, by having the surfaces of friction confined to so small an extent, arising from the circumstance of their being more easily made true, kept smooth, and fitted to each other. The only inconvenience is the height of the wheels, which must in most cases be added to that of the carriage itself.

A four-wheeled carriage may be drawn with five times as much ease as one that slides upon the same surface in the condition of a sledge. In four-wheeled carriages, the fore-wheels are made of a less size than the hind ones, in order to enable them to turn in less room; and not for the purpose of bringing into action any supposed pushing quality in high back-wheels. Large wheels have the advantage over small ones in overcoming obstacles, because wheels act as levers in proportion to their various sizes; but when they are so high as not to allow the line of draught to have the inclination before stated, their advantage as longer levers is counterbalanced by their lessening the intensity of the moving power; therefore the total advantages of wheels drawn horizontally do not increase proportionally to their height.

In ascending, high wheels will be found to facilitate the draught in exact ratio with the squares of their diameters; but in descending, they are liable to press in the same proportion. An admirable device was produced by lord Sommerville, to remedy thé latter evil; it consisted in throwing the weight behind the centre in going down hill, by raising the fore part of the body of the cart; so that while the shaft may inclino downwards, in proportion to tho line of declivity, the bottom of the cart's body should remain horizontal. This construction is now common in Devonshire, and some other counties.

As small wheels turn as much oftener round than large ones as their circumferences are less, so when the carriage is loaded with an equal weight on both axles, the fore axle must sustain as much more friction, and consequently wear out as much sooner than the hind axle, as the fore-wheels are less than the hind ones. This points out that the greatest weight should be laid upon the large wheels; yet it is generally the practice to put the greatest load over the small wheels, which not only makes the friction greatest where it ought to be the least, but also presses the fore-wheels deeper into the ground than the hind-wheels, notwithstanding the former are with more difficulty drawn out of it than the latter. The limitation to loading the hind-wheels with the greatest part of the weight, will consist in not carrying it to such an excess as to endanger the tilting of the vehicle, in going up-hill.

Wheels are commonly made with what is called a dish, that is, the spokes are inserted not at right angles, but with an inclination towards the axis of the nave or centre piece; so that, if the interior end of the nave were placed on the ground, the spokes being higher at the outside than at their termination in the nave, the wheel appears dished or hollow. Wheels are usually dished about four inches in a diameter of five feet. If the wheels were always to go on smooth and level ground, the best way would be to make the spokes perpendicular to the naves and axle; as roads are generally uneven, one wheel often falls into a cavity, when the other does not, and then it bears much more than an equal share of the load; but when a dished wheel falls into a rut, the spokes become perpendicular in the rut, and therefore have the greatest strength when the obliquity of the load throws most of its weight upon them; whilst those on the high ground, having less weight to bear, have no occasion for their utmost strength. Dished wheels, when on straight or horizontal axles have many other excellences; they make carriages stand on a broader base, and therefore render them less liable to be overturned; they give more room to the body of the carriage; they also stand against side-jolts like an arch, and when the carriage is going along the inclined side of a road, they render it less liable to be upset. If the spokes be set so far from the outer end of the nave, that a perpendicular from the sole to the under side of the axle may fall from 1 to 2 inches between the bushes, the pressure will be somewhat greater on the outer than on the inner bush, when the wheels are on a level. This will be an advantage, particularly when the inner part of the axle-arm is much larger than the outer, and the pressure should be diminished; besides, every sinking of one wheel more than the other, causes it to pinch the inner bush. It has been proposed, as the best mode of placing the spokes in the naves, to mortise them in two rows, alternately. The question whether broad or narrow wheels are best, has been much contested. The popular opinion has always been in favour of narrow wheels.

If the tire or iron binding of a wheel be in separate parts, and not in one single hoop, these parts should not be made quite to meet each other at the first; because, when the wheel has been some time in use, they will settle more closely to the wheel than they can be laid, and the vacancies will then be filled up. The axle-arm should be a perfect cylinder, or if tapered towards the extremity, the difference of its two diameters should be very trifling; a small degree of taper is preferred by many, as it gives the wheel rather a disposition to slide off, thus preventing it from being apt to close inwardly, and creating excessive friction; but it increases the necessity for good iron washers exteriorly, and of substantial linch-pins. It is not an uncommon practice to *set* the wheels, that is, to give them a slight inclination towards each other, whereby they are, perhaps, an inch nearer at the front than at the back. This is chiefly done to wheels that are bevelled, with a view to make them run more evenly on their sole or bearing part, and to prevent their gaping forward; but it is evidently a distortion, an attempt to rectify one bad thing by another of the same stamp, as if the multiplication of mischief would produce good. The nave of a heavy wheel, as for an ordinary cart for field purposes, need not be more than twelve or fourteen inches in length, exclusive of the pan at the outer end.

The proportions of wheels are often regulated as much by the purposes to which the vehicles are applied, as by the facilities they afford to motion; thus waggons have in general large hind-wheels, while in timber-carriages the four are nearly of the same height; the London common stage-carts have large wheels, while the drays used by brewers have very low ones. The reason is obvious: waggons and carts load behind; but drays and the timber carriages alluded to, load at the sides; and therefore, for them, large wheels, however much they might favour the draught, would be extremely inconvenient, indeed incompatible with their use. The wheels of single-horse carts for ordinary purposes, where there is no particular necessity for having them low, may be from four feet to four feet six inches in diameter, for a horse of about sixteen hands high. For four-wheeled carriages, suppose four feet to be the height of the fore-wheels, and the line of traction to be drawn at an elevation of fourteen degrees from the centre of its axle, the point where that line cuts the circumference of the wheel in its front, gives that height from the plane on which the carriage stands, that will determine the radius of the hind-wheels.

Wheels, whatever their size, should be made of well-seasoned, tough wood, perfectly free from blemish; the naves are generally of elm, the spokes of oak, and the fellies of elm or ash. The bent fellies, when the wood has not been hurt by too much heat, have greater strength with less wood, than those which are cut by the saw in a curved direction.

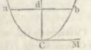
For relieving the horse of a loaded cart from the weight pressing on his shoulders, when it is necessary for any purpose to stop awhile, a pole or staff, which, turning on a hook-and-eye hinge, is let down from one of the shafts when the occasion requires.

Case Hardening. The hardness and polish of steel may be united, in a certain degree, with the firmness and cheapness of malleable iron, by what is called case-hardening—an operation much practised, and of considerable use. It is a superficial conversion of iron into steel, and only differs from cementation in being carried on for a shorter time. Some artists pretend to great secrets in the practice of this art, using saltpetre, sal ammoniac, and other fanciful ingredients, to which they attribute their success. But it is now an established fact, that the greatest effect may be produced by a perfectly tight box, and animal carbon alone. The goods intended to be case-hardened, being previously finished with the exception of polishing, are stratified with animal carbon, and the box containing them luted with equal parts of sand and clay. They are then placed in the fire, and kept at a light red heat for half an hour, when the contents of the box are emptied into water. Delicate articles like files, may be preserved, by a saturated solution of common salt, with any vegetable mucilage to give it a pulpy consistence. The carbon here spoken of, is nothing more than any animal matter, such as horns, hoofs, skins, or leather, just sufficiently burned to admit of being reduced to powder. The box is commonly made of iron, but the use of it, for occasional case-hardening upon a small scale, may be easily dispensed with; as it will answer the same end to envelope the articles with the composition above directed to be used as a lute, drying it gradually, before it is exposed to a red heat; otherwise it will probably crack. It is easy to infer, that the depth of the steel induced by case-hardening, will vary with the time the operation is continued. In half an hour it will scarcely be the thickness of a sixpence, and therefore will be removed by violent abrasion, though sufficient to answer well for fire irons, and a multitude of other utensils, in the common usage of which its hardness prevents its being easily scratched, and its polish is preserved by friction with so soft a material as leather.

CATCH; a contrivance employed in machinery, acting on the principle of a latch. See *Disengagement of Machinery*.

CATENARY; a curve assumed by a chain or cord of uniform substance and texture, when it is hung upon two points of suspension (whether those points be in a horizontal plane or not), and left to adjust itself in equilibrio in a vertical plane. This curve is of great interest to practical men on account of its connexion with bridges of suspension, or chain bridges.

Let AB be the points of suspension of such a cord, A*a*C*b*B the cord itself when hanging at rest in a vertical position. Then the two equal and symmetrical proportions A*a*C, C*b*B, both exposed to the force of gravity upon every particle, balance each other precisely at C. And, if one half, as C*b*B, were taken away, the other half A*a*C would immediately adjust itself in the vertical position under the point A, were it not prevented. Suppose it to be prevented by a force acting horizontally at C, and



equal to the weight of a portion of the cord or chain equal in length to CM; then is CM the measure of the *tension* at the vertex of the curve: it is also regarded as the *parameter* of the catenary. Whether the portion A*a*C hang from A, or a shorter portion as *a*C hang from *a*, the tension at C is evidently the same: for, in the latter case, the resistance of the pin at a, accomplishes the same as the tension of the line at AaC hanging from A, which may easily be determined experimentally, by letting the cord hang very freely over a pulley at C, and lengthening or shortening the portion there suspended, until it keeps AaC, in its due position; then is the portion so hanging beyond the pulley equal in length to CM.

Two examples will serve to illustrate the use of the table.

Ex. 1. Suppose that the span of a proposed suspension bridge is 560 feet, and the depression in the middle $25\frac{7}{8}$ feet; what will be the length of the chain, the angle of suspension at the extremities, the ratio of the horizontal pressure at the lowest point, and the oblique pressures at the points of suspension with the entire weight of the chain?

Here $DB \div DC = 280 \div 25{\cdot}875 = 10{\cdot}82$, a number which is to be found in the table.

Opposite to that number, we find 11° for the angle of suspension, DB = ·19318, CB = ·19438, tension at A or B = 1·0187, the constant tension at the vertex being 1.

Consequently, ·19318 : 19438 : : 560 : 563·48, length of the chain.

Also, horizontal pressure at C	is as 1·0000
oblique pressure at A or B	1·0187
entire weight of chain	·39876

Ex. 2. Suppose, that, while the span remains 560, the depression is increased to 51.

Here $DB \div DC = 280 \div 51 = 5{\cdot}49$. This number is not to be found exactly in the table. The nearest is 5·553 in the last column, agreeing with 20°, the angle of suspension.

Now, $5{\cdot}55 - 5{\cdot}49 = {\cdot}06$, and $5{\cdot}55 - 5{\cdot}27 = {\cdot}28$, the former difference being nearly one-fifth of the latter. Hence, adding to each number, in the line agreeing with 20°, one-fifth of the difference between that and the corresponding number in the next line, we shall have

Angle of suspension = 20° 12′, DC = ·06556, DB = ·36010, CD = ·36797, tension at A = 1·10656.

Hence ·36010 : 36797 : : 560 : 572·24, length of chain.

Also, horizontal pressure at C	is as 1·0000
oblique pressure at A or B	1·10656
entire weight of chain	·73594

Comparing this with the former case, it will be seen that the tensions at C and A, in reference to the weight of the chain, are diminished nearly in the inverse ratio of the two values of DC.

In practical cases with regard to bridges of suspension, it will be easy, when the weight of the material and its cohesive strength are known, to find the relative strength of any proposed structure.—*Gregory's Math.*

TABLE OF RELATIONS OF CATENARIAN CURVES, THE PARAMETER OR LINE CM BEING 1.

Angle of suspension.	DC	DB	CB	Tension at A or B.	DB ÷ DC
1° 0	·00015	·01745	·01745	1 0001	114·586
2 0	·00061	·03491	·03492	1·0006	57·279
3 0	·00137	·05238	·05241	1·0014	38·171
4 0	·00244	·06987	·06993	1·0024	28·613
5 0	·00382	·08738	·08749	1·0038	22·874
6 0	·00551	·10491	·10510	1·0055	19·046
7 0	·00751	·12248	·12278	1·0075	16 309
8 0	·00983	·14008	·14054	1·0098	14·254
9 0	·01247	·15773	·15838	1·0123	12·654
10 0	·01543	·17542	·17633	1·0154	11·372
11 0	·01872	·19318	·19438	1·0187	10 820
12 0	·02238	·21099	·21256	1·0223	9·444
13 0	·02630	·22887	·23087	1·0263	8·701
14 0	·03061	·24681	·24933	1·0306	8·062
15 0	·03528	·26484	·26795	1·0353	7 508
16 0	·04030	·28296	·28675	1·0403	7·021
17 0	·04569	·30116	·30573	1·0457	6·591
18 0	·05146	·31946	·32492	1·0515	6·208
19 0	·05762	·33786	·34433	1·0576	5·863
20 0	·06418	·35637	·36397	1·0642	5·553
21 0	·07114	·37502	·38386	1·0711	5·271
22 0	·07853	·39376	·40403	1·0786	5 014
23 0	·08636	·41267	·42447	1 0864	4·778
24 0	·09484	·43169	·44523	1·0946	4·562
25 0	·10338	·45087	·46631	1·1034	4·361
26 0	·11260	·47021	·48773	1·1126	4 176
28 0	·13257	·50940	·53171	1·1326	3·843
30 0	·15470	·54930	·57735	1·1547	3·551
32 4	·18004	·5912	·62649	1·1800	3·284
34 16	·21003	·6371	·68130	1·2100	3·034
36 52	·24995	·6932	·74991	1·2499	2·773
39 11	·29011	·7443	·81510	1·2901	2·567
41 44	·34004	·8029	·89201	1·3400	2·362
44 0	·39016	·8566	·96569	1·3902	2·196
46 1	·43999	·9066	1·0361	1·4400	2·060
48 11	·49981	·9623	1·1178	1·4998	1·925
50 8	·56005	1·0142	1·1974	1·5800	1·811
52 9	·62973	1·0706	1·2869	1·6297	1 699
54 13	·71021	1·1304	1·3874	1·7102	1·592
56 28	·81021	1·1995	1·5089	1·8102	1·481
58 3	·88972	1·2510	1·6034	1·8897	1·416
60 0	1·0000	1·3169	1·7321	2·0000	1·317
64 6	1·2894	1·4702	2·0594	2·2894	1·140
67 28	1·6095	1·6135	2·4102	2·6095	1·002
67 32	1·6168	1·6164	2·4182	2·6168	0·9998

Cements. The first quality of all cements is tenacity in ordinary circumstances; but, besides this, it is sometimes required, that they should retain this tenacity, independent of the action of heat and moisture.

A very strong glue is made by adding some powdered chalk to common glue when melted: and a glue, which will resist the action of water, may be formed by boiling one pound of common glue in two quarts (English measure) of skimmed milk. See *Glue*.

Turkey Cement. Dissolve five or six bits of mastich, as large as peas, in as much spirit of wine as will dissolve it. In another vessel dissolve as much isinglass, (which has been previously soaked in water till it is softened and swelled,) in one glass of strong whisky; add two small bits of gum galbanum, or ammoniacum, which must be rubbed or ground till they are dissolved, then mix the whole, by the assistance of heat. It must be kept in a stopped phial, which should be set in hot water, when the cement is to be used.

For Glass. A cement that will resist heat is composed of equal quantities of wheat flour, glass finely powdered, and powdered chalk. To this mixture, add half as much brick dust, and a little scraped lint, in the white of eggs. This mixture should be applied to the crack in the glass, and the glass should be well dried before it is put in the fire.

For turners, an excellent cement is made by melting in a pan over the fire, one pound of resin, and when melted, add a quarter of a pound of pitch—while these are boiling, add brick dust, until, by dropping a little upon a cold stone, you think it hard enough. In winter, it is sometimes found necessary to add a little tallow. By means of this cement, when warmed, a piece of wood may be fastened to the chuck, which will hold, when cool; and, when the work is finished, it may be loosed by a smart stroke with the tool.

In joining the flanches of iron cylinders or pipes, to withstand the action of boiling water or steam, great inconvenience is often felt by the workmen for want of a durable cement. The following will be found to answer:—Boiled linseed oil, litharge, and white lead, mixed up to a proper consistence, and applied to each side of a piece of flannel, linen, or even pasteboard, and then placed between the pieces, before they are brought home, as it is called, or joined. The quantities of the ingredients may be varied, without materially hurting the cement—taking care, however, not to make it too thin by the oil, and observing that the use of the litharge is to dry speedily. This cement is useful in joining broken stones; and if the seams of the stones of a water cistern are done over with it, the durability and efficacy of the structure will be greatly promoted.

For *Steam Engines*, an excellent cement is as follows:—Take of sal ammoniac, two ounces; sublimed sulphur, one ounce; and cast iron filings, or fine turnings, one pound: mix them in a mortar, and keep the powder dry. When it is to be used, mix it with twenty times its quantity of clean iron turnings, or filings, and grind the whole in a mortar, then wet it with water, until it becomes of a convenient consistence, when it is to be applied to the joint; after a time it becomes as hard and strong as any other part of the metal.

Central Forces. When a body is made to revolve in a circle round some fixed point, it will have a continual tendency to fly off in a straight line at a tangent to the circle, which tendency is called the centrifugal force; and the opposing power by which the body is retained in the circular path is called the centripetal force. When both forces are spoken of together, they are denominated central forces. This is the case of a stone revolving in a sling. Should the cord break or be let go, the stone will, in consequence of its centrifugal force, fly off at a tangent to the circle in which it formerly revolved; the cord acted as the centripetal force so long as it retained the stone in its circular motion. Whenever the one force begins to predominate over the other, the body will deviate from the circular path, but while the body remains moving in a circular path, the centripetal and centrifugal forces must be equal to each other, and therefore the measure of the one will be likewise the measure of the other.

The centrifugal forces of two unequal bodies, moving with the same velocity, and at the same distance from the central body, are, to one another, as the respective quantities of matter in the two bodies. The centrifugal forces of two equal bodies, which perform their revolution round the central body in the same time, but at different distances from it, are to one another as their respective distances from the central body. —The centrifugal forces of two bodies which perform their revolution in the same time, and whose quantities of matter are inversely as their distances from the centre, are equal to one another.—The centrifugal forces of two equal bodies, moving at equal distances from the central body, but with different velocities, are to one another as the squares of their velocities.—The centrifugal forces of two unequal bodies, moving at equal distances from the centre, with different velocities, are to one another in the compound ratio of their quantities of matter, and the squares of their velocities.—The centrifugal forces of two equal bodies, moving with equal velocities, at different distances from the centre, are inversely as their distances from the centre.—The centrifugal forces of two unequal bodies, moving with equal velocities, at different distances from the centre, are to one another as their quantities of matter multiplied by their respective distances from the centre.—The centrifugal forces of two unequal bodies, moving with unequal velocities, at different distances from the central body, are in the compound ratio of their quantities of matter, the squares of their velocities, and their distances from the centre.

The subject of central forces would require for its investigation much more space and mathematical reasoning than is consistent with the nature of our work. What follows, however, will be found sufficient for all practical purposes.

(A.) $\frac{\text{velocity}^2 \times \text{weight}}{\text{radius} \times 32} = \text{centrifugal force.}$

(B.) Divide the velocity by 4·01, square the quotient, and divide by the diameter: this last quotient multiplied by the weight, will give the centrifugal force.

(C.) $\frac{\text{Number of revolutions per minute}^2 \times \text{diameter}}{5870} \times \text{weight} = \text{the}$ centrifugal force.

(D.) $\frac{\text{velocity}^2 \times \text{radius}}{\text{centrifugal force} \times 3^2} = \text{radius.}$

(E.) $\frac{\text{radius} \times \text{centrifugal force} \times 32}{\text{velocity}^2} = \text{weight.}$

(F.) $\sqrt{\left(\frac{\text{radius} \times \text{centrifugal force} \times 32}{\text{weight}}\right)} = \text{the velocity.}$

The following examples will illustrate the application of these rules.

What is the centrifugal force of the rim of a fly-wheel moving with a velocity of $32\frac{1}{6}$ feet in a second, and whose diameter is 20 feet.

(By B.) $\frac{32\frac{1}{6}}{4\cdot 01} = 8\cdot 02$, then $\frac{8\cdot 02^2}{20} = 3\cdot 216$, which multiplied by the weight of the rim, will give the centrifugal force.

A grindstone makes 120 revolutions in the minute, the radius of the circle of its motion being 2 feet, and its weight 6 lbs.

(By C.) $\frac{120^2 \times 4}{5870} \times 6 = \frac{57600}{5870} \times 6 = 9\cdot 81 \times 6 = 58\cdot 86 =$ the centrifugal force.

A fly-wheel makes 65 revolutions per minute, its diameter being 12 feet, and the weight of the rim one ton, the weight of the entire fly being $1\frac{1}{2}$ tons, the circle of gyration is 5·5 feet from the axis, the wheel consisting of two halves joined by bolts capable of resisting a pressure of 4 tons, wherefore,

$\frac{12 \times 3\cdot 1416 \times 65}{60} = 40\cdot 84 =$ velocity in feet per second.

And (by A.) $\frac{40 \sqrt{84^2} \times 1}{32 \times 6} = 8\cdot 687$ tons, the centrifugal force.

And (by F.) $\sqrt{\left(\frac{32 \times 4 \times 5\cdot 5 \times 2}{1\cdot 5}\right)} = \sqrt{\frac{1403}{1\cdot 5}} = 30\cdot 638,$

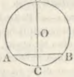
and since $2 \times 5{\cdot}5 \times 3{\cdot}1416 = 34{\cdot}5576$ = the circle of gyration, therefore,

$\frac{30{\cdot}0638 \times 60}{34{\cdot}5576} = 53{\cdot}195$, the number of revolutions per minute, which would cause the fly to burst asunder.

Centre, in a general sense, denotes a point equally remote from the extremes of a line, surface, or solid.

Centre of Attraction of a body, is that point into which, if all its matter was collected, its action upon any remote particle would still be the same.

Centre of a Circle; is that point in a circle which is equally distant from every point of the circumference; and, if more than two equal lines can be drawn from any point within a circle to the circumference, that point will be the centre. To find the centre of a circle, draw any chord AB; and bisect it perpendicularly with the line CD, which will be a diameter. Therefore CD bisected in O, will give the centre, as required. To describe the circumference of a circle through three given points, A, B, C. From the middle point B, draw chords BA, BC, to the two other points, and bisect these chords perpendicularly by lines meeting in O, which will be the centre. Then from the centre O, at the distance of any one of the points, as OA, describe a circle, and it will pass through the two other points B, C, as required.



Centre of Equilibrium, is the same, in respect to bodies immersed in a fluid, as the centre of gravity is to bodies in free space.

Centre of Friction, is that point in the base of a body on which it revolves, into which, if the whole surface of the base and the mass of the body were collected and made to revolve about the centre of the base of the given body, the angular velocity destroyed by its friction would be equal to the angular velocity destroyed in the given body by its friction in the same time.

Centre of Gravity of any body, or system of bodies, is that point upon which the body, or system of bodies, acted upon only by the force of gravity, will balance itself in all positions; hence it follows, that if a line or plane passing through the centre of gravity be supported, the body or system will be also supported. See *Gravity*.

Centre of Gyration, is that point into which, if the whole mass were collected, a given force applied at a given distance would produce the same angular velocity in the same time as if the bodies were disposed at their respective distances. This point differs from the centre of oscillation only in this, that, in the latter case, the motion is produced by the gravity of the body; but in the former, the body is put in motion by some other force acting at one place only. See *Gyration*.

CENTRE OF MAGNITUDE, is the point which is equally distant from the similar external parts of a body.

CENTRE OF MOTION, is that point in a revolving body which remains at rest.

CENTRE OF OSCILLATION, is that point in the axis of suspension of a vibrating body, in which, if all the matter of the system were collected, any force applied there would generate the same angular velocity in a given time, as the same force at the centre of gravity, the parts of the system revolving in their respective places. See *Oscillation*.

CENTRE OF PERCUSSION, is that point in a body revolving about an axis, at which, if it be struck, all the motion of the body will be destroyed, so that after the stroke, the moving body will incline neither way. Thus, if a common walking stick be held by one end, and struck against any obstacle at different points of its length, it will be found that there is only one point on which it can be struck, that will cause no shock to the hand; this point will be found to be two-thirds of the length of the stick from the hand—it is called the centre of percussion, and is determined by the same rules as the centre of oscillation. See *Oscillation*.

CENTRE OF POSITION, is such a point in a body, that if a plane be made to pass through it, and a perpendicular line be drawn from that place to the surface of the body, the sum of the perpendicular on one side of the plane, shall be the same as the sum of the perpendiculars on the other. The motion of this part determines the average motion of the whole mass.

CENTRE OF PRESSURE, or meta centre of a fluid against a plane, is that point, in which, if a force were applied equal and contrary to the whole pressure of the fluid, the body would remain unmoved. See *Floating Bodies*.

CENTRE OF SPONTANEOUS ROTATION, is that point which remains at rest, and round which a body moves when it is put into motion. When a body of any magnitude or form is left untouched, after being put into a rotatory engyrating motion it will have three axes of motion perpendicular to each other, and all passing through the centre of gravity.

CHAFFERY; a kind of forge in the manufacture of iron, in which the metal is exposed to a welding heat.

CHAMFER; used among carpenters; a groove to receive the tenon.

CHEEKS; those pieces of timber in machinery which are double, and like to each other.

CHIMNEY. It is necessary that the engineer should attend to the best proportions for the chimneys of engine furnaces. For the purpose of avoiding the nuisance of smoke, the stalk ought to be as high as possible, never less than 50 feet. For the area of the cross section of the chimney of a low pressure steam engine, we may employ the rule,

$$\frac{\text{horse's power of the engine} \times 200}{\sqrt{\text{of the height of the chimney in feet}}} = \text{area in square inches.}$$

Find the area of a chimney, the height of which is 64 feet, the power of the engine being 36 horses.

$$\frac{36 \times 200}{\sqrt{64}} = \frac{7200}{8} = 910,$$ the area of the chimney in square inches. Now if the flues are to be square, we have only to extract the square root of the area for the length of the side, therefore $\sqrt{900} = 30$, the length of the side; or if the flue is to be cylindrical, then $\sqrt{(\text{area} \times 1 \cdot 27)}$ = diameter, wherefore, $\sqrt{(900 \times 1 \cdot 27)} = 33 \cdot 79$, the diameter of the flue of the chimney, if cylindrical. For the chimneys of steam boilers being cylindrical the same rule may be employed, but, instead of the number 200, we may employ 90, therefore, for a 36 horse engine. These rules are applicable where the engine is of the best construction, and where it requires about 10 lbs. of coal per hour, for each horse's power; but if more coal be required, the area of the chimney must be increased proportionally. When wood is burnt, instead of coal, the area of the chimney ought to be one half greater than that required for coal. The Egyptian obelisk seems to be the best form of a chimney top; it opposes least resistance to the wind, is least expensive, and if rightly proportioned, by no means destitute of elegance. See *Furnace.*

CHORD; in geometry, a right line drawn from one part of the arch of a circle to another. See *Trigonometry*.

CHIPPING. This operation not only produces the intended effect in an expeditious manner, but saves much expense in the files which would otherwise be required. It is most frequently applied to cast iron, the dark rind or outside of which, taken as it comes from the mould, is always harder than the rest, and frequently so very hard, that it would spoil the best file in a few minutes, while, at no greater depth than the twentieth part of an inch, or even less, it is nearly as soft as brass. The chisel will penetrate this hard crust, and afterwards, as may be easily understood, its edge needs only to be made to act upon the soft part. The chisel, for this description of work, need not be more than seven inches long, but it ought to be made of the best cast steel. It is held in an angle of about forty-five degrees, and the blows of the hammer are given in quick succession. Some dexterity, certainly, which can only be acquired by practice, is requisite to preserve a tolerably equable surface, but the art is not of difficult acquirement. A pellicle of iron may, by the chisel, be taken from a surface of a hundred square inches, in four or five hours, and when it has been well done, the file very speedily levels the inequalities which it leaves. When much exactness is required, it is advisable to examine the work, before the chipping is commenced, and if improper protuberances or hollows appear in it, the chisel must be struck more or less deep at such places as the circumstance requires.

CHISELS. The large chisels used by millwrights for heavy work, are generally composed of iron and steel, welded together,—the steel forming but a small portion of the whole, seldom extending higher than the broad part of the tool, and being often no more than a third of the thickness The small and middle-sized chisels of the best kind, are always made of cast steel. As all chisels, not exclusively employed in turning, are driven more or less by blows, they are, except the socket chisel, provided with a shoulder, at the end of the handle into which the tang is driven, and prevents it from being split. The basil of chisels is on one side, and if well formed should be quite flat. The *gouge* used by the joiners and cabinet-makers is similar to that of the turner, though not always sharpened in the same way. The edge, by joiners and cabinet-makers, is made straight across the end, and not convex like the turner's gouge; but millwrights often make the basil on the concave side of the gouge in order to cut perpendicularly. The thin broad chisel, the sides of which are parallel for a certain length, and then taper towards the shoulder, is called the *firmer chisel* when driven by the mallet, and the *paring chisel*, when the hand only is employed. The common *mortise chisel*, the section of which is almost a square, is employed in making mortises; the basil being made on one of its narrow sides. As it has to sustain extremely heavy blows with the mallet, and is partly used as a lever to get out the pieces of wood as they are severed, in the course of cutting the mortise, it must necessarily be made very strong. The *socket-chisel* is distinguished from other chisels by its having a conical socket, instead of a tang and shoulder, to receive the handle. It is much used for very large work, and for the same purposes as the mortise-chisel, but is not so thick in proportion to its breadth. The upper end of the handles of chisels driven by percussion, should be made convex.

CHORD, a right line joining the extremities of an arc.

CIRCLE, in Geometry, a plane figure bounded by a curve line, every where equally distant from a point within it, called the centre. The periphery or circumference, is sometimes called the circle, though that name denotes the space contained within the circumference, and not the circumference itself.

We will give here tables of the circumferences and areas of circles, from 1 to 100, which will be found of great use in calculation.

A TABLE OF THE AREAS, CIRCUMFERENCES OF CIRCLES, AND SIDES OF EQUAL SQUARES CORRESPONDING TO ALL DIAMETERS, FROM 1 TO 100.

Diam.	Area.	Circumfer.	Side of eq. sq.	Diam.	Area.	Circumfer.	Side of eq. sq.
1·00	0·78539	3·141592	0·88622	15·25	182·654160	47·909287	13·51496
1·25	1·227184	3·926990	1·10778	15·5	188·691908	48·694686	13·73651
1·5	1·767145	4·712388	1·32934	15·75	194·827831	49·480084	13·95807
1·75	2·405281	5·497787	1·55089	16·	201·061929	50·265482	14·17963
2·	3·141592	6·283185	1·77245	16·25	207·394202	51·050880	14·40118
2·25	3·976078	7·068583	1·99401	16·5	213·824649	51·836278	14·62274
2·5	4·908738	7·853981	2·21556	16·75	220·353272	52·621676	14·84430
2·75	5·939573	8·639379	2·43712	17·	226·980069	53·407075	15·06585
3·	7·068583	9·424777	2·65868	17·25	233·705040	54·192473	15·28741
3·25	8·295768	10·210176	2·88023	17·5	240·528187	54·977871	15·50897
3·5	9·621127	10·995574	3·10179	17·75	247·449508	55·763269	15·73052
3·75	11·044661	11·780972	3·32335	18·	264·469004	56·548667	15·95208
4·	12·566370	12·566370	3·54490	18·25	266·586675	57·334065	16·17364
4·25	14·186254	13·351768	3·76646	18·5	268·802521	58·119464	16·39519
4·5	15·904312	14·137166	3·98802	18·75	276·116541	58·904862	16·61675
4·75	17·720546	14·922565	4·20957	19·	283·528736	59·690260	16·83831
5·	19·634954	15·707963	4·43113	19·25	291·039106	60·475658	17·05986
5·25	21·647536	16·493361	4·65269	19·5	298.647651	61·261056	17·28142
5·5	23·758294	17·278759	4·87424	19·75	306·354371	62·046454	17·50298
5·75	25·967226	18·064157	5·09580	20·	314·159265	62·831853	17·72453
6·	28·274333	18·849555	5·31736	20·25	322·062334	63·617251	17·94609
6·25	30·679615	19·634954	5·53891	20·5	330·063578	64·402649	18·16765
6·5	33·183072	20·420352	5·76047	20·75	338·162996	65·188047	18·38920
6·75	35·784703	21·205750	5·98203	21·	346·360590	65·973445	18·61076
7·	38·484560	21·991148	6·20358	21·25	354·656358	66·758843	18·83232
7·25	41·282490	22.776546	6·42514	21·5	363·050301	67·544242	19·05387
7·5	44·178646	23·561944	6·64670	21·75	371·542418	68·329640	19·27543
7·75	47·172977	24·347343	6·86825	22·	380·132711	69·115038	19·49699
8·	50·265482	25·132741	7·08981	22·25	388·821178	69·900436	19·71854
8·25	53·456162	25·918139	7·31137	22·5	397·607820	70·685834	19·94010
8·5	56·745017	26·703537	7·53292	22·75	406·492636	71·471232	20·16166
8·75	60·132046	27·488935	7·75448	23·	415·475628	72·256631	20·38321
9·	63·617251	28·274333	7·97604	23·25	424·556794	73·042029	20·60477
9·25	67·200630	29·059732	8·19759	23·5	433·736135	73·827427	20·82633
9·5	70·882184	29·845130	8·41915	23·75	443·013651	74·612825	21·04788
9·75	74·661912	30·630528	8·64071	24·	452·389342	75·398223	21·26944
10·	78·539816	31·415926	8·86226	24·25	461·863207	76·183621	21·49100
10·25	82·515894	32·201324	9·08382	24·5	471·435247	76·969020	21·71255
10·5	86·590147	32·986722	9·30538	24·75	481·105462	77·754418	21·93411
10·75	90·762575	33.772121	9·52693	25·	490·873852	78·539816	22·15567
11·	95·033177	34·557519	9·74849	25·25	500·740416	79·325214	22·37722
11·25	99·401955	35·342917	9·97005	25·5	510·705155	80·110612	22·59878
11·5	103·868907	36·128315	10·19160	25·75	520·768069	80·896010	22·82034
11·75	108·434033	36·913713	10·41316	26·	530·929158	81·681408	23·04190
12·	113·097335	37·699111	10·63472	26·25	541·188421	82·466807	23·26345
12·25	117·858811	38·484510	10·85627	26·5	551·545860	83·252205	23·48501
12·5	122·718463	39·269908	11·07783	26·75	562·001473	84·037603	23·70657
12·75	127·676288	40·055306	11·29939	27·	572·555261	84·823001	23·92812
13·	132·732289	40·840704	11·52095	27·25	583·207223	85·608399	24·14968
13·25	137·886465	41·626102	11·74250	27·5	593·957361	86·393797	24·37124
13·5	143·138815	42·411500	11·96406	27·75	604·805673	87·179196	24·59279
13·75	148·489340	43·196898	12·18562	28·	615·752160	87·964594	24·81435
14·	153·938040	43·982297	12·40717	28·25	626·796821	88·749992	25·03591
14·25	159·484914	44·767695	12·62873	28·5	637·939658	89·535390	25·25746
14·5	165·129963	45·553093	12·85029	28·75	649·180669	90·320788	25·47902
14·75	170·873187	46·338491	13·07184	29·	660·519855	91·106186	25·70058
15·	176·714586	47·123889	13·29340	29·25	671·957216	91·891585	25·92213

Diam.	Area.	Circumfer.	Side of eq. sq.	Diam.	Area.	Circumfer.	Side of eq. sq.
29·5	683·492751	92·676983	26·14369	44·75	1572·808909	140·586271	39·65865
29·75	695·126461	93·462381	26·36525	45·	1590·431280	141·371669	39·88021
30·	706·858347	94·247779	26·58680	45·25	1608·151826	142·157067	40·10176
30·25	718·688406	95·033177	26·80836	45·5	1625·970547	142·942465	40·32332
30·5	730·616641	95·818575	27·02992	45·75	1643·887443	143·727863	40·54488
30·75	742·643050	96·603974	27·25147	46·	1661·902513	144·513262	40·76643
31·	754·767635	97·389372	27·47303	46·25	1680·015758	145·298660	40·98799
31·25	766·990393	98·174770	27·69459	46·5	1698·227178	146·084058	41·20955
31·5	779·311327	98·960168	27·91614	46·75	1716·536773	146·869456	41·43110
31·75	791·730436	99·745566	28·13770	47·	1734·944542	147·654854	41·65266
32·	804·247719	100·530964	28·35926	47·25	1753·450487	148·440252	41·87422
32·25	816·863177	101·316363	28·58081	47·5	1772·054606	149·225651	42·09577
32·5	829·576810	102·101761	28·80237	47·75	1790·756899	150·011049	42·31733
32·75	842·388617	102·887159	29·02393	48·	1809·557368	150·796447	42·53889
33·	855·298599	103·672557	29·24548	48·25	1828·456011	151·581845	42·76044
33·25	868·306756	104·457955	29·46704	48·5	1847·452829	152·367243	42·98200
33·5	881·413088	105·243353	29·68860	48·75	1866·547822	153·152641	43·20356
33·75	894·617595	106·028752	29·91015	49·	1885·740990	153·938040	43·42511
34·	907·920276	106·814150	30·13171	49·25	1905·832332	154·723438	43·64667
34·25	921·321133	107·599548	30·35327	49·5	1924·421849	155·508836	43·86823
34·5	934·820163	108·384946	30·57482	49·75	1943·909541	156·294234	44·08978
34·75	948·417369	109·170344	30·79638	50·	1963·495408	157·079632	44·31134
35·	962·112750	109·955742	31·01794	50·25	1983·179449	157·965030	44·53290
35·25	975·906305	110·741141	31·23949	50·5	2002·961666	158·650429	44·75445
35·5	989·798035	111·526539	31·46105	50·75	2022·842057	159·435827	44·97601
35·75	1003·787940	112·311937	31·68261	51·	2042·820622	160·221225	45·19757
36·	1017·876019	113·097335	31·90416	51·25	2062·897363	161·006623	45·41912
36·25	1032·062274	113·882733	32·12572	51·5	2083·072278	161·792021	45·64068
36·5	1046·346703	114·668131	32·34728	51·75	2103·345368	162·577419	45·86224
36·75	1060·729307	115·453530	32·56883	52·	2123·716633	163·362817	46·08380
37·	1075·210085	116·238928	32·79039	52·25	2144·186073	164·148216	46·30535
37·25	1089·789039	117·024326	33·01195	52·5	2164·753687	164·933614	46·52691
37·5	1104·466167	117·809724	33·23350	52·75	2185·419477	165·719012	46·74847
37·75	1119·241470	118·595722	33·45506	53·	2206·183440	166·504410	46·97002
38·	1134·114947	119·380520	33·67662	53·25	2227·045579	167·289808	47·19158
38·25	1149·086600	120·165918	33·89817	53·5	2248·005893	168·075206	47·41314
38·5	1164·156427	120·951317	34·11973	53·75	2269·064381	168·860605	47·63469
38·75	1179·324429	121·736715	34·34129	54·	2290·221044	169·646003	47·85625
39·	1194·590696	122·522113	34·56285	54·25	2311·475882	170·431401	48·07781
39·25	1209·954958	123·307511	34·78440	54·5	2332·828894	171·216799	48·29936
39·5	1225·417484	124·092909	35·00596	54·75	2354·280082	172·002197	48·52092
39·75	1240·978185	124·878307	35·22752	55·	2375·829444	172·787595	48·74248
40·	1256·637041	125·663706	35·44907	55·25	2397·476981	173·572994	48·96403
40·25	1272·394112	126·449104	35·67063	55·5	2419·222692	174·358392	49·18559
40·5	1288·249337	127·234502	35·89219	55·75	2441·066579	175·143790	49·40715
40·75	1304·202737	128·019900	36·11374	56·	2463·008640	175·929188	49·62870
41·	1320·254312	128·805298	36·33530	56·25	2485·048876	176·714586	49·85026
41·25	1336·404062	129·590696	36·55686	56·5	2507·187287	177·499984	50·07182
41·5	1352·651986	130·376095	36·77841	56·75	2520·423872	178·285383	50·29337
41·75	1368·998086	131·161493	36·99997	57·	2551·758632	179·070781	50·51493
42·	1385·442360	131·946891	37·22153	57·25	2574·191567	179·856179	50·73649
42·25	1401·984809	132·732289	37·44308	57·5	2596·722677	180·641577	50·95804
42·5	1418·625432	133·517687	37·66464	57·75	2619 351962	181·426975	51·17960
42·75	1435·364230	134·303085	37·88620	58·	2642·079421	182·212373	51·40116
43·	1452·201204	135·083484	38·10775	58·25	2664·905055	182·997772	51·62271
43·25	1469·136352	135·873882	38·32931	58·5	2687·828864	183·783170	51·84427
43·5	1486·169674	136·659280	38·55087	58·75	2710·850848	184·568568	52·06583
43·75	1503·301172	137·444678	38·77242	59·	2733·971006	185·353966	52·28738
44·	1520·530844	138·230076	38·99398	59·25	2757·189339	186·139364	52·50894
44·25	1537·858691	139·015474	39·21554	59·5	2780·505847	186·924762	52·73050
44.5	1556·284713	139·800873	39·43709	59·75	2803·920530	187·710161	52·95205

Diam.	Area.	Circumfer.	Side of eq. sq.	Diam.	Area.	Circumfer.	Side of eq. sq.
60·	2827·433388	188·495559	53·17364	75·25	4447·366187	236·404847	66·68857
60·25	2851·044420	189·280957	53·39517	75·5	4476·965880	237·190245	66·91043
60·5	2874·753627	190·066355	53·61672	75·75	4506·663748	237·975643	67·13168
60·75	2898·561009	190·851753	53·83828	76·	4536.459791	238·761041	67·35324
61·	2922·466566	191·637151	54·05984	76·25	4566·354009	239·546439	67·57480
61·25	2946·470297	192·422550	54·28139	76·5	4596·346401	240·331837	67·79635
61·5	2970·572203	193·207948	54·50295	76·75	4626·436968	241·117236	68·01791
61·75	2994·772284	193·993346	54·72451	77·	4656·625710	241·902634	68·23947
62·	3019·070540	194·778744	54·94606	77·25	4686·912627	242·688032	68·46102
62·25	3043·466970	195·564142	55·16762	77·5	4717·297718	243·473430	68·68258
62·5	3067·961575	196·349540	55·38918	77·75	4747·780985	244·258828	68·90414
62·75	3092·554355	197·134939	55·61073	78·	4778·362426	245·044226	69·12570
63·	3117·245310	197·920337	55·83229	78·25	4809·042041	245·829625	69·34725
63·25	3142·034440	198·705735	56·05385	78·5	4839·819832	246·615023	69·56881
63·5	3166·921744	199·491133	56·27540	78·75	4870·795797	247·400421	69·79037
63·75	3191·907223	200·276531	56·49696	79·	4901·669937	248·185819	70·01192
64·	3216·990877	201·061929	56·71852	79·25	4932·742252	248·971217	70·23348
64·25	3242·172705	201·847327	56·94007	79·5	4963·912742	249·756615	70·45504
64·5	3267·452709	202·632726	57·16163	79·75	4995·181406	250·342014	70·67659
64·75	3292·830887	203·418124	57·38319	80·	5026·548245	251·327412	70·89815
65·	3318·307240	204·203522	57·60475	80·25	5058·013259	252·112810	71·11971
65·25	3343·881768	204·988920	57·82630	80·5	5089·576448	252·898208	71·34126
65·5	3369·554470	205·774318	58·04786	80·75	5121·237811	253·683606	71·56282
65·75	3395·325347	206·559716	58·26942	81·	5152·997350	254·469004	71·78438
66·	3421·194399	207·345115	58·49097	81·25	5184·855063	255·254403	72·00593
66·25	3447·161626	208·130513	58·71253	81·5	5216·810950	256·039801	72·22749
66·5	3473·227028	208·915911	58·93409	81·75	5248·865013	256·825799	72·44905
66·75	3499·390604	209·701309	59·15564	82·	5281·017250	257·610597	72·67060
67·	3525·652355	210·486707	59·37720	82·25	5313·267662	258·395995	72·89216
67·25	3552·012287	211·272105	59·59876	82·5	5345·616249	259·181393	73·11372
67·5	3578·470381	212·057504	59·82031	82·75	5378·063011	259·966792	73·33527
67·75	3605·026657	212·842902	60·04187	83·	5410·607947	260·752190	73·55683
68·	3631·681107	213·628300	60·26343	83·25	5443·251058	261·537588	73·77839
68·25	3658·433732	214·413698	60·48498	83·5	5475·992344	262·322986	73·99994
68·5	3685·284532	215·199096	60·70654	83·75	5508·831805	263·108384	74·22150
68·75	3712·233506	215·984494	60·92810	84·	5541·769440	263·893782	74·44306
69·	3739·280655	216·769893	61·14965	84·25	5574·805251	264·679181	74·66461
69·25	3766·425979	217·555291	61·37121	84·5	5607·939236	265·464579	74·88617
69·5	3793·669478	218·340689	61·59277	84·75	5641·171395	266·249977	75·10773
69·75	3821·011152	219·126087	61·81432	85·	5674·501730	267·035375	75·32928
70·	3848·451000	219·911485	62·03588	85·25	5707·930239	267·820773	75·55084
70·25	3875·989023	220·696883	62·25744	85·5	5741·456923	268·606171	75·77240
70·5	3903·625221	221·482282	62·47899	85·75	5775·081782	269·391570	75·99395
70·75	3931·359594	222·267680	62·70055	86·	5808·804816	270·176968	76·21551
71·	3959·192141	223·053078	62·92211	86·25	5842·626024	270·962366	76·43707
71·25	3987·122863	223·838476	63·14366	86·5	5876·545408	271·747764	76·65862
71·5	4015·151760	224·623874	63·36522	86·75	5910·562966	272·533162	76·88018
71·75	4043·278832	225·409272	63·58678	87·	5944·678698	273·318560	77·10174
72·	4071·504079	226·194671	63·80833	87·25	5978·892606	274·103959	77·32329
72·25	4099·827500	226·980069	64·02989	87·5	6013·204688	274·889357	77·54485
72·5	4128·249096	227·765467	64·25145	87·75	6047·614945	275·674755	77·76641
72·75	4156·768867	228·550865	64·47300	88·	6082·123377	276·460153	77·98796
73·	4185·386812	229·336263	64·69456	88·25	6116·729983	277·245551	78·20952
73·25	4214·102933	230·121661	64·91612	88·5	6151·434765	278·030949	78·43103
73·5	4242·917228	230·907060	65·13767	88·75	6186·237721	278·816347	78·65263
73·75	4271·829698	231·692458	65·35923	89·	6221·138852	279·601746	78·87419
74·	4300·840342	232·477856	65·58079	89·25	6256·138157	280·387144	79·09575
74·25	4329·949162	233·263254	65·80234	89·5	6291·235638	281·172542	79·31730
74·5	4359·156156	234·048652	66·02390	89·75	6326·431293	281·957940	79·53886
74·75	4388·461325	234·834050	66·24546	90·	6361·725123	282·743338	79·76042
75·	4417·864669	235·619449	66·46701	90·25	6397·117128	283·528736	79·98198

Diam.	Area.	Circumfer.	Side of eq. sq.	Diam.	Area.	Circumfer.	Side of eq. sq.
90·5	6432·607307	284·314135	80·20353	95·75	7200·579449	300·807496	84·85622
90·75	6468·195662	285·099533	80·42509	96·	7238·229473	301·592894	85·07778
91·	6503·882191	285·884931	80·64669	96·25	7275·977673	302·378292	85·29934
91·25	6539·666894	286·670329	80·86820	96·5	7313·824047	303·163691	85·52089
91·5	6575·549773	287·455727	81·08976	96·75	7351·768595	303·949089	85·74245
91·75	6611·530826	288·241125	81·31132	97·	7389·811319	304·734487	85·96406
92·	6647·610054	289·026524	81·53287	97·25	7427·952217	305·519885	86·18551
92·25	6683·787457	289·811922	81·75443	97·5	7466·191290	306·305283	86·40712
92·5	6720·063035	290·597320	81·97599	97·75	7504·528538	307·090681	86·62868
92·75	6756·436788	291·382718	82·19754	98·	7542·963961	307·876080	86·85023
93·	6792·908715	292·168116	82·41910	98·25	7581·497558	308·661478	87·07179
93·25	6829·478817	292·953514	82·64066	98·5	7620·129330	309·446876	87·29335
93·5	6866·147093	293·738913	82·86221	98·75	7658·859277	310·232274	87·51490
93·75	6902·913545	294·524311	83·08377	99·	7697·687399	311·017672	87·73646
94·	6939·778171	295·309709	83·30533	99·25	7736·613695	311·803070	87·95802
94·25	6976·740972	296·095107	83·52688	99·5	7775·638167	312·588469	88·17957
94·5	7013·801943	296·880505	83·74844	99·75	7814·760813	313·373867	88·40113
94·75	7050·961099	297·665903	83·97000	100·	7853·981633	314·159265	88·62269
95·	7088·218424	298·451302	84·19155	100·25	7893·300629	314·944663	88·84424
95·25	7125·579924	299·236700	84·41311	100·5	7932·717799	315·730061	89·06580
95·5	7163·027599	300·022098	84·63467	100·75	7972·233144	316·515459	89·28736

AREAS OF CIRCLES, IN SQUARE INCHES.

Diameter in inches.	Tenths of Inches.									
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
	Areas.	Areas.	Areas.	Areas.	Areas.	Areas.	Areas.	Areas.	Areas.	Areas.
0	0·0	0·007	0·031	0·070	0,125	0·196	0·282	0·384	0·502	0·636
1	0·785	0·950	1·130	1·327	1·539	1·767	2·010	2·269	2·544	2·835
2	3·141	3·463	3·801	4·154	4·523	4·908	5·309	5·725	6·157	6·605
3	7·068	7·547	8·042	8·553	9·079	9·621	10·178	10·752	11·341	11·945
4	12·566	13·202	13·854	14·522	15.205	15·904	16·619	17·349	18·095	18·857
5	19·635	20·428	21·237	22·061	22·902	23·758	24·630	25·517	26·420	27·339
6	28·274	29·224	30·190	31·172	32·169	33·183	34·212	35·256	36·316	37·412
7	38·484	39·592	40·715	41·853	43·008	44·178	45·364	46·566	47·783	49·016
8	50·265	51·530	52·810	54·106	55·417	56·745	58·082	59·446	60·821	62·212
9	63·617	65·038	66·476	67·929	69·397	70·882	72·387	73·898	75·429	76·977
10	78·540	80·118	81·713	83·323	84·948	86·590	88·248	89·920	91·609	93·313
11	95·033	96·769	98·520	100·287	102·070	103·860	105·683	107·513	109·359	111·220
12	113·097	114·990	116·898	118·823	120·763	122·718	124·690	126·677	128·679	130·698
13	132·732	134·782	136·848	138·929	141·026	143·139	145·267	147·411	149·571	151·747
14	153·938	156·145	158·368	160·606	162·860	165·130	167·415	169·717	172·034	174·366
15	176·715	179·079	181·358	183·854	186·265	188·692	191·134	193·593	196·067	198·556
16	201·062	203·583	206·120	208·672	211·241	213·825	216·424	219·040	221·671	224·318
17	226·980	229·658	232·352	235·062	237·787	240·528	243·285	246·057	248·846	251·650
18	254·469	257·324	260·155	263·022	265·905	268·803	271·716	274·646	277·591	280·552
19	283·529	286·521	289·529	292·553	295·593	298·698	301·719	304·805	307·908	311·026
20	314·160	317·309	320·474	323·655	326·852	330·064	333·292	336·536	339·795	343·070
21	346·361	349·667	352·990	356·328	359·681	363·051	366·435	369·837	373·253	376·685
22	380·133	383·597	387·076	390·571	394·082	397·608	401·150	404·708	408·282	411·871
23	415·476	419·097	422·733	426·385	430·053	433·737	437·436	441·151	444·881	448·628
24	452·390	456·168	459·961	463·770	467·595	471·436	475·292	479·164	483·052	486·955
25	490·875	494·809	498·760	502·726	506·708	510·706	514·719	518·748	522·793	526·854
26	530·930	535·022	539·129	543·253	547·392	551·547	555·717	559·903	564·105	568·323
27	572·556	576·805	581·070	585·350	589·646	593·958	598·286	602·729	606·988	611·363
28	615·753	620·159	624·581	629·019	633·472	637·941	642·425	646·926	651·442	655·973
29	660·521	665·084	669·663	674·258	678·868	683·494	688·136	692·793	697·466	702·155
30	706·860	711·580	716·316	721·067	725·835	730·618	735·417	740·231	745·061	749·907
31	754·769	759·646	764·539	769·448	774·372	779·313	784·269	789·240	794·227	799·230

Diameter in inches.	Tenths of Inches.									
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
	Areas.	Areas.	Areas.	Areas.	Areas.	Areas.	Areas.	Areas.	Areas.	Areas.
32	804·249	809·284	814·334	819·399	824·481	829·578	834·691	839·820	844·964	850·124
33	855·300	860·492	865·699	870·922	876·160	881·415	886·685	891·970	897·282	902·589
34	907·922	913·270	918·635	924·015	929·426	934·822	940·249	945·692	951·150	956·625
35	962·115	967·620	973·142	978·679	984·231	989·800	955·384	1000·984	1006·600	1012·231
36	1017·878	1023·541	1023·219	1034·913	1040·623	1046·349	1052·090	1057·847	1063·620	1069·408
37	1075·212	1081·022	1086·867	1092·719	1098·586	1104·468	1110·367	1116·281	1122·210	1128·156
38	1134·117	1140·094	1146·087	1152·095	1158·119	1164·159	1170·214	1176·285	1182·372	1188·475
39	1194·593	1200·727	1206·877	1213.042	1219·223	1225·420	1231·632	1237·861	1244·105	1250·364
40	1256·640	1262·931	1269·237	1275·560	1281·898	1288·254	1294·621	1301·007	1307·408	1313·824
41	1320·257	1326·705	1333·169	1339·648	1346·144	1352·655	1359·181	1365·724	1372·282	1378·856
42	1385·445	1392·050	1398·671	1405·308	1411·960	1418·628	1425·312	1432·011	1438·727	1445·458
43	1452·204	1458·966	1465·744	1472·538	1479·348	1486·173	1493·013	1499·870	1506·742	1513·630
44	1520·534	1527·453	1534·388	1541·339	1548·306	1555·288	1562·270	1569·299	1576·329	1583·374
45	1590·435	1597·521	1604·603	1611·711	1618·835	1625·974	1633·129	1640·300	1647·486	1654·688
46	1661 906	1669·139	1676·389	1683·654	1690·934	1698.231	1705·543	1712·871	1720·214	1727·573
47	1734·948	1742·339	1749·745	1757·167	1764·605	1772·058	1779·527	1787·012	1794·529	1802·029
48	1809·561	1817·109	1824·672	1832·251	1839·846	1847·457	1855·082	1862·725	1870·382	1878·056
49	1885·745	1893·442	1901·170	1908·906	1916·658	1924·426	1932·209	1940·008	1947·823	1955·653
50	1963·500	1971·361	1979·239	1987·132	1995·041	2002·966	2010·906	2018·862	2026·834	2034·822
51	2042·825	2050·844	2058·878	2066·929	2874·995	2083·077	2091·174	2099·287	2107·416	2115·561
52	2123·721	2131·897	2140·089	2148·296	2156·514	2164·758	2173·013	2181·283	2189·569	2197·871
53	2206·188	2214·521	2222·870	2231·235	2239·815	2248·011	2256·422	2264·850	2273·293	2281·751
54	2290·226	2298·716	2307·222	2315·744	2324·281	2332·834	2341·403	2349·987	2358·537	2367·203
55	2375·835	2384·482	2393·145	2401·823	2410·518	2419·228	2472·954	2436·695	2445·452	2454·225
56	2463·014	2471·818	2480·638	2489·474	2498·325	2507·193	2516·086	2524·974	2533·888	2542·818
57	2551·764	2560·726	2569·703	2578·695	2587·704	2596·728	2605·768	2614·824	2623·895	2632·982
58	2642·085	2651·204	2660·338	2669·488	2678·653	2687·835	2697·032	2706·244	2715·473	2724·717
59	2733·977	2743·252	2752·544	2761·851	2771·173	2780·512	2789·866	2799·235	2808·621	2818·023
60	2827·440	2836·872	2846·321	2855·785	2865·222	2874·760	2884·271	2893·798	2903·341	2912·899
61	2922·473	2932·063	2941·668	2951·289	2960·926	2970·579	2980·247	2989·931	2999·631	3009·346
62	3019·077	3028·824	3038·586	3048·365	3058·159	3067·968	3077·794	3087·635	3097·491	3107·364
63	3117·252	3127·155	3137·076	3147·011	3156·962	3166·929	3176·911	3186·909	3196·923	3206·963
64	3216·998	3227·059	3237·136	3247·228	3257·336	3267·460	3277·599	3287·755	3297·926	3308·112
65	3318·315	3328·533	3338·766	3349·016	3359·281	3369·562	3379·858	3390·171	3400·499	3410·842
66	3421·202	3431·577	3441·968	3452·374	3462·797	3473·235	3483·688	3494·158	3504·643	3515·144
67	3525·660	3536·192	3546·740	3557·304	3567·883	3578·478	3589·089	3599·715	3610·358	3621·016
68	3631·689	3642·378	3653·083	3663·804	3674·541	3685·293	3696·060	3706·844	3717·643	3728·458
69	3739·289	3750·135	3760·997	3771·875	3782·769	3793·678	3804·560	3815·543	3826·500	3837·472
70	3848·460	3859·463	3870·482	3881·517	3892·567	3903·634	3914·716	3925·814	3936·927	3948·056
71	3959·201	3970·361	3981·538	3992·730	4003·937	4015·161	4026·400	4037·655	4048·925	4060·210
72	4071·513	4082·831	4094·164	4105·513	4116·878	4128·258	4139·654	4151·066	4162·494	4173·937

To find the area, or circumference, of a circle, the diameter being given.

1. Multiply the diameter by 3·14159, and the product will be the circumference. 2. Multiply the square of the diameter by ·7854, and the product will be the area. Thus, if 6 be the diameter of a circle, then $6 \times 3{\cdot}1416 = 18{\cdot}8496$ = circumference, and $6^2 \times {\cdot}7854 = 36 \times {\cdot}7854 = 28{\cdot}2744$ = the area.

To find the centre of a given circle. Draw any chord, bisect it, and through the point of section draw a line at right angles. This line is a diameter, which bisected, gives the centre.

To describe a circle through any three given points not in the same straight line. Join the points by two straight lines, bisect those lines at right angles, and the intersection of the bisecting lines is the centre.

To divide a given circle into any number of co-centric parts, equal to each other. Divide the radius into as many equal parts as are required; and from the parts of division, erect perpendiculars upon the radius; describe a semicircle meeting the perpendiculars; and through the points of intersection draw the circles.

To divide a circle into any number of parts, equal both in area and periphery. Divide the diameter into the number of parts, and describe a semicircle upon the alternate sides of each division, so as to touch the point of contact, and also the extremities of the diameter.

Circular Saw. Circular saws, revolving upon an axis, have the advantage that they act continually in the same direction, and no force is lost by a backward stroke. They also are susceptible of much greater velocity than the reciprocating saws, an advantage which enables them to cut more smoothly. The size of circular saws, however, is limited; for, if made too large, and of the usual thinness, they are liable to waver, and bend out of their proper plane; and, on the other hand, if made thick enough to secure an adequate degree of strength, they waste both the power and the material, by cutting away too much. Hence, they are not commonly applied to the slitting of large timber, but are nevertheless very useful in smaller works, for cutting off bodies which can be included within a certain distance of the axis, and thus allow the saw to be of small size. Circular saws, however, of large size, are used in cutting thin layers of mahogany for *veneering;* for in this case the saw can be strengthened by thickening it on one side towards the centre, the flexibility of the layer of wood allowing it to turn aside, as fast as it is sawn off. Circular saws may be rendered more steady by giving them a greater velocity, so that the centrifugal force shall assist in confining the saw to its proper plane.

An ingenious machine has been invented in Maine, for sawing off sheets of wood of an indefinite length, for veneering, by cutting a spiral layer from the surface of a cylindrical log, the layer being turned off like a ribbon when unwound from a roller.

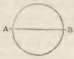
The sawing of marble is performed by saws made of soft iron, and without teeth. A quantity of sand and water is kept interposed between them, and the sand, becoming partly imbedded in the iron, serves to grind away the marble. These saws are worked horizontally for the convenience of retaining the sand, and are moved either by hand, or by reciprocating machinery. The cylindrical blocks which form the tambours, or frusta, of columns, are sometimes cut out of marble, by perforating the block at the centre, and inserting an iron axis, to the ends of which are attached frames, upon which a narrow or a concave saw is stretched parallel to the axis. An alternating motion is then given to the frame, until the saw has cut its way round the axis.

CIRCUMFERENCE; in a general sense, denotes the line, or lines, bounding any figure.

CIRCUMGYRATION; the whirling motion of a body round any given centre.

CLACK; a bell so contrived that it will ring whenever more grain is required in a corn mill.

CLACK VALVE; one of the most simple of all valves. It is usually made of a plate of leather somewhat larger than the opening which it is to cover, part of it being fastened at the one side as a hinge. When the valve is not very small it is strengthened by fixing to it a metal plate on each side, the plate next the opening being smaller than the space the valve has to cover, and the outer plate being larger. Sometimes the clack valve is made double, two semicircular disks being attached to one hinge, AB, which stretches over the opening. This construction is preferable to the single clack, where the piston is large, and this kind is also employed for steam engine air pumps, in which case the valve is made of metal. To diminish the effect of the weight of these valves, the orifice which they cover is sometimes made to incline a little, in order that the weight of the clack shall just be sufficient to close it. In the construction of these valves, it should be borne in mind that they ought to open to an angle of at least 30 degrees.



COAL. This mineral is so much used in mechanical arts, that we deem it necessary to acquaint the reader with the distinguishing characters of its various kinds, and several other particulars which could not have been so properly introduced under any other head. 1st. Caking or cubical coal, has a fine black colour. It is lamellated, or, to use the technical phrase of miners, the reed of the coal runs parallel to the bed in which it rests; and when this kind of coal is broken, the fragments are of a diced or cubical form. One kind of this species of coal runs into cakes during the process of burning. Coal of this class during the process of burning gives out great heat and flame. To this species belongs the Newcastle coal.—2nd. The rough or rock coal is of a black colour, but not so bright as the caking coal. When pure this coal leaves a small residue. This coal is very abundant in Scotland.—3d. Splint, slate, or stone coal, has a slaty structure, burns with a strong flame, and great smoke, leaving a considerable proportion of white ashes. To the same species belongs that coal called in Scotland run splint; it is difficult to separate.—4th. Cannel coal is of a black colour, and slaty structure, gives out great light in burning.—5th. Culm or blind coal, is of a clear glossy black colour with a metallic lustre: not easily kindled; but when once combustion commences, it burns with intense heat, but without smoke or flame, throwing out however a suffocating vapour. With regard to the effect of coal in producing heat, it has been stated by Dr Black, that 100 lbs. weight of Newcastle coal when applied in the most judiciously contrived furnace, would convert one and a half wine hogsheads = 790 lbs. of water into steam, equal in pressure to one atmosphere; from which we would infer, that one part of coal will convert nearly eight parts of water into steam. Count Rumford makes the number six and two thirds, Watt seven and a half, and he also states, that it required three times that weight of wood to produce the same effect. The effect of the Newcastle coal is to the same quantity of Glasgow coal, as 4 to 3. A bushel of the former is equivalent to a hundred weight of the latter. If small coal or culm (sometimes also called dross or slack), be employed, twice the weight will be required to produce the same effect as large cubical pieces. The comparative value of coal to other species of fuel has been determined by finding how much of each is required to melt a given quantity of ice, in a given time. Thus:

1 lb. of good coal will melt	90 lbs. of ice.
culm . .	45
coke . .	94
charcoal of wood	95
wood . .	92
peat . .	19
hydrogen gas .	370

Charcoal may be obtained from coal, as well as from wood, and much in the same manner, as in the process of making coal gas. It is called coke, and is much employed in the smelting of iron, for which purpose it is commonly prepared as follows; large heaps of coal are piled on the ground in the open air, and sometimes a short brick chimney is placed in the middle of the pile, at the bottom, in which large holes are opened, so that currents of air may be introduced to the pile when ignited, which accelerates the combustion. The operation of coking is intended to dissipate the volatile parts merely, so that when the burning of any particular part of the pile goes on too rapidly, ashes are occasionally thrown on, and the parts sufficiently coked are covered with ashes, until the whole is completed, when the covering is allowed to remain until the heap be cooled below the point of ignition. When the coke thus made is cold and separated from dust, it is fit for the furnace.

Cock; a contrivance for stopping at pleasure the passage of a fluid through a pipe, being a sort of revolving valve. The common form of the cock is so well known, that it needs no description in this place; peculiar modifications of it are employed in several hydraulic and pneumatic machines, which we shall take notice of. Where the opening and shutting of a passage does not require to be constant, the cock seems preferable to any other contrivance; as for instance, in the injection pipe of the condensing engine. In this case the cock has only one passage, but in others two, and sometimes three are employed, and when applied to the nozzles of the steam engine, it has four passages, being then denominated the four way cock. For a description of this, see *Nozzles*. The greatest care should be taken that the plug of the cock be properly ground in the socket. The plug is usually of the form of a truncated cone, nearly approaching to the form of a cylinder, the difference of the diameters of the broad and narrow ends being 1-16th of the length of the plug. Thus, if the length of the plug be $1\frac{1}{2}$ inches, and the greater diameter $\frac{3}{4}$ of an inch, then $\frac{1\cdot5}{16} = 0\cdot09$, wherefore, since $\frac{3}{4} = \cdot75$, we have $\cdot75 - \cdot09 = \cdot66$, the diameter of the smaller end.

Cog Teeth, formed of a different material than the body of the wheel; a timber tooth on a cog wheel, is one made of wood, where the teeth stand perpendicularly to the plane of the wheel.—See *Wheel*.

Cohesion, that species of attraction which, uniting particle to particle, retains together the component parts of the same mass; being thus distinguished from adhesion, or that species of attraction which takes place between the surfaces of similar or dissimilar bodies. The absolute cohesion of solids is measured by the force necessary to pull them asunder. Thus, if a rod of iron be suspended in a vertical direction, having weights attached to its lower extremity till the rod breaks, the whole weight attached to the rod, at the time of fracture, will be the measure of its cohesive force, or absolute cohesion. The particles of solid bodies, in their natural state, are arranged in such a manner that they are in equilibrium in respect to the forces which operate on them; therefore, when any new force is applied, it is evident that the equilibrium will be destroyed, and that the particles will move among themselves till it be restored. When the new force is applied to pull the body asunder, the body becomes longer in the direction of the force, which is called the extension: and its area at right angles to the direction of the force contracts. When the force is applied to compress the body, it becomes shorter in the direction of the force, which is called the compression; and the area of its section, at right angles to the force, expands. In either case, a part of the heat or any fluid, that occupies the pores or interstices of the body, before the new force was made to act upon it, will be expelled. See *Materials, Strength of*.

COHESIVE FORCE OF METALS.

NAMES OF METALS.	Specific Gravity.	Cohesive force of a square inch in lbs. Avoirdupois.	NAMES OF METALS.	Specific Gravity.	Cohesive force of a square inch in lbs. Avoirdupois.
Antimony, cast	4·500	1·060	Iron, bar, Ger. marked L.	from 7·600 to 7·800.	69·538
Bismuth, cast	9·810	3·250	———, marked L		85·900
———, cast	9·926	3·008	——, Liege		62·369
Copper, cast, Barbary	8·182	22·570	——, ditto.		82·839
——— Japan	8·726	20·272	——, Oosement		68·728
———, wire		61·228	——, ditto.		76·697
Gold, cast	19·238	20·450	——, Spanish		81·901
——, wire		30·888	——, Swedish		68·728
Iron, cast			——, ditto		88·972
——, grey of Cruzot, 1 fusion		30·162	——, cable		54·513
			——, cable		73·024
——, Do. 2d fusion		30·680	——, wire		85·797
——, English		52·000	——, wire		113·077
———, soft		40·824	Lead, cast	11·479	0·885
——, French		70·367	——, wire		2·547
——, French		50·981	——, wire	11·282	2·581
——, French		42·666	——, wire	11·348	3·146
——, French, soft		63·622	——, milled	11·407	3·328
———, grey		37·680	Platinum, wire		52·987
——, German	7·807	68·295	———, wire	20·847	56·473
——, wrought			Silver, cast	11·091	40·902
——, bar, coarse grained		20·460	———, wire		38·257
——— medium fineness	from 7·600 to 7·800.	34·081	Steel, soft	7·780	120·000
———, fine grained		49·982		to	
———, of good quality		55·000	———, razor, tempered	7·840	150·000
——, bar		61·041	Tin, cast, Banca	7·217	3·679
——, do., of best quality		66·000	———, English block	7·295	5·322
——, bar		80·000	———, ditto.		6·650
——, bar		80·333	———, Malacca	6·126	3·211
——, bar		84·443	———, wire		7·129
———, German, marked B.R.		61·361	Zinc, cast, Goslar	7·215	2·937
			——— ditto	7·215	2·689
———, ditto		93·069	——, patent sheet		16·616
———, common		69·133	——, wire		22·551

COHESIVE FORCE OF ALLOYS.

Parts. Parts.			Parts. Parts.		
Brass		45·882	Tin, Banca, 10 Antimon. 1	7·359	11·181
Copper 10—Tin 1		32·093	8 1	7·276	9·881
8 1		36·088	6 1	7·228	12·632
6 1		44·071	4 1	7·192	13·480
4 1		35·739	2 1	7·105	12·029
2 1		1·017	1 1	7·060	3·184
1 1		0·725	10 Bismuth 1	7·576	12·688
Gold 5—Copper 1		50·000	4 1	7·613	16·692
2—Silver 1		28·000	2 1	8·076	14·017
Lead, Scotch, 10—Bismuth 1	10·827	2·826	1 1	8·146	12·020
			1 2	8·580	10·013
2 1	11·090	5·840	1 4	9·009	7·875
1 1	10·931	7·319	1 10	9·439	3·871
Silver 5—Copper 1		48·500	10—Zinc, Indian 1	7·288	12·914
4—Tin 1		41·000			

NAMES OF ALLOYS.	Specific Gravity.	Cohesive force of a square inch in lbs. avoirdupois.	NAMES OF ALLOYS.	Specific Gravity.	Cohesive force of a square inch in lbs. avoirdupois.
Tin, Banca, 2 1	7·000	15·025	Tin, English, 6 1		7·997
1 1	7·321	15·844	4 1		10·607
1 2	7·100	16·023	2 1		7·470
1 10	7·130	5·671	1 1		7·074
4—Antim. 1		11·323	8 Zinc, Goslar 1		10·607
3 2		3·184			
1 1	7·000	1·450	4 1		10·258
Tin, English. 10—Lead 1		6·904	2 1		10·964
8 1		7·922	1 1		9·024

COHESIVE FORCE OF WOODS.

Acacia	0·860	16.000	Fir, Memel, seasoned		10·876
Alder		14·186	—, weakest		8·280
Arbutus		7·667	—, strong red		11·040
Arbutus		17·379	—, strongest		12·420
Ash	0·840	16·700	—, ditto.		13·000
Ash	0·780	19·600	Hawthorn	0·910	10·700
Ash		17·000	Hawthorn		9·200
Ash		12·000	Holly	0·760	16·000
Ash, red, seasoned	0·812	17·892	Jujube		18·915
——, white, seasoned	0·685	14·220	Jasmine		12·020
Bay		14·572	Jasmine		11·756
Bay		10·220	Laburnum	0·920	10·500
Beech	0·720	22·200	Lance-wood	1·010	23·400
Beech		17·709	Lance-wood	1·022	24·696
Birch	0·640	15·000	Larch	0·636	11·093
Box	0·990	15·500	——, Scotch, seasoned	0·496	7·888
Cane	0·400	6·300	————, very dry	0·470	7·020
Cedar	0·540	11·400	Lemon		9·457
Cedar		4·973	Lignum Vitæ	1·220	11·800
Chestnut, horse	0·610	12·100	Lime-tree	0·760	23·500
——, sweet	0·610	10·500	Locust-tree		20·582
——, sweet, 100 years in use.	0·877	12·168	Mahogany	0·870	21·800
			Mahogany	0·800	16·500
Citron		8·176	——, Spanish	0·753	12·186
Citron		12·782	Maple, Norway	0·793	10·584
Cypress		5·105	Mulberry	0·660	17·400
Cypress		6·895	Mulberry	0·660	10·600
Damson	0·790	14·000	Mulberry		14·054
Deal, Norway spruce	0·340	18·100	Oak, American, white		11·501
——, ditto.		17·600	——, Baltic, seasoned	0·673	11·412
——, Christiana	0·460	12·400	——, Dantzic		7·704
——, ditto	0·460	12·300	——, English		8·820
——, ditto	0·460	14·000	——, ditto		10·224
——, English	0·470	7·000	——, ditto, old	0·760	14·000
——, Scotch, white	0·498	4·290	——, ditto	0·760	15·000
————, yellow	0·472	8·478	——, ditto	0·700	19·800
Elder		10·230	——, pile out of the river Cam	0·610	4·500
Elm		13·489			
Fir, American	0·416	8·874	——, black Linc. log.	0·670	7·700
—, Riga		9·072	——, dry, cut four years		16·079
—, Russian	0·459	10·008	——, French, unseasoned		9·043
—, ditto		10·000	——, ditto	1·068	9·985
—, ditto		9·792	——, seasoned		13·659

NAMES OF WOODS.	Specific Gravity.	Cohesive force of a square inch in lbs. avoirdupois.	NAMES OF WOODS.	Specific Gravity.	Cohesive force of a square inch in lbs. avoirdupois.
——, Hamburg	0·660	16·300	Poplar		6·641
——, ditto	0·660	14·000	Poplar		4·596
——, Provence, seasoned	0·771	12·839	Quince		5·878
————, seasoned	0·828	13·602	Quince		8·822
————, seasoned	1·164	14·685	Sallow	0·700	18·600
Pine, pitch		7·818	Sycamore	0·690	13·000
——, pitch		12·096	Tamarisk		6·895
——, pitch		13·176	Tamarisk		11·247
——, Norway	0·590	12·400	Teak, old	0·530	8·200
——, Norway	0·660	14·300	——, Java, seasoned	0·697	14·220
——, St Petersburg	0·550	13·100	——, Malabar, seasoned	0·688	13·140
——, St Petersburg	0·490	13·300	——, Pegu	0·619	13·194
Plum-tree		11·351	Walnut	0·590	7·800
Plum-tree		12·782	Willow	0·390	14·000
Pomegranate		8·308	Willow		12·782
Pomegranate		11·501	Willow, dry		7·628
Poplar	0·360	7·200	Yew	0·790	8·000

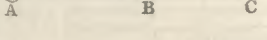
COHESIVE FORCE OF MISCELLANEOUS SUBSTANCES.

Brick		0·300	Paper, strips glued together		30·000
Brick		0·280			
—— from Dorking		0·275	Plaster of Paris		0·072
Bone of an Ox		5·265	Slate, Welsh		12·800
Glass, plate	2·453	9·420	Stone, Givry, hard	2·357	2·166
Hemp, fibres glued together		92·000	————, soft	2·071	0·385
			——, Portland		0·784
Horn of an Ox		8·949	——, homogeneous, white of a fine grain		0·207
Ivory		16·626			
Marble, white		9·000	Whalebone		7·667
Mortar, 16 years old		0·050			

Cold, the privation of heat. In general, cold contracts most bodies, and heat expands them: though there are some instances to the contrary; thus, though iron expands with heat, yet when melted it is always found to expand in cooling again, and water, in the act of freezing, suddenly expands with great force. The sensation of heat is occasioned by caloric passing into our bodies; that of cold by caloric passing out of them. And the strength of the sensations of heat and cold depends upon the rapidity with which the caloric enters or departs; and this rapidity is in proportion to the difference of the temperature between our bodies and the hot or cold substance, and to its conducting power. The higher the temperature of a body is, the stronger sensation of heat it gives; and the lower the temperature, the stronger sensation of cold: and when the temperature is the same, the sensations depend upon the conducting power of the substance. Thus, therefore, what is commonly called cold is only the absence of the usual quantity of caloric. But there have been philosophers, who held that cold is a positive thing endowed with specific qualities. See *Heat.*

COLLAR; a plate of metal screwed down upon the stuffing box, with a hole to allow the piston rod to pass through. See *Piston.*

COLLISION OF BODIES. If one body A strike another body B, which is either at rest or moving towards the body A, or moving from it, but with a less velocity than that of A; then the momenta, or quantities of motion of the two bodies, estimated in any one direction, will be the very same after the stroke that they were before it.



Thus, if A with a momentum of 10, strike B at rest, and communicate to it a momentum of 4, in the direction AB. Then A will have only a momentum of 6 in that direction; which, together with the momentum of B, viz. 4, make up still the same momentum between them as before, namely, 10.

If B were in motion before the stroke, with a momentum of 5, in the same direction, and receive from A an additional momentum of 2; then the motion of A after the stroke will be 8, and that of B, 7, which between them make 15, the same as 10 and 5, the motions before the stroke.

Lastly, if the bodies move in opposite directions, and meet one another, namely, A with a motion of 10, and B, of 5; and A communicate to B a motion of 6 in the direction AB of its motion. Then, before the stroke, the whole motion from both, in the direction of AB, is 10—5, or 5; but after the stroke, the motion of A is 4 in the direction AB, and the motion of B is 6—5, or 1 in the same direction AB; therefore, the sum 4 + 1, or 5, is still the same motion from both as it was before.

If a hard or fixed plane be struck by either a soft or a hard unelastic body, the body will adhere to it; but if the plane be struck by a perfectly elastic body, it will rebound from it again with the same velocity with which it struck the plane.

The effect of the blow of the elastic body on the plane, is double to that of the unelastic one, the velocity and mass being equal in each. Non-elastic bodies lose, by their collision, only half the motion lost by elastic bodies, their mass and velocities being equal; for the latter communicate double the motion of the former.

If an elastic body A impinge on a firm plane DE, at the point B, it will rebound from it in an angle equal to that in which it struck it; or the angle of incidence will be equal to the angle of reflection; namely, the angle ABD equal to the angle FBE.

Let the non-elastic body B, moving with the velocity V in the direction Bb, and the body b with the velocity v, strike each other. Then,

BV + bv, if the bodies moved the same way, or

BV — bv, if they moved contrary ways, and

BV only, if the body b were at rest.

and the common velocity after the stroke in the direction BC; will be, $\frac{BV + bv}{B + b}$ in the first case, $\frac{BV - bv}{B + b}$ in the second, and $\frac{BV}{B + b}$ in the third.

For example, if the bodies or weights B and b be as 5 to 3, and their velocities V and v; as 6 to 4, or 3 to 2, before the stroke; then 15 and 6 will be as their momentums, and 8 the sum of their weights; consequently, after the stroke the common velocity will be as

$$\frac{15 + 6}{8} = \frac{21}{8}, \text{ or } 2\tfrac{5}{8} \text{ in the first case;}$$

$$\frac{15 - 6}{8} = \frac{9}{8}, \text{ or } 1\tfrac{1}{8} \text{ in the second; and}$$

$$\frac{15}{8}, \quad . \quad . \quad \text{or } 1\tfrac{7}{8} \text{ in the third}$$

Let the elastic body B move in the direction BC, with the velocity V; and let the velocity of another elastic body b be v, then,

$$\frac{(B - b)\,V + 2bv}{B + b}, \text{ the velocity of B:}$$

$$\frac{(B - b)\,v + 2BV}{B + b}, \text{ the velocity of } b.$$

both in the direction BC, when the bodies both moved towards C before the collision. But if the body b moved in the contrary direction before the collision, or towards B; then,

$$\frac{(B - b)\,V - 2bv}{B + b}, \text{ the velocity of B,}$$

$$\frac{(B - b)\,v + 2BV}{B + b}, \text{ the velocity of } b, \text{ in the direction BC.}$$

And if b were at rest before the impact,

$$\frac{B - b}{B + b}\,V, = \text{ the velocity of B, and}$$

$$\frac{2B}{B + b}\,V, = \text{ the velocity of C,}$$

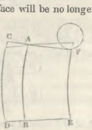
for the velocities in this case.

Column, in architecture, a round pillar, made to support and adorn a building, and composed of a base, shaft, and capital. See *Order*.

Combustion, is a change in the nature of combustible bodies, accompanied by the emission of light. It was the favourite theory of Lavoisier, that combustion arose from the combustible body absorbing oxygen, and from light and heat being given out in the process. This is true in ordinary cases; but there are many exceptions in which there is combustion without the presence of oxygen, where there is an intense action, and light and heat are given out.

Compression. When a bar or beam is compressed in the direction of its length, it resists more powerfully than in any other way. If the beam be long, and its strength be overpowered by pressure, it bends, and then breaks; but if its thickness be as much as a seventh part of its length, it commonly swells in the middle, splits, and is crushed. When a stone block or pillar is crushed, the parts nearest to the force break away, and slide off diagonally at the sides, leaving a pyramidal base. The lower stories of buildings, the piers and piles of bridges, the spokes of carriage wheels, and the legs of furniture, are subjects of this force. According to Mr Tredgold, a cubic inch of malleable iron will support, without alteration, a weight of about 17000 pounds; cast iron, 15000; brass, 7000; oak and mahogany, nearly 4000; tin, 3000; lead, 1500. Granite is crushed by 11000 pounds to the square inch; white marble, by 6000; Portland stone, by 4000.

When a force acts on a straight column in the direction of its axis, it can only extend or compress it equally through its whole substance. But if the direction of the force is not in the axis, but parallel to it, the extension or compression will then be partial. In a rectangular column or block, when the compressing force is applied to a point more distant from the axis than one sixth of the depth, the remoter surface will be no longer compressed, but extended. In this case, the distance from the axis of the neutral point, or that which is neither compressed nor extended, will be inversely as that of the point to which the force is applied. For example, a weight or compressing force being applied on one side of the block or column CDEF, and acting in a direction parallel to its axis, the compression will extend only to the line AB, the parts beyond this being extended.



Condensation. When steam is brought into contact with a body colder than itself its temperature and elasticity will be diminished. The quantity of diminution of temperature and elasticity will vary with the difference of the temperature of the cold body and steam, and also on the quantity of the one compared with the other. The body employed for condensation should expose as large a surface as possible to the steam, and for this purpose nothing answers so well as a jet of water. Water cannot always be procured of the same temperature, and, therefore, in order to economise the water, and at the same time procure a complete condensation of the steam, we must determine what quantity of water is necessary to condense steam, both being at various temperatures. Let q represent the quantity of water necessary to form steam, Q that necessary for condensation, T the temperature of the steam, t of the condensing water, and e that of the condensed water, S the content of the cylinder; then, Q being in inches, and S in feet.

$$\frac{(1000 + \mathrm{T} - e)}{c - z} \times 1{\cdot}1\,\mathrm{S} = \mathrm{Q}, \text{ and}$$

$$\frac{(1000 + \mathrm{T}) + \mathrm{Q} \times t}{2 - 1{\cdot}1} = c.$$

By these theorems it will be found, that when

T = 220°, t, 52°, c = 100°, then Q = 25⅓ times S.
220, ... 52, ... 130, ... 14 ...... S.
220, ... 70, ... 130, ... 18 ...... S.
220, ... 70, ... 100, ... 37 ...... S.

The mixture of the condensed steam and injection water in the condenser would never exceed 100°, whether a separate condenser be used or not.

The modes of condensation have been various in the different forms of the steam engine. In those of Savary and Newcomen, the condensation is effected in the same vessel where the moving power of the steam is applied; in that of Watt it is condensed in a separate vessel. Savary condensed the steam by pouring the water on the vessel containing it; Newcomen by throwing the water among it; Watt, by exposing it to large surfaces of cold water; Cartwright, to large surfaces of cold solids; and Perkins, by pressing cold fluids against the vessels containing it. Two or more of these methods may be combined. See *Condenser*.

The following Tables will be useful for reference.

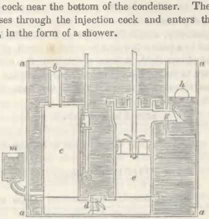
A Table of the Quantity of Water required for condensation per hour in an atmospheric engine. The mean pressure of the steam in the boiler being 35 inches of mercury.

Horses power.	Water required in cubic ft.	Diameter of cylinder.	Horses power.	Water required in cubic ft.	Diameter of cylinder.
10	133·2	26·4	60	800·4	54·2
15	200·4	31·1	65	865·2	56·0
20	267·6	34·9	70	936·	57·6
25	332·4	38·1	75	999·6	59·2
30	399·6	41·1	80	1068	60·8
35	468·	43·7	85	1120	62·3
40	534·6	46·1	90	1340	43·7
45	600	48·3	95		66·3
50	666	50·4	100		
55	734·4	52·3			

Table of the Quantity of Water for condensation, &c. required in a double acting Steam Engine, not acting expansively.

Horses power.	Diameter of cylinder in inches.	Diameter of injection pipe in inches.	Water required per hour for condensation in cubic feet.	Length of stroke.	Number of strokes per minute.
1	7·8	0·21	19·2	1·5	44
2	10·25	0·29	27·68	1·75	37·5
3	12·05	0·33	56·64	2	35
4	13·52	0·38	75·12	2·25	33
5	14·9	0·4	94·08	2·5	31·5
6	16	0·44	112·8	2·65	30·5
7	17	0·48	132	2·8	29·25
8	17·9	0·49	157·2	2·97	29
9	18·7	0·52	169·2	3·1	28·25
10	19·5	0·54	187·48	3·25	26·25
12	20·9	0·59	225·6	3·5	26·5
14	22·3	0·61	264	3·7	25·75
16	23·6	0·65	302·4	3·9	25
18	24·7	0·69	338·4	4·1	24·5
20	25·75	0·7	376·8	4·3	24
22	26·75	0·74	415·2	4·5	23·5
24	27·7	0·77	451·2	4·6	23·25
26	28·6	0·79	489·6	4·75	22·75
28	29·45	0·82	528	4·9	22·5
30	30·27	0·84	602·4	5·04	22·25
32	31	0·86	640·8	5·2	21·75
34	31·82	0·88	679·2	5·3	21·5
36	32·56	0·9	712·8	5·43	21·25
38	33·3	0·92	753·6	5·53	21
40	34	0·94	868·8	5·67	21
46	35·9	0·99	943·2	6	20·5
50	37·13	1·00	1056	6·2	20
56	38·85	1·09	1128	6·49	19·5
60	40	1·1	1160	6·65	19·5
66	41·5	1·19	1243·2	6·9	19·
70	42·5	1·2	1230	7·1	18·25
76	43·9	1·26	1455·2	7·3	18·5
80	44·8	1·35	1500	7·4	18·5
86	45·9	1·38	1596	7·47	18·5
90	46·97	1·4	1692	7·83	17·75
96	48·0	1·46	1785	8·0	17·5
100	49	1·5	1874	8·16	17·5
105	49·95	1·58	1970	8·32	17·5
110	50·9	1·59	2104	8·5	17
120	52·7	1·6	2299	8·6	17

Condenser. In the atmospheric engine of the old construction the condensation was carried on in the cylinder, an arrangement which was accompanied with a great waste of steam. Mr Watt's first and great improvement consisted in condensing the steam in a separate vessel. The accompanying cut will show the construction of Watt's condenser. *a*, *a*, *a*, *a*, represents a section of the cistern, containing cold water, *b* is the eduction pipe through which the steam passes from the cylinder into the condenser *c*. The condenser communicates with the air pump *e*, by a pipe at the bottom, furnished with a valve *d*, called the foot valve. This valve is of the clack form. The air pump *e*, is of the common suction kind, but the piston is furnished with two valves, as will be seen in the figure. The valve *g* opens into the hot well *h*, and the opening at *h* is the end of a pipe that allows the surplus hot water in the well to run off, the remainder being pumped into the boiler. At the side of the condenser a rod is seen rising in the cistern, the lower end being attached to an injection cock near the bottom of the condenser. The water from the cistern passes through the injection cock and enters the condenser through a rose, in the form of a shower.



Before the engine is set a going, the injection cock is shut, and steam is admitted into the cylinder, which, passing down through the pipe *b* into the condenser, fills it, there being no cold water yet admitted, it finds no other way of escape save through the valve *m*, which is covered by a little water, and is called the blowing-through valve. The injection cock is kept shut, and the steam allowed to blow through and displace the water and air contained in the condenser. This is continued until it is supposed that as much steam has been blown through as is sufficient to fill the cylinder and condenser. The injection cock is then opened, and the steam being condensed, the piston will begin to move. The piston rod and air pump rod being attached to the same end of the beam, rise and fall together; when the piston rises, the valve in the bucket of the air pump will be shut, and all the air and water above the bucket will be lifted through the valve *g* into the hot well *h*. At the same time a vacuum being formed in the air pump *e*, below the bucket, more perfect than that in the condenser, the foot valve *d* will be opened, and the water and air will pass from the condenser into the air pump. When the bucket descends, the valve in it will open, and allow the air and water to pass into the space above it, while the valves *g* and *d* will be shut. At the return, the water and air is lifted through the valve *g* to the hot well or cistern, as before, &c. The condenser is usually made of the same capacity as the air pump, each being equal to one eighth of tho content of the cylinder; that is, the length of the air pump should be one half of the length of the cylinder, and also its diameter one half that of the cylinder. In Rees's Cyclopedia, the diameter of the air pump is made two thirds that of the cylinder, and the length the same as before stated, but this makes the pump too large, and causes an unnecessary waste of power.

CONE, in geometry, a solid figure, having a circle for its base, and its top terminated in a point; it might be called a round pyramid. Cones are distinguished into right, or those which have the axis or line drawn from the vertex to the middle of the base, perpendicular to the plane of that base ; and those which have the axis of the cone inclined at some other angle, these are called oblique cones.

The solid content $= \frac{\text{area of base} \times \text{axis.}}{3.}$

Thus, the content of a cone whose height is 10, and diameter of base 7, will be,

$$\frac{7 \times 3{\cdot}1416 \times 10}{3} = 73{\cdot}304.$$

The surface $= \frac{\text{area of base} + \text{Circumference of base} \times \text{slant height.}}{2.}$

Thus the diameter of base being 7 and the slant height 13, we have

$3{\cdot}1416 \times 7 = 21{\cdot}9912 =$ circumference of base, and

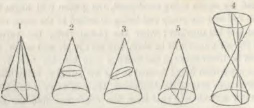
$\sqrt{7^2} \times {\cdot}7854 = 6{\cdot}2035 =$ area of base.

Wherefore,

$$\frac{21{\cdot}9912 \times 13}{2} + 6{\cdot}2035 = 149{\cdot}1463$$

= the whole surface of the cone.

There are certain sections, or cutting of a cone, by which figures bounded by particular lines are formed. Thus in the annexed wood-cut.



If the cone, fig. 1, be cut from the vertex perpendicularly to the base, the section is a triangle. If, as in fig. 2, it be cut parallel to the base, the section is a circle. If, as in fig. 3, the cone be cut obliquely to the base, that is, the one side of it nearer to the base than another, the section is an ellipse. If, as in fig. 4, the cone be cut perpendicular to the base, but not through the axis, the section is an hyperbola. If, as in fig. 5, the cone be cut parallel to the slanting side, the section is a parabola.—See *Ellipse*, *Hyperbola*, and *Parabola*.

CONE, DOUBLE. It is sometimes necessary that a machine should be propelled with a velocity which is not equable, but which continually changes in a given ratio. This happens in cotton mills, where it is necessary that the speed of certain parts of the machinery should continually decrease from the beginning to the end of an operation. To effect this object, two cones, or conical drums, are used, having their larger diameters in opposite directions. They are connected by a belt, which is so governed by proper mechanism that it is gradually moved from one extremity of the cones to the other, thus acting upon circles of different diameter, causing a continual change of velocity in the driven cone, with relation to that which drives it.

The cone is extensively used in cotton spinning for the purpose of obtaining the requisite change of velocity, for the equable tension of thread in the filling of bobbins or cops, as in the fly frame. The belt is moved by a rack, whose teeth are not all equal, but cut according to the law indicated by the equation of the parabola. Of late a substitute for the double cone has been employed in the cotton spinning machinery of America. It consists of two series of wheels, mounted upon two spindles placed parallel to each other. The wheels on either spindle continually decrease in size, from the one end to the other; the larger wheels of the one acting in the smaller wheels of the other. One of these spindles is connected with the power, is hollow, and has an opening running from one end to the other. The wheels on this axis are loose, but capable of being caught in succession by a projecting pin, which is moved along the hollow of the spindle. The wheels on the other spindle are all fixed, so that it turns round with a different velocity, according to the wheel that is put in gear by the catch in the other spindle.

The following table shows the proportional number of teeth of the wheels on both spindles, to give the proper variation of speed in the fly frame.

No. of Gear.	Fast.	Loose.	No. of Gear.	Loose.	Fast.
1	11	16	31	71	76
2	13	18	32	73	78
3	15	20	33	75	80
4	17	22	34	77	82
5	19	24	35	79	84
6	21	26	36	81	86
7	23	28	37	83	88
8	25	30	38	85	90
9	27	.32	39	87	92
10	29	34	40	89	94
11	31	36	41	91	96
12	33	38	42	93	98
13	35	40	43	95	100
14	37	42	44	97	102
15	39	44	45	99	104
16	41	46	46	101	106
17	43	48	47	103	108
18	45	50	48	105	110
19	47	52	49	107	112
20	49	54	50	109	114
21	51	56	51	111	116
22	53	58	52	113	118
23	55	60	53	115	120
24	57	62	54	117	122
25	59	64	55	119	124
26	61	66	56	121	126
27	63	68	57	123	128
28	65	70	58	125	130
29	67	72	59	127	132
30	69	74	60	129	134

Conical Valve, the pupet or T valve, that first used by Watt in the construction of his engines. It consists of a circular plate of metal, having a bevelled edge, fitted to a seat. The angle of bevel ought to be 45°. Both the seat cover and ought to be accurately turned, and then ground together with emery. These valves are commonly formed of brass, but gun metal is preferable. The diameter of the widest part of this sort of valve ought never to exceed two thirds of the diameter of the valve box, and the corner of the valve should never rise less than one-sixth of the diameter of the base. This sort of valve never works well when its diameter is more than six inches.

Contact, is when one line, plane, or body, is made to touch another, and the parts which thus touch are called the points of contact.

Content, in geometry, the area or quantity of matter or space included in certain bounds. The content of a ton of round timber is 43 solid feet. A load of hewn timber contains 50 cubic feet; in a foot of timber are contained 1728 cubic or solid inches; and as often as 1728 inches are contained in a piece of timber, be it round or square, so many feet of timber are contained in the piece.

CONTRACTILE FORCES. Forces which decrease. See *Forces*.

CONTRATE WHEELS. See *Crown Wheel.*

CONVEX, the exterior surface of gibbous or globular bodies, in opposition to the internal or concave surface.

CORNER STONES, among builders, the two stones which stand one in each joint of the chimney, commonly made of Reigate or freestone.

CO-SECANT, in geometry, the secant of an arch, which is the complement of another to 90°.

CO-SINE, in trigonometry, the sine of an arch which is the complement of another to 90°.

CO-TANGENT, in trigonometry, the tangent of an arch, which is the complement of another.

CONVOY or DRAG. When a carriage has to descend a hill, a crooked lever is applied to the surface of one of the wheels, which retards its motion and prevents the vehicle from acquiring too great velocity.

COPPER is a very brilliant sonorous metal, of a fine red colour, possessing a considerable degree of hardness and elasticity. It is extremely malleable, and may be reduced to leaves so fine, that they may be carried about by the wind. Its tenacity is very great. A wire of one-tenth of an inch in diameter will support a weight equal to 300 lbs. avoirdupois without breaking. It does not melt till the temperature is elevated to about 27° of Wedgwood, or (by estimation) 1450° of Fahrenheit. When rapidly cooled, it exhibits a granulated and porous texture. When the temperature is raised beyond what is necessary for its fusion, it is sublimed in the form of visible fumes. None of the malleable metals is so difficult to file or turn smooth as copper; but it is cut by the graver, or ground by gritty substances, with great ease.

When miners wish to know whether an ore contains copper, they drop a little nitric acid upon it; after a little time, they dip a feather into the acid, and wipe it over the polished blade of a knife; if there be the smallest quantity of copper in it, this metal will be precipitated upon the knife, to which it will impart its peculiar colour. Roman vitriol, much used by dyers, and in many of the arts, is a sulphate of copper. A solution of this salt is used for browning fowling-pieces and tea-urns.

In domestic economy, the necessity of keeping copper vessels perfectly clean, cannot be too strongly inculcated; but it is worthy of remark, that fat and oily substances, and vegetable acids, do not attack copper while hot; and therefore copper vessels may be used, for culinary purposes, with perfect safety, if no liquor be ever suffered to grow cold in them. The mere tinning of copper and brass vessels does not afford complete security. The tinning is never so perfect as to cover every part of them.

The alloys of copper, especially those in which this metal predominates, are more numerous and important in the arts than those of any other metal. Many of them are perfectly well known, and have been immemorially in use. The exact composition, and particularly the mode of preparing several, are kept as secret as possible. By the aid of chemistry, we may detect the precise composition of an alloy; yet we may not always be able, by common methods, to produce a mixture having all the excellencies, which, perhaps, mere accident has taught the possessor of the secret to combine. Brass is the most important of all the alloys of copper. See *Brass.*

Five or six parts of copper and one of zinc form pinchbeck. Tombac has still more copper, and is of a deeper red than pinchbeck. Princes' metal is a similar compound, excepting that it contains more zinc than either of the former.

The alloys of copper, with different portions of tin, are of great importance in the arts. They form compounds which have distinct and appropriate uses. Tin renders copper more fusible, less liable to rust, harder, denser, and more sonorous. Copper and tin separately, are not more remarkable for their ductility, than, when united, the compounds they form, are for their brittleness.

Eight to twelve parts of tin, combined with one hundred parts of copper, form bronze, which is of a greyish yellow colour, harder than copper, and the usual compositions for statues. The customary proportions for bell metal are three parts of copper and one of tin. The greater part of the tin may be separated by melting the alloy, and then throwing a little water upon it. The tin decomposes the water, is oxidized, and thrown upon the surface. The proportion of tin in bell metal is varied a little at different founderies, and for different sorts of bells. Less tin is used for church bells than clock bells; and in very small bells a trifling quantity of zinc is used, which renders the composition more sonorous; and it is still further improved, in this respect, by the addition of a little silver. A small quantity of antimony is occasionally found in bell metal. When copper, brass, and tin are used to form bell metal, the copper is from seventy to eighty per cent, including the portion contained in the brass, and the remainder is tin and zinc. When tin is nearly one third of the alloy, it is then beautifully white, with a lustre almost like mercury, extremely hard, close grained, and brittle; but when the proportion of tin is one half, it possesses these properties in a still more remarkable degree, aud is susceptible of so exquisite a polish as to be admirably adapted for the speculums of telescopes. If more tin be added than amounts to half the weight of the copper, the alloy begins to lose that splendid whiteness for which it is so valuable as a mirror, and becomes of a blue grey. As the quantity of tin is increased, the texture becomes rough grained, and totally unfit for manufacture.

CORE, the internal mould which forms a hollow in the casting of metals, as the bore of a tube or pipe.

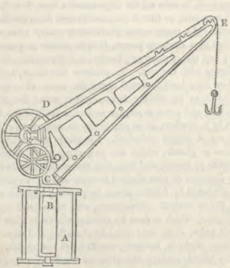
COUNTER, a contrivance to indicate the number of strokes that an engine makes in a given time. It consists of a train of wheel work, resembling that of a clock, and so contrived that at each stroke of the piston rod a small detent is moved one tooth. It is useful for regulating the consumpt of fuel.

COUNTERSINK, to take off the edge round a hole, in order to let in the head of a screw nail, so that it may not project from the surface.

COUPLINGS. In many cases, particularly where numerous machines are propelled by a common power, it is important to possess the means of stopping any one of them at pleasure, and of restoring its motion, without interfering with the rest. To produce this effect, a great variety of combinations have been invented under the name of *couplings*. These in most instances are sliding boxes, which move longitudinally upon shafts or axles, and serve to engage or lock a shaft which is at rest, with one which is in motion; so as practically to convert the two into one, until they are at length unlocked. Couplings are sometimes provided with *clutches* or *glands*, which are projecting teeth, intended to catch on other teeth or levers, and thus lock the shafts together. Sometimes they have *bayonets* or pins adapted to enter holes. Sometimes the connexion is produced by friction alone, by pressing together surfaces which are either *flat* or conical. Sometimes, also, the wheels are thrown *into* and *out of gear*, which is done by causing wheels to slide in the direction of their axles, or in some cases by elevating and depressing the axle itself. These methods, however, are difficult and unsafe. The *fast* and *loose pulley* afford perhaps the simplest mode of engagement. They consist of two parallel band-wheels on the same axle, one of which is fast, and the other loose, or capable of turning without the axle. The band which communicates the power is placed upon the loose pulley, when it is desired to stop the machine, and upon the fast pulley when it is intended to set the machine in motion. A common band may also be made to admit of motion or rest, according as it is rendered tense or loose, by a *tightening wheel* pressed against its side by a lever.

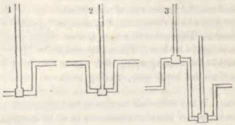
COUPLING-BOX, a strong piece of hollow iron to connect shafts and throw machinery in and out of gear.

CRANE; a machine employed in raising or lowering heavy weights. Cranes are generally constructed by an application of the wheel and axle, cog-wheel, wheel and pinion, on the principle of the hydrostatic press. The first may be regarded as somewhat resembling the capstan, and the last Bramah's press, which have already been described. The subjoined cut will illustrate the form and operation of the wheel and pinion crane, made of cast-iron. The collar B is made to revolve in an iron or stone cylinder A, fixed in the ground; the collar revolving on balls at the top, for the purpose of diminishing friction. The post C is firmly attached to the collar, and carries the gib and stay, D E. It has a double gib and stay, which screw on each side of the post, and admit the pulley between them. This crane is very commodious, and may be made of great power.



The method of calculating the strength of the different parts of a crane will be given in our article *Materials*, Strength of.

CRANK. The common crank affords one of the simplest and most useful methods of changing circular into alternate motion, and *vice versa*. The single crank, 1, can only be used upon the end of an axis. The bell crank, 2, may be used in any part of an axis. The double crank, 3, produces two alternate motions, reciprocating with each other. The alternate parts in all these cases are attached to the crank by connecting rods, or by some of the kinds of mechanism hereafter described. The motion produced by cranks is easy and gradual, being most rapid in the middle of the stroke, and gradually retarded towards the extremes; so that shocks and jolts in the moving machinery are diminished, or wholly prevented by their use.



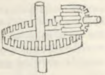
The connecting rod does not act upon the crank perpendicularly all the way round, which has led many to suppose that there is a positive loss of power, independent of friction. As the connecting rod acts upon the crank, the effect is compared to what it would be if it acted perpendicularly; as twice the diameter of a circle is to the circumference, that is as 2 is to 3·1416; for, while the crank moves through its circumference, the connecting rod, or moving power, moves through twice the diameter. This explains a mistake into which many practical men have fallen in considering that there is a loss of power in the use of the crank. There is, indeed, a small loss of power in consequence of friction, but in other respects the crank is like all other mechanical contrivances, a director of motion; for, since the connecting rod moves through a space equal to 2, the crank moves in the same time through a space equal to 3·1416, according to the ordinary way of expressing the law of virtual velocities. What is lost in power is gained in velocity.

Crowbar; a strong bar of iron, used as a temporary lever.

Crucibles. Crucibles, melting pots, and other vessels intended for use in the furnace, require to be made of substances which sustain a high temperature without fusion. When they are made of about one part of pure clay, mixed with three of sand, and slowly dried and annealed, they are found to bear a great heat, and will retain most of the metals which are melted for use in the arts. Such crucibles, however, are liable to be acted upon, and destroyed at high temperatures, if the metals are suffered to become oxidized, or if saline fluxes are used. To prevent this accident, some crucibles are made entirely of clay, which is burnt, coarsely powdered, and mixed with fresh clay. These are found very refractory in the furnace. Crucibles are also made of plain Stourbridge clay, of Wedgewood's ware, of graphite, and of platina.

Crown, in geometry, a plane ring, included between two concentric perimeters, generated by the motion of part of a right line round the centre, to which the moving part is not contiguous. See Circle.

Crown Wheels. Circular motion is communicated at right angles, by means of teeth or cogs, situated parallel to the axis of the wheel. Wheels thus formed are denominated *crown* or *contrate* wheels. They act either upon a common pinion or upon a *lantern*. The crown wheel is represented in the accompanying cut. It is less in use than the bevel geer, having more friction.



Crushing. When materials require to be broken into minute parts, or when the texture of vascular substances is to be destroyed, that they may yield their fluid contents, the operation of crushing is resorted to. It is performed either by percussion, with hammers, stampers, and pestles, or by simple pressure, with weights, rollers, and runner stones.

Culverts. It sometimes happens that the embankments act as a dam, to prevent the land on one side of a canal from being properly drained. In this case, culverts, or subterranean passages, are constructed underneath the canal, but not communicating with it, to effect the necessary draining. Culverts are made of brick or stone, and require to be strong and tight. An ingenious mode of ventilation is adopted by means of an empty culvert, one end of which opens into the building, while the other end is provided with a turncap, presenting its open mouth to the wind. The air, in passing this culvert, partakes of the temperature of the earth, and is thus warmed in winter, and cooled in summer. The effect is of a limited kind, since the continual transmission of air must bring the surface of the culvert to a temperature approaching that of the surface of the ground.

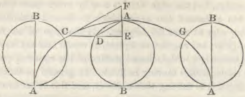
Cupel, in metallurgy, a small vessel which absorbs metallic bodies when changed by fire into a fluid scoria; but retains them as long as they continue in their metallic state. One of the most proper materials for making a vessel of this kind is the ashes of animal bones; there is scarcely any other substance which so strongly resists vehement fire, and which so readily imbibes metallic scoriæ.

Cup Valve, a valve resembling the conical valve, with this difference that the seat is made to fit a couver in the form of a base or of the portion of a sphere. The only advantage of the cup over the conical valve is in the case of a safety valve for the boiler of a steam-vessel, for if the weight be hung below the valve, within the boiler, the motion of the vessel will cause it to oscillate; and thus, by keeping the valve in continual motion, prevent it from striking.

Cutting. Cutting instruments act, in dividing bodies, upon the same principle as the wedge. The blade of the instrument is in general a thin wedge, but the edge itself is usually much more obtuse. Mr Nicholson has estimated the angle which is formed ultimately by the finest cutting edge at about 56 degrees. If the edge of an instrument were not angular, but rounded or square, it would still act as a wedge, by pushing before it a wedge-shaped portion of the opposing particles, as is done by obtuse bodies moving in fluids. In general an oblique motion is more favourable to cutting than a direct, and this is because the edges of steel instruments are rough with minute asperities, like saw teeth. This circumstance, however, is of less importance when the material operated upon is very firm and the cutting is deep; for in this case the friction and compression consume more force than the actual division. This takes place with axes and chisels, which are necessarily made thick to secure the requisite strength. The quality in tools which is called temper is opposed to brittleness on the one hand and to flexibility on the other. Independently of the quality of the metal, it appears to be somewhat influenced by temperature, since axes and other tools are liable to break, or gap, in frosty weather, and razors cut best after being immersed in hot water. The kind of cutting which is performed by scissors depends upon the process called *detrusion*, in which the coherent particles are pushed by each other in opposite directions. In this case the cutting edges require to be angular, but the angle not very acute. The shearing of woollen cloths, the slitting and punching of metals, the cutting of nails, and various other mechanical processes, are performed on this principle.

A variety of fibrous and woody substances used by druggists and dyers require to be reduced to a coarse powder like saw-dust, to facilitate the extraction of their soluble matter. This is not easily done in any of the common mills, owing to the toughness of the material, It is sometimes effected by machinery with circular rasps or saws; but a more economical application of a dividing force in these cases is obtained by the rapid revolutions of a sharp cutting instrument. In Bramah's surface planing machinery, and in Blanchard's ingenious engine for cutting definite forms by a pattern, sharp instruments of different forms are made to revolve upon axles, or slide in grooves, while the material operated on is put in motion, so as to place itself in the proper position to receive the cut.

CYCLOID, a curve much used in mechanics. It is thus formed :—

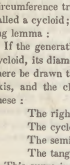


If the circumference of a circle be rolled on a right line, beginning at any point A, and continued till the same point A arrive at the line again, making just one revolution, aud thereby measuring out a straight line ABA equal to the circumference of a circle, while the point A in the circumference traces out a curve line ACAGA: then this curve is called a cycloid; and some of its properties are contained in the following lemma :

If the generating or revolving circle be placed in the middle of the cycloid, its diameter coinciding with the axis AB, and from any point there be drawn the tangent CF, the ordinate CDE perpendicular to the axis, and the chord of the circle AD; then the chief properties are these :

The right line CD = the circular arc AD;
The cycloidal arc AC = double the chord AD;
The semi-cycloid ACA = double the diameter AB, and
The tangent CF is parallel to the chord AD.

This curve is the line of swiftest descent, and that best suited for the path of the ball of a pendulum.



CYLINDER, in geometry, a solid formed by the revolution of a paralelogram about one of its sides which remains fixed. Thus if the paralelogram, being right angled, AC revolve round its fixed side AB, a cylinder will be formed. The circular planes which form the ends of a cylinder are called its bases, and the line AB its axis. The surface of a cylinder is found by multiplying the circumference by the length of the axis, and adding to this the area of the two ends. To find the solid content multiply the area of the base by the altitude or length of the axis. If the length of a cylinder's axis be 12 inches, and the diameter 3 inches, then $3^2 \times \cdot7854 = 7\cdot0685$ = area of base, and $3 \times 3\cdot1416 = 9\cdot4247$ = circumference; hence $9\cdot4247 \times 12 + (2 \times 7\cdot0685) = 127\cdot2834$ = surface, and $7\cdot0685 \times 12 = 84\cdot832$ = solidity.

CYLINDER of a steam engine, the hollow vessel in which the piston moves. The proportion of the length to the diameter of the cylinder is a subject in which makers do not seem to be always guided by the same rule; it would appear, however, by the investigations of Tredgold that there will be the greatest saving of heat when the length of the cylinder is twice its diameter. Circumstances will sometimes determine the length of the strokes in relation to the cylinder; and cylinders have been made, the length of which was to the diameter as 9 to 1·5, the cylinder lying horizontally; and other engines have been constructed where the length of the cylinder was to the diameter as 6 to 1; and also where the one was equal to the other. To determine the thickness of metal necessary for a cylinder, let T be the thickness of the cylinder, E the elastic force of the steam in pounds per circular inch, D the diameter of cylinder in inches.

$$\frac{4\,E \quad D}{6000} \times \frac{D}{D-2{\cdot}2} + \tfrac{1}{2} = T.$$

Thus, a cylinder being 30 inches in diameter, and the pressure of steam = 15 lbs to the circular inch, then

$$\frac{4 \times 15 \times 30}{6000} = 0{\cdot}3 \text{ and } 0{\cdot}3 \times \frac{30}{30-2{\cdot}2} = 0{\cdot}3 \times 1{\cdot}08 = {\cdot}324$$

and $\cdot324 + \frac{1}{2} = \cdot824$.

The diameter of the cylinder being 10, the pressure 60, then

$$\frac{4 \quad 60 \times 10}{6000} = {\cdot}4 \text{ and } \frac{10}{10-2{\cdot}2} = 1{\cdot}28, \text{ also}$$

$${\cdot}4 \times 1{\cdot}28 = {\cdot}512 \text{ and } {\cdot}512 + \tfrac{1}{2} = 1{\cdot}012 =$$

the thickness of the metal.

This rule applies to the cast iron cylinder only. The position of the cylinder has been varied in various ways, the most common being the upright, where the axis is perpendicular to the horizon. This position seems to be the best, as the wear of the cylinder and piston rod is equal on all sides; but in some particular cases the cylinder is either inclined to some angle with the horizon, and sometimes the cylinder is laid parallel to the horizon. The advantage gained by these latter positions is that a longer stroke is made practicable than would be with the erect cylinder, but the cylinder and piston rod wear unequally from the action of gravity. There have also been constructed revolving cylinders, as that of Mr Witty (See Galloway's Steam Engine, p. 110), but not to be approved of. The vibrating cylinder of Maudsley seems to be less objectionable. Hornblower employed two cylinders in such a way that when the steam had acted in the one, it, instead of being wholly condensed, passed into the other and acted there expansively. When this invention was made it could not be put in action, for the patent for a separate condenser was yet in the hands of the original discoverer, and Hornblower's engine was superseded by the subsequent invention of Mr Watt's expansive engine. See *Steam Engine.*

D

Dam, a mole, mound of earth, or wall erected for the confinement of water. Dams are most commonly erected for the supply of water wheels. Most water-mills are now removed to the side of the river, one channel being from the river to the mill to supply it with water, and another to return the water from the mill to the river. The difference of level between these two channels is the fall of water to work the mill, and this is kept up by means of a wear or dam across the river. The water can run freely over this dam in case of floods, without at all affecting the mill, the entrance to the channel of supply being regulated by sluices and side walls.

The dam should be erected across the river at a broad part, where it will pen up the river so as to form a large pond or reservoir, which is called the mill pond or dam head. This reservoir is useful to gather the water which comes down the river in the night, and reserve it for the next day's consumption; or for such mills as require more water, when they do work, than the ordinary stream of the river can supply in the same time. The larger the surface of the pond is, the more efficient it will be, but depth will not compensate for the want of surface.

The dam of a large river should be constructed with the utmost solidity; wood framing is very commonly used, but masonry is preferable, and great care must be taken, by driving pile planking under the dam, to intercept all leakage of the water beneath the ground under the dam. Some place the dam obliquely across the river, with a view of obtaining a greater length of wall for the water to run over. Such a form requires great strength, which is obviated by making the dam in two lengths which meet in an angle, the vertex pointing up the stream. A still better form is a segment of a circle. This was the form generally used by Mr Smeaton. The foot of the dam where the water runs down should be a regular slope with a curve, so as to lead the water down regularly; and this part should be evenly paved with stone, or planked. When the fall is considerable, it may be divided into more than one dam; but if the lower dam is made to pen the water upon the foot of the higher dam, then the water running over the higher dam will strike into that of the lower and lose its force.

With regard to the best proportions for the thickness of dam walls see *Pressure on Walls.*

DAMASCUS STEEL, a sort of steel brought from the Levant, greatly esteemed for the manufacture of cutting instruments.

DAMPER, a sort of valve or sliding plate of iron, which, by being raised or depressed, increases or diminishes the draught in the flue of a furnace. The damper of the steam engine furnace is made to act by the pressure of the steam, in such a manner that when it becomes too strong the damper is lowered and the intensity of the fire diminished, and *vice versa*. See *Boiler*.

DATA; certain quantities for things which are given or known.

DATUM, the singular of data.

DEALS, planks or thin boards of fir. Deals of various kinds are sold by the wood merchants of various lengths and in breadth seldom exceeding nine inches, the thickness being three inches. A deal is cut into boards or leaves; those divided into two are called whole deal, into four slit deal, and into five cut stuff. Deals are made harder by being soaked in salt water for two or three days. White deal is employed for inside work, but the yellow deal is best adapted for work exposed to the weather. See *Fir*.

DECAGON, a plane geometrical figure of ten equal sides and angles. If the radius of a circle, or the side of the inscribed hexagon, be divided in extreme and mean proportion, the greater segment will be the side of a decagon inscribed in the same circle; or, to find the side of a decagon inscribed in a circle, multiply the radius by 0·118034, and the area of the polygon = square of one side $\times$ 7·694209.

DECANGULAR, having ten angles.

DEFINITION, a brief description of any thing by its properties.

DEFLECTIVE FORCES are those forces which act upon a moving body in a direction different from that of its actual course, in consequence of which the body is deflected, turned, or drawn aside from the direction in which it would otherwise move.

DEGREE, in geometry or trigonometry, is the 360th part of the circumference of any circle. The degree, according to the New French system, is the 400th part of the circumference. See *Angle*.

DENSITY is used as a term of comparison, expressing the proportion of the quantity of matter in one body to that in the same bulk of another body. It is, therefore, directly as the quantity of matter, and inversely as the magnitude of the body. The density of any body is directly as its weight and inversely as its magnitude; or the inverse ratio of the magnitudes of two bodies, having experimentally equal weights (in the same place), constitutes the ratio of their densities. No body is absolutely or perfectly dense; that is, no space is perfectly full of matter, so as to have no vacuity or interstices, or be destitute of pores.

DESCENT OF BODIES; see *Accelerated Motion* and *Inclined Plane*.

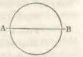
DETENT, something that locks or unlocks a movement; applied chiefly to clock work.

DIADROME, the swing of a pendulum.

DIAGONAL, in geometry, a right line drawn across a quadrilateral or other figure, whether plane or solid, from one angle to another. Every diagonal divides a parallelogram into two equal parts. Two diagonals in any parallelogram bisect each other. A line passing through the middle point of the diagonal of a parallelogram bisects the figure. The diagonal of a square is incommensurable with one of its sides. The sum of the squares of the two diagonals of every parallelogram is equal to the sum of the squares of the four sides. In any quadrilateral inscribed in a circle, the rectangle of the two diagonals is equal to the sum of the two rectangles under the two pairs of opposite sides. In every parallelopiped, the sum of the squares of the four diagonals of the solid is equal to the sum of the squares of its twelve edges.

DIAGRAM, a drawing made in order to explain geometrical properties.

DIAMETER, a line which, passing through a circle or other curvilinear figure, divides its ordinates into two equal parts. The diameter A B of a circle is to its circumference as 1 to 3·1416.



DIGESTER, a kind of boiler invented by M. Papin for raising water to a higher temperature than the common boiling point, 212°. This is effected by forming a vessel somewhat resembling a kitchen pot. The mouth is formed into a flat ring, so that a cover may be screwed tightly on; this cover is furnished with a safety valve, loaded to the required pressure.

DIGIT, a measure of length = ¾ of an inch.

DIMENSION, is either length, breadth, or thickness. A line has only one dimension, length; a surface two, length and breadth; and a body or solid, length, breadth, and thickness.

DIPLINTHIUS, a wall two bricks thick.

DIRECTION, QUANTITY OF; a term sometimes used to denote Momentum.

DIRECTLY, one body is said to impinge directly upon another, when the former strikes the latter perpendicular to its surface.

DIRECTRIX, in the conic sections, is a certain right line perpendicular to the axis of the curve. Also that line or plane along which another line or plane is supposed to move, in the generation of a surface or solid.

DISCHARGE OF FLUIDS. A knowledge of the quantity of water discharged through pipes and orifices, or over wears, is indispensible in the erection of hydraulic machines; and accordingly men of science have applied both to theory and experiment, in order to ascertain the laws of discharge under different circumstances. The following is a statement of the most useful results.

When an aperture is made in the bottom or side of a vessel containing water, such particles of fluid as are nearest the orifice will escape, and those immediately above them, together with the whole of the particles in the vessel, will descend in lines nearly vertical, until they arrive within three or four inches of the place of discharge, when they will acquire a direction more or less oblique, and make directly for the orifice; by which means the particles of the fluid have a tendency to converge to a point on the outside of a vessel, and the circumference of the issuing stream becomes much smaller than that of the orifice. This contraction reduces the area of the section of the discharged stream, at the distance of about half its diameter from the orifice, to about four-fifths of the orifice.

If the area of the cross section of the contracted vein be 100, then the breadth of the orifice to give that contraction will be according to different authors as follows :—

Sir Isaac Newton	141
Poleni	140
Bossut	150·6
Bernoulli	156
Du Buat	150
Michelotti	156
Venturi	158·5
Eytelwein	156·2

The quantity of water discharged is very nearly, but not quite, sufficient to fill this section with the velocity due, or corresponding to the height; for finding more accurately the quantity discharged, the orifice must be supposed to be diminished to 0·619, or nearly five-eighths.

The velocity of water flowing out of a horizontal aperture is as the square root of the height of the head of water; otherwise the pressure or the height is as the square of the velocity. By Bossut's experiments the velocities, with a pressure of 1, 4, and 9 feet, were 2722, 5436 and 8135 instead of 2722, 5444, and 8166, given by calculation. The velocity of the flowing water is equal to that of a heavy body falling from the height of the head of water, which is found very nearly by multiplying the square root of that height in feet by 8, for the number of feet described in a second. This is the theoretical velocity, but from the contraction of the stream we must multiply the square root of the height in feet by 5 instead of 8. Thus a head of 12 feet gives $\sqrt{12}$ $5 = 5\times3{\cdot}4641 = 17{\cdot}3205$ = velocity in feet per second. We subjoin tables by Bossut and Prony, exhibiting a comparison of theoretical and real discharges.

Constant weight of the water in the reservoir above the centre of the orifice.	Theoretical discharge through a circular orifice one inch in diameter.	Real discharges in the same time through the same orifice.	Ratio of the theoretical to the real discharges.
Paris Feet.	Cubic Inches.	Cubic Inches.	
1	4381	2722	1 to 0·62133
2	6196	3846	1 to 0·62073
3	7589	4710	1 to 0·62064
4	8763	5436	1 to 0·62034
5	9797	6075	1 to 0·62010
6	10732	6654	1 to 0·62000
7	11592	7183	1 to 0·61965
8	12392	7672	1 to 0·61911
9	13144	8135	1 to 0·61892
10	13855	8574	1 to 0·61883
11	14530	8990	1 to 0·61873
12	15180	9384	1 to 0·61819
13	15797	9764	1 to 0·61810
14	16393	10130	1 to 0·61795
15	16968	10472	1 to 0·61716

Constant height of the water in the reservoir above the centre of the orifice.	Theoretical discharges through a circular orifice one inch in diameter.	Real discharges in the same time by a cylindrical tube, one inch in diameter and two inches long.	Ratio of the theoretical to the real discharges.
Paris Feet.	Cubic Inches.	Cubic Inches.	
1	4381	3539	1 to 0·81781
2	6196	5002	1 to 0·80729
3	7589	6126	1 to 0·80724
4	8763	7070	1 to 0·80681
5	9797	7900	1 to 0·80638
6	10732	8654	1 to 0·80638
7	11592	9340	1 to 0·80573
8	12392	9975	1 to 0·80496
9	13144	10579	1 to 0·80485
10	13855	11151	1 to 0·80483
11	14530	11693	1 to 0·80477
12	15180	12205	1 to 0·80403
13	15797	12699	1 to 0·80390
14	16393	13177	1 to 0·80382
15	16968	13620	1 to 0·80270

According to Eytelwein—

Shortest tube that will cause the stream to adhere everywhere to its sides	1 to 0·8125
Short tubes, having their lengths from two to four times their diameters	1 to 0·82
Conical tube, approaching to the form of the contracted vein	1 to 0·92
The same tube, with its edges rounded off	1 to 0·98
A tube projecting within the reservoir	1 to 0·50

The contraction of the stream is by no means constant, but rises with the form and position of the orifice, the thickness of the plate in which the orifice is made, the form of the vessel, and the velocity of the issuing fluid.

It has been found that the quantities of fluid discharged in equal times from different sized apertures, the altitude of the fluid in the reservoir being the same, are to each other nearly as the area of the apertures, and the quantities of water discharged in equal times by the same orifice under different heads of water are nearly as the square roots of the corresponding heights of the water in the reservoir above the centre of the apertures; but, in consequence of friction, the smallest orifice discharges proportionally less water than those which are larger and of a similar figure, under the same heads of water; and also of those orifices whose areas are equal, that which has the smallest perimeter will discharge more water than the other, under the same altitudes of water in the reservoir; hence circular apertures are to be preferred. From a slight increase which the contraction of the vein undergoes, in proportion as the height of the fluid in the reservoir increases, the expenditure ought to be a little diminished in calculation. The discharge through a cylindrical horizontal tube, the diameter and length of which are equal to one another, is the same as through a simple orifice, but if the cylindrical horizontal tube be of greater length than the extent of the diameter, the discharge of water is much increased; and it has been found that the length of the cylindrical horizontal tube may be increased with advantage to four times the diameter of the orifice. The discharges by different additional cylindric tubes under the same head of water are nearly proportional to the areas of the orifices, and the discharges by additional cylindric tubes of the same diameter under different heads of water are nearly proportional to the square roots of the head of water. In general, the discharge during the same time, by different additional tubes, and under different heads of water in the reservoir, are to one another nearly in the compound ratio of the squares of the diameters of the tubes, and the square roots of the heads of water.

The discharge of fluids by additional tubes of a conical figure, when the inner to the outer diameter of the orifice is as 33 to 26, is augmented very nearly one-seventeenth and seven-tenths more than the discharge by cylindrical tubes: but when the enlargement is pushed too far, there is a tendency to produce an exterior contraction of the vein, and thus to make the circumstances of the case the same as in simple orifices, in which the discharges are the least possible.

From the experiments of M. Venturi it appears that if the part of the additional tube nearest the reservoir have the form of the contracted vein, the expenditure will be the same as if the fluid were not contracted at all; but if to the smallest diameter of this cone a cylindrical pipe be attached, of the same diameter as the least section of the contracted vein, the discharge of the fluid will, in a horizontal direction, be diminished. When the same tube is applied in a vertical direction, the expenditure will be augmented; so that the greater the length of the pipe the more abundant is the discharge of fluid. If the additional compound tube have another cone applied to the opposite extremity, the expenditure will, under the same head of water, be increased in the ratio of 24 to 10. In vertical tubes, the upper ends of which have the form of the contracted vein, the quantity discharged is that which corresponds with the height of the fluid above the inferior extremity of the tube. In compound conical tubes, the discharge of the fluid is increased in the proportion of the area of the section of the contracted vein, whatever may be the position of the tube, provided that its internal figure be adapted throughout to the lateral communication of motion; and, by varying the divergence of the sides of the tubes, the lateral communication of motion has a minimum of effect when the angle made by the sides of the tube with each other exceeds sixteen degrees, and a maximum effect when the same angle is about three degrees.

From the experiments of M. Venturi, the height of water in the reservoir being 32·5 inches, he found that a cylindrical horizontal tube, having the conical end of the form of the contracted vein, with a diameter 14.5 lines and length 15 inches—and another cylindrical curved tube, having a conical end similar to the last, of the same diameter and length, and another cylindrical angular tube, having a conical end similar to the two preceding, also of the same diameter and length—their several discharges of cubic feet (Paris) were hence made in 4550 and 70 seconds; hence it is very evident that angles ought to be as much as possible avoided.

Let V be the velocity of the water in the pipe, S the sine of the angle of bending, and N the number of bendings, then

$$\frac{V^2 \times S^2 \times N}{300}$$

will be the measure of the resistance.

Comparison of the discharge by conduit pipes of different lengths, 16 lines in diameter, with the discharge by additional tubes inserted in the same reservoir.

Constant altitude of the Water above the centre of the aperture.	Length of the conduit pipe.	Quantity of Water discharged in a minute.		Ratio between the quantities furnished by tube and pipe.
		by additional tube, 16 lines in diameter.	by conduit pipe, 16 lines in diameter.	
Feet,	Feet,	Cubic Inches,	Cubic Inches,	
1	30	6330	2778	100 to 43·39
1	60	6330	1957	100 to 30·91
1	90	6330	1587	100 to 25·07
1	120	6330	1351	100 to 21·34
1	150	6330	1178	100 to 18·61
1	180	6330	1052	100 to 16·62
2	30	8939	4066	100 to 45·48
2	60	8939	2888	100 to 32·31
2	90	8939	2352	100 to 26·31
2	120	8939	2011	100 to 22·50
2	150	8939	1762	100 to 19·71
2	180	8939	1583	100 to 17·70

Comparison of the discharge by conduit pipes of different lengths, 24 lines in diameter, with the discharge by additional tubes inserted in the same reservoir.

Constant altitude of the Water above the centre of the aperture.	Length of the conduit pipes.	Quantity of Water discharged in a minute.		Ratio between the quantities furnished by tube and pipe.
		by additional tube, 24 lines in diameter.	by conduit pipe, 24 lines in diameter.	
Feet,	Feet,	Cubic Inches,	Cubic Inches,	
1	30	14243	7680	100 to 53·92
1	60	14243	5564	100 to 39·06
1	90	14243	4534	100 to 31·83
1	120	14243	3944	100 to 27·69
1	150	14243	3486	100 to 24·48
1	180	14243	3119	100 to 21·90
2	30	20112	11219	100 to 55·78
2	60	20112	8190	100 to 40.72
2	90	20112	6812	100 to 33.87
2	120	20112	5885	100 to 29.26
2	150	20112	5232	100 to 26.01
2	180	20112	4710	100 to 23.41

The following are the results of Bossut's experiments on the ratio of the initial and final velocities of fluids in pipes:—

Leaden pipe 50 *feet in length and* 12 *lines in diameter.*

			Ratios.
Rectilineal horizontal pipe,			
	The altitude of water,	4 inches,	100 to 3·55
		1 foot,	100 to 3·18
Ditto, with several horizontal flexures,			
	The altitude of water,	4 inches,	100 to 3·78
		1 foot,	100 to 3·43
Ditto, with several vertical flexures,			
	The altitude of water,	4 inches,	100 to 3·93
		1 foot,	100 to 3·44

Pipe of cast iron 180 *feet in length and* 16 *lines in diameter.*

Rectilinear horizontal pipe,

	The altitude of water,	1 foot,	100 to 6·01
		2 feet,	100 to 5·64

Pipe of cast iron 180 *feet in length and* 24 *lines in diameter.*

Rectilinear horizontal pipe,

	The altitude of water,	1 foot,	100 to 4·57
		2 feet,	100 to 4·27

Pipe of cast iron 118 *feet in length and* 16 *lines in diameter.*

Rectilinear inclined pipe, so that its length is to the depression as 2124 is to 241,

The altitude of water, 13 ft., 4 in., 8 lines, 100 to 4.

Pipe of cast iron 159 *feet in length and* 16 *lines in diameter.*

Rectilinear inclined pipe, so that its length is to the depression as 2124 is to 241,

The altitude of water, 6 ft., 8 in., 4 lines, 100 to 2·82

Pipe of east iron 177 *feet in length and* 16 *lines in diameter.*

Rectilinear inclined pipe, so that its length is to the depression as 2124 is to 241,

The altitude of the water, 20 ft., 11 in., 100 to 5·

Conduit pipe, almost entirely of iron, 1782 *feet in length and* 48 *lines in diameter.*

With several vertical and horizontal flexures,

The altitude of the water,	9 inches,	100 to 28·5
	1 foot, 9 inches,	100 to 26·53
	2 feet, 7 inches,	100 to 25·79

Conduit pipe, almost entirely of iron, 1710 *feet in length and* 72 *lines in diameter.*

With several vertical and horizontal flexures,

The altitude of the water, 3 inches, ... 100 to 12·35
5 inches, 3 lines, 100 to 11·37

Conduit pipe, partly stone and partly lead, 7020 *feet in length, and* 60 *lines in diameter.*

With several vertical and horizontal flexures,

The altitude of the water, 5 inches, 7 lines, 100 to 23·10
11 inches, 4 lines, 100 to 20·98
1 foot, 4 inches, 9 lines, 100 to 19·49
1 foot, 9 inches, 1 line, 100 to 18·78
2 feet, 1 inch, ... 100 to 18·46

Conduit pipe of iron, 3600 *feet in length and* 144 *lines in diameter.*
With several vertical and horizontal flexures,

The altitude of the water, 12 ft., 1 in., 3 lines, 100 to 10·08

Conduit pipe of iron, 3600 *feet in length and* 216 *lines in diameter.*
With several vertical and horizontal flexures,

The altitude of the water, 12 ft., 1 in., 3 lines, 100 to 6·05

Conduit pipe of iron, 4740 *feet in length and* 216 *lines in diameter.*
With several vertical and horizontal flexures,

The altitude of the water, 4 ft., 7 in., 6 lines, 100 to 10·11

Conduit pipe of iron, 14040 *feet in length and* 144 *lines in diameter.*
With several vertical and horizontal flexures,

The altitude of the water, 20 ft., 3 in., 100 to 19·34

Hence we may conclude that the less the diameter of the pipe is the less proportionally is the discharge of fluid, and also the greater the length of conduit pipe the greater the diminution of discharge; and the discharges in equal times by horizontal pipes of different lengths, but of the same diameter, and under the same head of water, are to one another inversely as the square roots of the lengths. In order to have a perceptible and continuous discharge of fluid, the altitude of the water in the reservoir, above the axis of the conduit pipe, must not be less than $1\frac{2}{12}$ inches for every 180 feet of the pipe's length.

The discharge by vertical pipes is augmented the greater the length of the pipe is; and a pipe which is considerably inclined will discharge in a given time a greater quantity of water than a horizontal pipe of the same diameter and length; wherefore the greater the angle of inclination the greater the discharge of fluid. When the angle of the conduit pipe is 6° 31′, or the depression of the lower extremity of the pipe is one-eighth of its length, the discharge of fluid is the same as by an additional horizontal tube of the same diameter.

A curvilinear pipe, the altitude of the water in the reservoir being the same, discharges less water when the flexure lies horizontally than a rectilinear pipe of the same diameter and length; and is still further diminished when the flexures lie in a vertical instead of a horizontal plane. When there is a number of contrary flexures in a large pipe, the air sometimes lodges in the highest parts of the flexures, and retards the motion of the water; which may be prevented by air-holes, or stop-cocks, which can be shut when the motion of the water is perfectly established.

Respecting this discharge by wears and rectangular notches it may suffice to state that the quantity of water discharged may be found by taking two-thirds of the velocity due to the mean height, and allowing for the contraction of the stream according to the form of the opening.

The discharge from reservoirs with lateral orifices of considerable magnitude, with a constant head of water, may be found by determining the differences in the discharge by two open orifices of different heights; or with nearly equal accuracy, by considering the velocity due to the distance of the centre of gravity of the orifice below the surface. For the discharge from prismatic reservoirs receiving no supply of water all the supplies may be calculated from the general law that twice as much would be discharged from the same orifice if the vessel were kept full during the time which is required for its emptying itself. Where the form is less simple, the calculations become intricate, and are of little importance.

The discharge through an orifice between two reservoirs, below the surface, is the same as if the water ran into the open air; and thus may be calculated the discharge, when the water has to pass through several orifices in the sides of as many reservoirs open above. In such cases, where the orifices are small, the velocity in each may be considered as generated by the difference of the heights in the two contiguous reservoirs, and the square root of the difference will therefore represent the velocity; which must be in the several orifices, inversely as their respective areas. Mr Ethelyn, in considering the case of a lock which is filled from a canal of an invariable height, determines the time required by comparing it with that of a vessel emptying itself by the pressure of the water that it contains, observing that the motion is retarded, in both cases, in a similar manner.

Disengagement and Engagement of Machinery. In all the contrivances for putting in and out of gear, the great object to be avoided is suddenness of change, which would endanger the machinery. All the contrivances that have been invented for this purpose may be arranged into two classes; those which act by bands, belts, or chains, and those which act by wheel work. Of the first description is the fast and loose pulley; one of the simplest, and, where applicable, one of the best methods of connecting or disconnecting machinery with the moving power. Two pulleys are placed upon the shaft by which the motion is to be transmitted, the one pulley being firmly fixed and the other loose, so that it may be easily turned round while the shaft remains at rest, or *vice versa*. A belt is made to pass over either of the pulleys, being led from a drum revolving on one of the main shafts driven by the first mover. The belt may be placed by means of a forked guide, either on the fast or loose pulley; if on the fast, the shaft, and consequently the machine will move; but if on the loose pulley the machine will remain at rest. See *Coupling Gland* and *Shaft*.

Divisibility, that quality of a body by which it admits of separation into parts. Some contend that this separation may be carried on *ad infinitum*, while others contend that it cannot be extended beyond certain limits. To the metaphysical divisibility there unquestionably is no end, but in the real division there is always a limit. An ounce of silver may be gilt with eight grains of gold, which may be afterwards drawn into a wire 13000 feet long.

In odoriferous bodies we can still perceive a greater subtilty of parts, and even such as are actually separated from one another; several bodies are scarcely observed to lose any sensible part of their weight in a long time, and yet continually fill a very large space with odoriferous particles.

The particles of light, if light consists of particles, furnish another surprising instance of the minuteness of some parts of matter. A lighted candle placed on a plane will be visible two miles, and consequently fill a sphere whose diameter is four miles with luminous particles before it has lost any sensible part of its weight. And as the force of any body is directly in proportion to its quantity of matter multiplied by its velocity, and since the velocity of the particles of light is demonstrated to be at least a million times greater than the velocity of a cannon ball, it is plain that if a million of these particles were round, and as big as a small grain of sand, we durst no more open our eyes to the light than to expose them to sand shot point blank from a cannon.

By help of microscopes, such objects as would otherwise escape our sight appear very large. There are some small animals scarcely visible with the best microscopes, and yet these have all the parts necessary for life, as blood and other liquors.

Dodecagon, a regular polygon of twelve equal sides and angles. To inscribe one in a circle: apply the radius of the circle six times round the circumference, which will divide it into six equal parts; then bisect

M 3

each of those parts and join the points. To find the area, multiply the side squared by 11·19615.

DODECAHEDRON, one of the regular Platonic bodies, comprehended under twelve equal sides or faces, each of which is a regular pentagon. To find the surface and solidity of a dodecahedron, the side of one of its equal faces being given, let s represent the given side, then will surface $= 20{\cdot}64577852 \times s^2$, and solidity $= 7{\cdot}66311896 \times s^3$.

DOME, in architecture, is a roof or vault, rising from a circular elliptical, or polygonal base or plan; with a convexity outwards or a concavity inwards, so that all the horizontal sections made by planes will be similar figures round a vertical axis. Domes, are called polygonal, circular, or elliptic domes according to the figure of the base. Circular domes are of several kinds, as spherical, spheroidal, or ellipsoidal, hyperboloidal, paraboloidal, &c. according to the figure of the vertical section. Domes that rise higher than the radius of the base are called surmounted domes, and those which rise less than this dimension are termed diminished or surbased domes.

For the purpose of measuring the area of a dome, if A be a circular dome, call A C the diameter, B D the height, and B A the distance between the vertex and one of the ends of the diameter, which last is called the sectorial radius; then $BA^2 \times 3{\cdot}1416$ = area of surface. If the dome be a frustum, then find the area of the entire segment of the sphere, and then of the part cut off, and subtract the one from the other.

DRACHM, or DRAM, the eighth part of an ounce in apothecaries' weight, and the sixteenth part of an ounce avoirdupois.

DRILLING the act of boring small holes. Drilling may be effected in a lathe: the drill is screwed upon the spindle, so that its point shall turn exactly opposite that of the screw in the shifting head. The piece to be drilled is then slightly pierced with a punch, where the drilling is to commence and also where it is intended to come out. Against the latter puncture the point of the screw in the fixed head is directed, and gradually pressed forward as the drill, on turning the wheel, is found to cut. The motion of the wheel must be slow, especially for iron. The rest, or any temporary support, may be used to keep the work steady. Small drills, used by clock-makers and others, are made of a single piece of steel wire, upon which, about the middle, a pulley or drill barrel is driven. Sometimes a shank or small mandrel is used, with a square hole about half an inch deep at the end of it, into which drill bits of various sizes can be alternately inserted. The disadvantage of this construction is, that the drill bit is seldom held true, which causes it to perform indifferently. These small drills are held horizontally, and pressed against the work by a breast piece made either of wood or sheet iron; but, in either case, is rather concave on its inside, to rest more steadily upon the breast, and in the centre of the outside is fixed a bit of steel for the blunt end of the drill to work in. The drill is turned by drawing backwards and forwards an elastic bow, the string of which is coiled once round the pulley. The best bows are made of steel, and the strings of catgut; the strength of which must be proportioned to the size of the drill. A piece of stout cane, or whalebone, makes a good substitute for a steel bow. To make large holes, a brace, not very unlike that used by joiners, is employed, and the drill is fitted as a bit; but instead of the stock which in the joiner's tool remains stationary while the rest is turning, there is a long tapering spindle, which, being a continuation of the brace, is necessarily carried round at the same time. The upper end of the spindle works in an iron or steel plate, which is fixed on the under side of a beam called the drill beam. One end of the beam turns upon a transverse pin between two uprights, pierced with various holes, to fix it at different elevations; the other end, which is pressed down by a weight, passes, when great steadiness is wanted, between two other uprights. The vertical part of the crank, by which the hand revolves the drill, ought to be very smooth, or, what is still better, it may be covered with a loose handle.

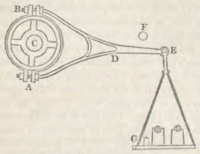
Drills ought to be made of the best steel, and the cutting part only should be hard; they are therefore, tempered by keeping the lower end out of the fire, but heating the rest considerably, till the point attains the desired colour, when it is instantly cooled in the usual manner. By this means, the cutting part of the bit may be tempered to a straw colour, while the rest is not higher than blue, so that its liability to break when in use, is greatly diminished. In drilling, forged iron and steel require oil, but to brass and cast iron none must be used. For brass, also, the drill bit is made thinner, harder, and the cutting edge formed by a more acute angle than for iron. Small drills, such as those used by clock makers, are brought to the proper temper by holding the point in the flame of a candle until it acquires a white heat, and then cooling it in the tallow of the candle.

Drum, a hollow cylinder fixed on the axis of a main shaft, having a belt passing round it, in order to communicate motion to subordinate machinery.

Ductility, a property of bodies analagous to malleability, by which they may be drawn out into wire without breaking. See *Wire*.

Dynamics is that branch of mechanics which treats of bodies in motion, and of the quantity and direction of the moving forces. When solid bodies in motion are considered, the simple term *dynamics* is used; but when our inquiries are directed to fluids in motion, the term *hydro* (water) is prefixed; hence *hydrodynamics*: and, in like manner, if we discuss the circumstances of aeriform or gaseous fluids, the science might be called *pneumadynamics*. Sec *Force* and *Motion*.

DYNAMOMETER. Instruments for measuring the relative strength of men and animals, as also the form of machinery are so called. The accompanying cut represents a very simple dynamometer, for measuring the force of machinery, A E B is a lever made of steel, having two spreading branches D A, D B, capable of being fixed on the circumference of a pulley by means of the pinching screws A and B. This pulley is firmly fixed on the end of the shaft C, so as to revolve with it. The pulley revolving in the direction A B, would carry the lever round with it, and the end E would revolve also, but it is checked by the pin F fixed in the wall. But there is a scale G attached to the end E of the lever, into which weights are put in order to weigh down the lever so that it will not rise to the pin F. When the pulley continues to revolve, and has power sufficient to keep the lever nearly touching the pin F, then the weights in the scale will indicate the mechanical effect.

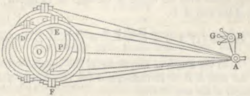


E

EBONY is an exceedingly hard and heavy kind of foreign wood, of a very smooth even grain, susceptible of a remarkably fine polish, and on that account used in mosaic and inlaid works, for toys, &c. It is of various colours, most usually black, brown, red, and green. The black is the kind most generally known, and preferred to that of other colours. The best is a jet black, free from veins and rind, very massive, astringent, and of an acrid pungent taste. Ebony is not in so much demand as formerly, from the improvements which have been made in giving other hard woods, especially the holly, a black colour. It is used for parallel rulers, and other mathematical instruments not requiring to be marked with figures, which the darkness of its colour would prevent from being distinctly seen.

ECCENTRIC, or EXCENTRIC, literally means out of the centre. In geometry, two circles, rings, or spheres, one of which is either wholly or partially contained within the other, but whose centres are not in the same point. In mechanics, the term eccentric is applied to a simple contrivance whereby variation in the direction and velocity of motion is effected. Camms moved by revolving wipers belong to the class eccentric.

The usual form of the eccentric wheel for working the valves of a steam engine is shown in the annexed figure. O is the end of



the shaft, P the centre of a wheel fixed on that shaft, so that the centre or axis of the shaft shall be at a given distance from the centre of the wheel. A brass ring is placed loosely, but not so as to shake, in the circumference of the wheel, to which ring the rods E A, F A are firmly attached. These arms unite at A, being formed into an eye through which a pin passes, connecting them to the lever A B. It is plain that as the shaft O turns upon its axis the wheel whose centre is P will be turned round with it, and the rods attached to the ring upon its circumference will be drawn backwards and forwards so as to move the end A and give an alternating motion to the line A B. To construct an eccentric wheel Messrs Hans and Dodds give the following directions in their useful treatise on mechanics.

From the centre of the shaft O take O P equal to half the length of the stroke which you intend the wheel to work; and from P as a centre, with any radius greater than P D, describe a circle, and this circle will represent the required wheel. For every circle, drawn from the centre P, will work the same length of stroke, whatever may be its radius; as, whatever you increase the distance of the circumference of the circle from the centre of motion on the one side, you will have a corresponding increase on the opposite side equal to it. Thus, suppose an eccentric wheel to work a stroke of 18 inches is required, the diameter of the shaft being six inches; and if two inches be the thickness of metal necessary for keying it on to the shaft, then set off, from O to P, nine inches; and $9 + 5 = 14$ inches, the radius of the wheel required. Let S represent the space the end A is moved through by the eccentric wheel, and s the space the slide moves; then $A B \times s = B C \times S$; and this equation, solved for A B, B C, S, and s, gives the following :—

$$A\,B = \frac{B\,C \times S}{s} \;(1) \qquad S = \frac{A\,B \times s}{B\,C} \;(3)$$

$$B\,C = \frac{A\,B \times s}{S} \;(2) \qquad s = \frac{B\,C \times S}{A\,B} \;(4)$$

Ex. 1. Given the length of the stroke of the slide = 8 inches, the length of the arm B C = 4 inches, and the distance of the centre of the eccentric wheel from the centre of the shaft = 10 inches; required the length of the arm A B.

By formula (1) $A\,B = \frac{B\,C \times S}{s} = \frac{4 \times 20}{8} = 10$ inches.

Ex. 2. Given the length of the stroke of the slide = 4 inches, the length of the arm A B = 10 inches, and the eccentricity 6 inches, to find the length of the arm B C.

By formula (2) $B\,C = \frac{A\,B \times s}{S} = \frac{10 \times 4}{12} = 3\frac{1}{3}$ inches.

Edge Railway, the kind of railway now most approved of for steam carriages. The rails may be made either of cast iron or wrought iron: when the former is used, the top of the rail is made convex, and the wheels are kept on the rail by flanges; when wrought iron is used the rail is made of a wedge shape. See *Railway*.

Elasticity, that property of bodies whereby they regain their original form after being compressed or extended. Springs act by reason of this force. The measure of the elastic force of any substance is called its *modulus* of elasticity; or the modulus of elasticity of any body is a column of that substance capable of producing by its weight a degree of compression on the base which is to the weight causing a certain degree of compression as the length of the body is to the compression. Wherefore the modulus of elasticity is found by multiplying the length when compressed by the length before compression, and dividing the product by the force that produced the compression.

When a force is applied to an elastic column of a rectangular prismatic form in a direction parallel to the axis, the parts nearest to the line direction of the force exert a resistance in an opposite direction; those particles which are at a distance beyond the axis, equal to a third proportional to the depth, and twelve times the distance of the line of direction of the force, remain in their natural state; and the parts beyond them act in the direction of the force.

Of the principal kinds of timber employed in building and carpentry, the annexed table will exhibit their respective modulus of elasticity, and the portion of it which limits their cohesion, or which lengthwise would tear them asunder.

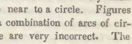
Teak	6,040,000 feet	168th.
Oak	4,150,000 —	144 -
Sycamore	3,860,000 —	108 -
Beech	4,180,000 —	107 -
Ash	4,617,000 —	109 -
Elm	5,680,000 —	146 -
Memel Fir	8,292,000 —	205 -
Christiana Deal	8,118,000 —	196 -
Larch	5,096,000 —	121 -

The modulus of the elasticity of hempen fibres may be reckoned about 5,000,000 feet. The metals differ more widely from each other in their elastic force than the several species of wood or vegetable fibres. English malleable iron has 7,550,000 feet for its modulus of elasticity, or the weight of 24,920,000 lb. on the square inch, while cast iron has 5,895,000 feet and 18,421,000 lb. Of other metals the modulus of elasticity is probably smaller, but has not yet been well ascertained.

ELASTIC FLUIDS are those which are possessed of an elastic property, as air, steam, &c.—See *Steam*.

ELEVATION, the representation of a machine, building, &c., drawn on a plain perpendicular to the horizon.

ELLIPSE, or ELLIPSIS, improperly called an oval, one of the conic sections, being that formed by a plane passing through the cone in any other direction than at right angles to the base, or parallel to one of the sides. There are various methods of describing the ellipse upon a plane surface; sometimes it is performed by an instrument called the elliptagraph, the bent form of which is that invented by Mr Farrey, of which a description will be found in the article *Drawing Instruments* in the Edinburgh Encyclopedia. Another instrument, called the trammel, is more commonly used, but it is very defective, as it will neither draw very small ellipses nor such as approach in curvature near to a circle. Figures resembling ellipses are frequently made by a combination of arcs of circles taken from different centres, but these are very incorrect. The simplest method of drawing an ellipse is by using two pins and a string. At a given distance, equal to the required eccentricity of the ellipse, place two pins, A and B, and pass a string, A C B, round them; keep the string stretched by a pencil or tracer, C, and move the pencil along, keeping the string all the while equally



tense, then will the ellipse C G L F H be described. A and B are the foci of the ellipse, D the centre, D A or D B the eccentricity, E F the principle axis or longer diameter, G H the shorter diameter, and if from any point L in the curve a line be drawn perpendicular to the axis, then will L K be an ordinate to the axis corresponding to the point L, and the parts of the axis E K, K F into which L K divides it are said to be the abscissæ corresponding to that ordinate.

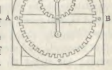
ELM is a very tough, pliable kind of wood, and the best kinds of it are very hard: it does not readily split, and bears the driving of bolts and nails into it better than any other wood. It is used for making axle-trees, mill wheels, keels of boats, water pipes, chairs, and coffins. It is frequently changed by art, so as to make an excellent resemblance of mahogany. For this purpose planks of it are stained with aquafortis, and rubbed over with a tincture of which alkanet roots, aloes, and spirit of wine are the principal ingredients.

ENTABLATURE, that part of a column over the capital comprehending the architrave, frieze, and cornice. It also denotes the row of stones on the top of a wall on which the timber and covering rests.

EPICYCLOID, a curve generated by a point in one circle, which revolves about another circle, either on the convacity or convexity of its circumference. Exterior epicycloids are those which are formed by the revolution of the generating circle about the convex circumference of the quiescent circle. Interior epicycloids are those that are formed when the generating circle revolves on a concave circumference.

To these curves belong several curious properties, of which we shall only mention a few of the most remarkable. If the generating and quiescent circle have to each other any commensurable ratio, then is the epicycloid both rectifiable and quadrable, although the area of the common cycloid, which is so much more simple in appearance, can never be completely obtained. If the generating and quiescent circle are incommensurable with each other, then the area of the epycloid cannot be found, but it is still in this case also rectifiable. If in the interior epycycloid the diameter of the generant is equal to the radius of the quiescent circle, the curve becomes a right line, equal and coincident with the diameter of the latter.

EPICYCLOIDAL WHEEL. A very beautiful method of converting circular into alternate motion, or alternate into circular, is shown in the annexed cut. A B is a fixed wheel, toothed on its inner side. C is a toothed wheel of half the diameter of the ring, revolving about the centre of the ring. While this revolution of the wheel C is taking place, any point whatever on its circumference will describe a straight line, or will pass and repass through a diameter of the circle once during each revolution; and thus a piston rod, or other reciprocating part, may be attached to any point on the circumference of the wheel C.



Equable Motion. See *Uniform Motion.*

Equiangular figures are those whose angles are equal; as the square and all regular figures. All equilateral triangles are also equiangular. An equilateral figure, inscribed in a circle, is always equiangular; but an equiangular figure inscribed in a circle is not always equilateral, except when it has an odd number of sides. If the number of the sides be even, then they may be either all equal, or else half of them will always be equal to each other, and the other half to each other; the equals being placed alternately. Equiangular is also applied to any two figures of the same kind, when each angle of the one is equal to a corresponding angle in the other, whether each figure, separately considered, be an equiangular figure or not.

Equilibrium means an equality of forces acting in opposite directions, whereby the body acted upon remains at rest, or in *equilibrio;* in which state, the least additional force being applied on either side, motion will then ensue. A body in motion is also said to be in equilibrio when the power producing the motion, and the force whereby it is resisted, are so adjusted that the motion may be uniform.

Escapement, that part of a clock or watch movement which receives the force of the spring or weight, to give motion to the pendulum or balance. See *Scapement.*

Evaporation, the conversion of water or any other fluid into vapour, which, in consequence of its becoming lighter than the atmosphere, is carried above the earth's surface.—See *Heat* and *Steam.*

Evolute, a curve formed by the end of a thread unwound from another curve, the radius or curvature of which is constantly encreasing. The evolute of the cycloid is another equal cycloid, which property was first discovered by Huygens, who by this means contrived to make a pendulum vibrate in a cycloidal arc, by placing it between two cycloidal cheeks, and thus rendered the vibrations isochronous.

Expansion, in physics, is the enlargement or increase in the bulk of bodies, in consequence of a change in their temperature. This is one of the most general effects of caloric being common to all bodies whatever, whether solid or fluid. The expansion of solid bodies is shown by the pyrometer, and the expansion of fluids by the thermometer. The expansion of fluids varies very considerably; but in general the denser the fluid the less the expansion: for instance water expands more than mercury, and spirits of wine more than water; and commonly the greater the degree of heat the greater is the expansion; but this is not universal, for there are cases in which expansion is produced, not by an increase but by a diminution of temperature. Water furnishes us with the most remarkable instance of this kind; its maximum of density corresponds with 39° of Fahrenheit's thermometer.

Expansion Engines. The steam which impels an engine is always diminished in volume, by the resistance which it has to overcome, and tends naturally to occupy a larger space than that to which it is confined while the engine is at work. If it be dismissed into the air, or into the condenser, while under its greatest working pressure, it will not have produced all the useful effect which it is capable of affording. The expansive power of steam may be converted to use in various ways, and most of the common forms of the steam engine may be made to act expansively by a proper arrangement of their valves. In Watt's engine, this effect is produced by cutting off the steam from the cylinder before the stroke of the piston is completed, leaving it to the steam already in the cylinder to assist by its expansion in completing the stroke. The steam in the boiler being thus intercepted, acts only at intervals. Nevertheless, its whole disposable force is accumulated in the fly wheel, while at the same time the force arising from the expansion of steam in the cylinder serves to increase the total amount. A great augmentation is thus produced in the useful effect of an engine, with the same amount of fuel and water. Mr Hornblower, who was one of the first inventors of the application of expansive steam, employed two cylinders having their pistons connected to the same beam. In the smaller of these, the steam was used at full pressure, after which it was discharged into the larger cylinder, where it again acted by its expansive force. This method affords a more equable mode of applying the expansive force of steam than that used by Mr Watt, but the engine is more complex and expansive. Mr Woolf afterwards adopted the plan of two cylinders with the addition of using his steam at high pressure, together with a condenser. He appears to have exaggerated the expansive force of steam, at high temperatures, as various other projectors have done. His engines, however, continue to be used and approved in some parts of England and Wales. See *Valve Expansion.*

Experimental Philosophy, that system of philosophy which is founded upon the results of various experiments, which thus furnish certain data that are assumed as the unalterable laws of nature, and on which finally rest every branch of modern philosophical investigation.

Extension is one of the general and essential properties of matter, the extension of a body being the quantity of space which it occupies, the extremities of which limit or circumscribe the body. It is otherwise called the magnitude or size of the body. The word extension, however, is commonly used to denote the surface of a body only without regard to its thickness.

Exterior Angle, that which is formed by producing the sides of a figure. The sum of all the exterior angles of any right-lined plane figure are equal to four right angles. The exterior angle of a triangle is equal to the sum of the two internal angles; and in any figure whatever the sum of the external angles is equal to four right angles.

F

FANNERS, vanes or flat discs revolving rouud a centre, so as to produce a current of air.

FEED PIPE, a part of the apparatus of the boiler of a steam engine for keeping up a regular supply of water. It consists of a long vertical pipe, whose lower extremity is below the surface of the water in the boiler, and whose upper extremity terminates in a small cistern at a considerable height above the boiler. The cistern *s* (see fig. 1 under the article *Boiler* in this dictionary) is supplied with water by a pipe worked by the engine, and the top of the feed pipe *u v v*, which terminates in the cistern is a valve opening downwards, which valve is attached to a small rod fixed to the lever *ss*. This lever rests upon a fulcrum on the edge of the cistern, and to one end of it is attached a long vertical rod which passes through a stuffing box, or steam-tight opening in the top of the boiler, and carries a large stone float, *p*, at the bottom. The other end of the lever, *s s*, carries a weight, *q*, which acts as a counterpoise to the stove *p*. When the water in the boiler, by evaporation, becomes lower in the surface than the level at which it is required to be, the stone float *p* descends with the fluid and lowers the end of the lever *s s*, to which its rod is attached. This, by moving the lever at the top, opens the valve at the bottom of the cistern, and water falls in until the stone float, by rising to the proper height, again shuts it. The feed pipe also contains the apparatus for regulating the damper. A cylindrical vessel is contained within the feed pipe, suspended from a chain that passes over two pulleys and is connected with the damper at the other end. When the clasticity of the steam becomes too great in the boiler it presses upon the surface of the water and forces it up the feed pipe; and, by raising the cylinder, depresses the damper, and thus lessens the intensity of the fire: hence the elastic force of the steam soon becomes diminished. The slightest reflection will show that the feed pipe must increase in height proportional to the elastic force of the steam generated in the boiler. The principal circumstance to be attended to in the construction of this apparatus is to make the height of the water in the cistern sufficient to balance the strength of the steam.

To find the height of a column of water necessary to feed a boiler raising steam of a given pressure, multiply the pressure of the steam in lbs. per square inch by 2·5, the product is the height of the column of water, or the length of the feed pipe. Thus if the clasticity of the steam in lbs. per square inch above the atmosphere pressure, then $3{\cdot}5 \times 2{\cdot}5$

× 8·75 feet = the height of the feed pipe above the surface of the water in the boiler.

FILE, a well known steel instrument, having teeth on the surface for cutting metal, ivory, wood, &c. When the teeth of these instruments are formed by a flat sharp-edged chisel, extending across the surface, they are properly called files; but when the tooth is formed by a sharp-pointed tool, in the form of a triangular pyramid, they are termed rasps. The former are used for all the metals harder than lead or tin, and the latter for the softer metals, ivory, bone, horn, and wood. When the teeth of files are a series of sharp edges, raised by the flat chisel, appearing like parallel furrows, either at right angles to the length of the file or in an oblique direction, the files are termed single cut; but when these teeth are crossed by a second series of similar teeth they are said to be double cut. The first are fitted for brass and copper, and are found to answer better when the teeth run in an oblique direction. The latter are suited for the harder metals, such as cast and wrought iron and steel, Each tooth presents a sharp angle to the substance, which penetrates the substance, while the single cut file would slip over the surface of these metals. The double cut file is less fit for filing brass and copper, since the teeth would be very liable to be clogged with the filings. Files are called by different names, according to their various degrees of fineness. Those of extreme roughness are called rough; the next to this is the bastard cut; the third is the second cut; the fourth the smooth; and the finest of all the dead smooth. The very heavy square files used for heavy smith work are sometimes a little coarser than the rough, called rubbers.

Files are also distinguished by their shape, as flat, half-round, three-square, four-square, and round. The first are sometimes of uniform breadth and thickness throughout, and sometimes tapering; the cross section is a parallelogram. The half-round is generally tapering, one side being flat and the other rounded; the cross section is a segment of a circle, varying a little for different purposes, but seldom equal to a semi-circle. The three-square generally consists of three equal sides, mostly tapering; those which are not tapering are used for sharpening the teeth of saws. The four square has four equal sides, the section being a square. These files are generally thickest in the middle, as is the case with the smith's rubber. In the round file the section is a circle, and the file generally conical. The heavy and coarser kind of files are made from the inferior marks of blistered steel. That made from the Russian iron, known by the name of old sable, and also called from its mark, C C N D, is an excellent steel for files. Some of the Swedish irons would doubtless make the best file steel, but their high price would be objectionable for heavy articles. The steel intended for files is more highly converted than for other purposes, to give the files proper hardness; but if the hardness is not accompanied with a certain degree of tenacity the teeth of the file break, and do but little service. Small files are mostly made of cast steel, which would be the best for all others if it were not for its higher price. It is much harder than the blistered steel; and, from having been in the fluid state, is entirely free from those seams and loose parts so common to blistered steel, which is not sounder than as it came from the iron forge before conversion. The smith's rubbers are generally forged in the common smith's forge, from the converted bars, which are, for convenience, made square in the iron before they come into this country. The files of lesser size are made from bars or rods, drawn down from the blistered bars and the cast ingots, called tilted steel.

The file-maker's forge consists of large bellows, with coak as fuel. The anvil block is one large stone of millstone slab. This anvil is of considerable size, set into and wedged fast in the stone; it has a projection at one end, with a hole to contain a sharp-edged tool for cutting the files from the rods. It also contains a deep groove for containing dies or bosses for giving particular forms to the files. The flat and square files are formed entirely by the hammer; one man holds the hot bar, and strikes with a small hammer; another stands before the anvil with a two-handed hammer; the latter is generally very heavy, with a broad face for the large files. They both strike with such truth as to make the surface smooth and flat, without what is called hand-hammering. This arises from their great experience in the same kind of work. The half-round files are made in a boss fastened into the groove above-mentioned. The steel being drawn out is laid upon the rounded recess, and hammered till it fills the die. The three-sided files are formed similarly in a boss, the recess of which consists of two sides, with the angle downwards. The steel is first drawn out square, and then placed in the boss with an angle downwards, so that the hammer forms one side and the boss two. The round files are formed by a swage similar to those used by common smiths, but a little conical.

The whole of the working part of the file is formed and finished with the hammer before it is cut off from the rod; the finished part is then held in tongs, and heated a second time to form the tang of the file: the very square shoulder formed by the tang of a file does not seem easy to form by the hammer; this is effected by first placing the file upon a sharp-edged tool, standing with its edge upwards in the anvil; a notch is now made on each side where the tang commences; it is then brought to the front edge of the anvil, and, by an acquired dexterity, the tang is drawn out without touching the shoulder with the hammer. In order to prepare the files for cutting, they require to have the surface perfectly metallic, smooth, and as even as possible. Tho state, however, in which the files leave the hammer is too hard for the dressing and cutting. The first thing to be done, therefore, after forging, is to soften the files by a process called annealing. This was formerly, and by many is still, performed by surrounding a close mass of the files with coals, keeping up the fire till the whole mass become red hot, and allowing them to cool gradually. In this process the files become softened, but the surface becomes so oxidated that a stratum of considerable thickness peels off. This scale, however, is very hard, and is removed but with difficulty. This last is not the greatest evil attending this process; the surface of the steel, lying immediately under the oxide, must have partly lost its property of steel. Indeed it is now known that, by a similar process, steel, and even cast iron, can be converted into pure iron. It will be obvious, that, by the oxidation which takes place, the part which has to form the teeth of the file will be much impaired by the abstraction of its carbon. Hence it will forcibly strike any one that steel, particularly in this instance, should be annealed in close vessels, to exclude the oxygen. This has been accomplished to a partial extent by some manufacturers, but still requires more minute attention. Tho annealing should be performed in troughs of fire-stone or fire-brick, similar to the cavities in which steel is converted, having the flame of a furnace playing on every side and over the top. The trough should be filled with alternate strata of the files to be annealed, and coal ashes, or the dust of the coaks, formed in the forge-hearth. The upper stratum of files should be covered with a thick stratum of the dust, and lastly with a mixture of clay and sand. The heat should be kept up no longer than till the mass will become red hot quite through. Tho whole must now be suffered to cool. When the files are withdrawn, instead of being scaled, as in the old method, they will exhibit a metallic surface, and the substance will be much softer than by the common annealing.

It should be here observed, that the mass to be heated should not be more than one foot in thickness, as it would be so long in heating and cooling that the metal would put on the crystalline form, under which it is too brittle to form a cutting edge. We have before observed that the steel requires high conversion for files; this will evidently become unnecessary with this mode of annealing. The surface of the files, which is the principal part, will become converted in an extra degree, by using more carbon in the annealing, and thus make steel of common conversion sufficiently hard for files.

The next process is the preparation of the surface for the teeth of the files. This is either done by means of filing or by grinding. The stones used for grinding files aro of sharp gritstone, and of considerablo size, for the large files, from four to five feet in diameter, and wear them down to about thirty inches. The grinder sits so as to lean over the stone, which turns directly from him, and presses on the file with both hands. The files are now transmitted to the cutter. The file-cutter requires an anvil of a size great or less according to the size of his files, with a face as even and flat as possible. The hammers are from one to five or six pounds. His chisels are a little broader than the file, sharpened to an angle of about 20°; the length is sufficient to be held fast between the finger and thumb, and of strength sufficient not to bend with the strokes of the hammer, the magnitude of which may be best conceived by the depth of the impression. The anvil is placed in the face of a strong wooden post, to which a wooden seat is attached, a small distance below the level of the anvil's face. The file is first laid on the bare anvil, one end projecting over the front and the other over the back edge of the same. A leather strap now goes over each end of the file, and passes down on each side the block to the workman's feet, which, being put into the strap on each side, like a stirrup, holds the file firmly upon the anvil while it is cut. While the point of the file is cutting, the strap passes over one part of the file only, while the point rests upon the anvil, and the tang upon a prop on the other side of the strap. While one side of the file is single cut, a fine file is run slightly over the teeth, to take away the roughness, when they are to be double cut, and another set of teeth are cut, crossing the former nearly at right angles. The file is now finished on one side, and it is evident that the cut side cannot be laid upon the bare anvil to cut the other. A flat piece of an alloy of lead and tin is interposed between the toothed surface and the anvil, while the other side is cut, which completely preserves the side already cut. Similar pieces of lead and tin, with angular and rounded grooves, are used for cutting three-square and half-round files.

Rasps are cut precisely in the same way, using a triangular punch instead of a flat chisel. The great art in cutting a rasp is to place every new tooth opposite to a vacancy as much as possible.

Although smooth files have many more teeth, they are not proportionate in labour; since more strokes can be made in the same time, as they are of less magnitude. In cutting a flat side, about half an inch broad, of the bastard cut fineness, a quick workman will make about three hundred strokes and as many teeth in one minute. The smaller files are generally cut by women and children, who very soon acquire great dexterity. The file-cutter, whatever may be the degree of fineness of the file, depends much more upon his feeling than his eyes; when one tooth is formed, the edge of the chisel and the surface of tho file being both very smooth, the former is pushed up against the back of the first tooth, which can be much better felt than seen. When the files are cut, the next process is to harden them, which is effected by heating them to redness and quenching them in cold water. The files were formerly first smeared with the residium of ale barrels, commonly called ale grounds, and then covered over with common salt in powder, which was retained merely by the adhesive nature of the ale grounds, and now dried before the fire. The files were now taken once or twice and heated in a smith's fire made of small coaks, frequently moving the file backward and forward, in order to heat it uniformly red hot. At this period the file gives off a white vapour from the surface, which is the salt in the act of subliming. The surface appears at the same time covered with the salt in a liquid state, which, like a varnish, preserves the surface from the oxygen of the atmosphere, during the time it is red hot. The file is now held in a perpendicular position, and the immersion in the water commences at the point, slowly depressing it up to the tang, which should not be hardened. All files are dipped in a perpendicular direction. These, however, which have a round side and a flat one, are moved also in a horizontal direction, with the round side foremost. Without this precaution files of this shape would warp towards the round side.

It is common, after hardening, to temper most cutting instruments. Files, however, are never tempered at all by the maker; nor are any but rough and the bastard cut files tempered by those who use them. If these were not in some cases tempered, the points of the teeth would break, and the file would do but little service. When files are hardened they are brushed with water and coak-dust. The surface becomes of a whitish grey colour, as perfectly free from oxidation as before it was heated.

In applying the salt, as above directed, a very great proportion of it is rubbed off into the fire and is lost. This may be saved by mixing ale grounds and the salt together, the salt being in such proportion as just to be taken up by the aqueous part of the grounds, which should not exceed three pounds of salt to one gallon of ale grounds. The files require only to be smeared thinly with the mixture, which, when dry, adheres firmly to the surface till the salt fuses. The manner of heating files for hardening has been also improved. Instead of putting the files singly into a coak fire, a fire-place or oven is formed, into which the blast enters. Two iron bearers are placed on the upper part of a cavity to support a number of files at once; these are heating gradually while the workman continues to select the hottest, and, in a hotter part of the fire gives them the full degree of heat required for dipping them into the water. Some manufacturers pretend to possess secrets for hardening, by introducing different substances into water, such as sulphuric and muriatic acid. The quantities, however, are so small, that if those bodies could be shown to possess any such qualities, the effect must be trifling. The only means which can be employed to increase the hardness of files is by more highly carbonating the surface of the file. This may be effected in a very simple manner. No more is necessary for this purpose than to introduce some animal carbon, ***ivory black***, in fine powder into the hardening composition above mentioned. This carbon may best be obtained from the refuse leather of shoemakers and curriers. They should be introduced into a vessel of cast or wrought iron, leaving only one small opening for the escape of vapour. The vessel being surrounded by a fire capable of heating the vessel red hot, the heat must be kept up till no more vapour escapes ; the hole must then be closed, and the whole suffered to cool. The contents of the vessel will be found to be a hard shining coal, which, being reduced to a powder will be fit to mix with the composition. As a proof of the efficacy of this substance in giving greater hardness to the files, if a file be made of iron and cut in the usual way, by covering it with a mixture of the salt, ale grounds, and powdered carbon, heating it red hot, and quenching it in cold water, the surface will become perfectly hard, and files may be made in this way, which, at the same time that they will bend into different forms, are hard enough to file wood, stone, and even metals.

FILING. To use the file well generally proves one of the most difficult tasks which the practical mechanic has to encounter, and this difficulty is owing chiefly to the want of a proper plan in setting about the work. Plane surfaces, for the plates of air pumps and other purposes, are of indispensable use ; but a knowledge of the manner in which they may be executed is confined to very few. Grinding is the common process employed, but two surfaces of metal may be ground together for ever without being made plane, unless, by some previous operation all their cross windings are completely removed. The application of turning to the production of plane surfaces is not an easy undertaking, and requires an expensive apparatus; and often the mere fixing upon the chuck the metal to be turned takes as much time as ought to be required for the completion of the work by the file.

A plane surface, already known to be true, could be made use of so as to show, with perfect facility and correctness, the errors of another upon which the artist may be employed, as often as he wishes to ascertain the state of his work, and all the projections may be removed by means of a file, without reducing the other parts, and thus enable him at length to bring the latter surface to an exact correspondence with the former. A perfectly straight steel ruler, or straightedge is also required. Since the scratches made by a file will be proportionate to the size of its teeth, the larger these are the greater will be the effect which an adequate force will produce at one stroke; hence the propriety of commencing the work with the coarsest file and afterwards in regular gradation employing finer and finer ones as it approaches to the finished state; yet for most purposes files of three or four degrees of fineness are quite sufficient.

The greater number of articles to which the file can be applied are composed of flat surfaces, and he who can file a flat surface well will find no difficulty in executiug whatever the file will enable him to do; we shall therefore detail the progress of a block of metal taken rough from the foundry till it is brought to a finished state; and, supposing a rectangular figure to be aimed at, its surfaces will then be truly flat, and, according to their situation either exactly parallel or exactly at right angles to each other. As somewhat greater difficulties occur in filing iron than brass, and as cast iron is not in general so easy to manage as the other descriptions of the same metal, we shall suppose it to be a block of cast iron, which let us suppose to be nine inches in length, seven in breadth, and one in thickness. The first step is to examine the state of the metal, whether it be hard or soft, warped or tolerably straight, perfectly solid, or interspersed with cavities. If very hard, which may be knowu by trying it with a file, it will be advisable to anneal it, which will greatly facilitate our work; but the outside will still be somewhat harder than the iuternal part, owing principally to some of the sand of the mould closely adhering to it. This outside may be removed by chipping, or with a large grindstone turned by machinery, or by the file, taking the precaution only of using a file that is already rather worn. The first is upon the whole the most economical and convenient process; and when, for the removal of imperfections or any other purpose, it is requisite to reduce the block materially, it is decisively to be preferred. If after the outside has been removed there appear any cavities or other imperfections which are not likely to be removed by the file, and which will unfit the piece for its destination, they may be drilled out, and the holes made by the drill filled with rivets. Small imperfections may be removed by drilling to the depth of about half an inch and then driving in a plug made of wire, which may be fitted sufficiently tight to bear any degree of hardship, and sufficiently correct to avoid the slightest appearance of a flaw, without the trouble, as in rivetting, of making the top of the hole wider than the rest.

As the holes in a piece of cast iron, which are occasioned either by stagnated air or the falling in of part of the mould, have mostly not only very rough surfaces but are wider internally than at the outside, they may be filled with melted lead, pewter, or some other soft metal which they will retain: type-metal will answer extremely well. This mode is applicable when levelness of surface is the principal object iu view, and it is not necessary to regard the uniformity of its appearance, the equal hardness of its several parts, or its being able to bear a strong heat, such as the table of a printing press.

Suppose the block completely freed from its hard black scurf, and every imperfection which the subsequent operations with the file are incapable of removing; we now select the file we intend to use first, a safe-edge one, about fourteen inches long, an inch and a half broad, and containing about fourteen rows of teeth in each inch. The file is held by the handle and pushed forward by the right hand, while the left, near the wrist, pressing upon its lower end, gives effect to the stroke, which must be directed as nearly horizontal as possible. By the occasional application of the straight-edge to the surface we are filing, in various directions, but in particular diagonally, we easily ascertain the state of our work and remove in succession the elevated parts. The inequalities at length become so small that it would be tedious to apply the straight-edge to discover them; but, being provided with a surface which we know to be true, and which we shall designate by calling it a table, as it ought always to be larger than the work we are filing, and for general purposes may with much advantage contain several square feet, we now make use of it for the detection of the remaining imperfections in the following manner: we mix finely washed red chalk or ochre with olive or any other oil which is not viscid, and we rub this mixture upon it with a piece of cloth, so as to cover the whole of it over very thinly and evenly; if the surface we are filing be then turned down upon it, and moved a few times backwards and forwards, it will be everywhere equally covered with ochre from the table, provided it be equally level; if not those parts which are highest will alone be reddened, and they must be reduced by the re-application of the file. As soon as it approaches nearly to a perfect plane the ochre will redden a great number of places in small spots or strips, and then we not only use a fine file but merely press upon it with two or three of our fingers, by which means we are enabled to observe more distinctly the spot upon which we bear, and to move with more expedition from one part to another.

Before finishing our work with much nicety we carefully attend to turning that side of the block we have been filing down upon the table, we strike the back of it, at the corners, centre, and various other parts at pleasure, with a mallet, or the end of the handle of a hammer held perpendicularly. If a dead sound, such as would be heard on striking the table itself in a similar manner, be produced, we have none of those twistings of the surface termed cross windings to remove; but if a sharp chinking sound be produced it is evident that the surfaces of the table and the block do not coincide. If the corner of the block, to the extent of a square inch, or even less, be lower than the remainder of the surface, in no greater degree than the thickness of a sheet of writing paper, this mode of trial will make the imperfection very distinctly visible. If, therefore, the block will not stand the test of this examination, we immediately proceed, by the use of the ochre, to detect the extent of the elevated parts; and, in moving the block upon the table for this purpose, we are careful to press only on those parts under which we know, by our previous trial with the hammer, they are comprized. Having obtained the marks we desire, we file away to the best of our judgment the convexities they indicate, and repeat the experiment and filing till the block will lie perfectly solid upon the table.

Although the test by the hammer answers an important purpose in proving the existence or non-existence of cross-windings, yet its application extends but little further; the depression of any particular part, before it can point it out, must not only extend to the edge of the block but must embrace a small portion at least of two sides. We use the hammer merely as a help : the use of the ochre simply is our universal test; but if we wish to know the measure of any particular imperfection we resort to a good straight-edge. Suppose that one surface of the block will bear examining in the different ways above mentioned; it will then coincide with the table so exactly that when laid upon it the finest hair could not be drawn out, or even moved, at whatever part, between the two planes, a portion of it were placed. The polishing we leave, if not to the last at least till the opposite side, to which we now proceed, is equally advanced. We have not only to make the second side as level as the first but also to make it parallel with it at the same time. The flatness is obtained by a repetition of the means adopted to bring the first surface to that state, and the parallelism of the two sides is a necessary consequence of making the block everywhere equally thick. Callipers, in experienced hands, may be made to answer for this purpose very well, but they are apt to mislead the unwary, as they afford different indications with slight differences in the manner of holding them. In using them, therefore, we always hold the centre of the head in such a manner that a line passing through it, and exactly midway between the points, should be parallel with the surfaces they inclose.

It is much easier to file correctly with the assistance of a gauge than a pair of callipers; and as the width of the former always remains the same two gauges may be made, one of them of the true width and the other a very little wider; the block may then be filed down to the latter with rather a coarse file, and afterwards to the former with a fine one. The heat produced by the strokes of a large coarse file expands the surface upon which they act, renders it convex, and the opposite one necessarily concave. These effects remain in part after the equilibrium of temperature is restored. While we are employed upon the first side they are overlooked, but when, after having nearly finished the second side, we find upon trial with the ochre that the other no longer affords the same indications of correctness which it did before, we are convinced of the propriety of having postponed the finishing of it. In a block eight or ten inches long the error seldom exceeds the five-hundredth part of an inch; and, therefore, not having begun to polish when it occurs, we can use a file by which it will quickly be removed.

Having now rendered the two principal surfaces of our block correctly plane and parallel with each other, we immediately direct our attention to the four which yet remain in the rough state; these, for the sake of distinction we may call the edges. We begin upon one of the two longest of them and file it true in the same manner as we did in the first example, except that we make use of a square, applied alternately from the two sides already filed, in order to assist us in keeping it exactly at right angles with them. As soon as this edge is true, we make the opposite one parallel with it by a suitable guage, checking the chance of error by applying the square, which can quickly be run along the whole length of the edge, and ascertaining, as usual, the general flatness of the whole surface by the use of the ochre and table. The remaining two edges are brought to the same state, by a repetition of exactly the same means. With a rectangular bar of iron, or any hard metal, the sides of which are very smooth and exactly perpendicular when it is placed upon the table, we may make use of it in the filing of these edges as follows: cover one side with the ochre and oil, place upon the table either of the sides at right angles with the one thus coated, opposite which place that edge of the block which is to be tried; press the block and the bar down upon the table and against each other at the same time, moving one of them, while they are in contact, backwards and forwards two or three times. By the marks left upon the block we detect at once all its deficiencies. This mode of trial would also completely succeed in other cases; for example if we had to file the inside of a frame such as printers use to fasten their types in, to which no other method would be so advantageously applicable. We pass with one of our smoothest files along the arris of the two surfaces upon which we are going to apply the square, in order to take off that extremo sharpness, and those overhanging particles of iron produced by filing. Our block being too broad to be held between the chaps of the vice, we place it, before we begin to file the principal surface, upon a piece of stout board, in breadth about an inch each way larger than itself. Close to the edge of the block we drive a strong nail here and there into the board, so as to prevent its horizontal motion but not its being lifted up and taken off perpendicularly. By a square piece of wood, about two inches broad, being firmly screwed to the under side of the board and fastened in the vice, a steady and convenient support is obtained for our work; but as soon as the filing of the edges is commenced, this board is discarded, and the vice alone, its teeth only being covered with lead, used to hold the block.

Planemakers and others, who use files to smooth their wood-work, select those the teeth of which are not jagged by cross cutting, and we find that upon iron, files of this sort answer better for polishing than any other. We use them of such a degree of fineness as will effect our purpose, if that can be effected by a file: the last degree of smoothness can only be obtained by grinding. When using a fine file spread the ochre so thin as hardly to colour the table, otherwise we should choke up its teeth: when it does choke up the teeth it may be removed with a brush. Those who have various sorts of metal to work have an economical mode of management in the use of files, which deserves to be noted. They use all their new files to brass in the first instance; when the original keenness of the teeth has been diminished by this metal they lay them aside to be ready for filing cast iron; and when they cease to be sharp enough for cast iron they use them to malleable iron, for which they will serve tolerably well awhile longer. The last uses of a file may be to smooth wood or metal revolving in the lathe; some keep them for a short time red hot in the open fire, and then retemper them before they use them in this way; the scale which they cast leaving them somewhat sharper than they were previously.—*Smith's Panorama.*

FIRMNESS denotes the consistence of a body, or that state wherein its sensible parts cohere or are united together, so that a motion of one part induces a motion of the rest. In which sense firmness stands opposed to fluidity.

FLOATING BODIES are those which swim on the surface of a fluid, the stability, equilibrium, and other circumstances of which form an interesting subject of mechanical and hydrostatical investigation, particularly as applied to the construction and management of ships and other vessels. The equilibrium of floating bodies is of two kinds, viz., stable or absolute, and unstable or tottering. In the one case, if the equilibrium be ever so little deranged, the bodies which compose the system only oscillate about their primitive position, and the equilibrium is then said to be firm, or stable: and this stability is absolute if it takes place, whatever be the nature of the oscillations; but it is relative if it only takes place in oscillations of a certain description. In the other state of equilibrium, if the system be ever so little deranged, all bodies deviate more and more, and the system, instead of any tendency to establish itself in its primitive position, is overset and assumes a new position, entirely different from the former; and this is called a tottering or unstable equilibrium. The stability of a floating body is the greater as its centre of gravity is lower than that of the displaced fluid, or as the distance between these centres is increased; it is for this reason that ballast is put in the lower part of vessels to prevent them from being overset. The nature of the equilibrium, as to stability, depends on the position of a certain point, called the centre of pressure. When the centre of pressure is above the centre of gravity, the equilibrium is stable; on the contrary, when the meta centre is lower than the centre of gravity, the equilibrium is tottering; when the meta centre coincides with the centre of gravity, the body will remain at rest in any position it is placed in, without any tendency to oscillation.

If through the centre of gravity of the section of the surface of the water on which a body floats we conceive a horizontal axis to pass, such that the sum of the products of every element of the section, multiplied by the square of its distance from this axis, be less than any other horizontal axis drawn through the same centre, the equilibrium will be stable in every direction; when this sum surpasses the product of the volume of the displaced fluid, by the height of the centre of gravity of the body above the centre of gravity in this volume. This rule is principally useful in the construction of vessels which require sufficient stability to enable them to resist the effects of storms, which tend to submerge them. In a ship, the axis drawn from the stern to the prow is that relative to which the sum above mentioned is a minimum; it is easy, therefore, to ascertain and measure its stability by the preceding rule. In order that the floating body may remain in equilibrium, it is also necessary that its centre of gravity be in the same vertical line with the centre of gravity of the displaced fluid, otherwise the weight of the solid will not be completely counteracted by the pressure of the displaced fluid. When the lower surface of a floating body is spherical or cylindrical, the centre of pressure must coincide with the centre of the figure, since the height of this point, as well as the form of the portion of the fluid displaced, must remain invariable in all circumstances.

Fluid, or **Fluid Body**, is that whose parts yield to the smallest force impressed upon them, and by yielding are easily moved amongst each other; in which sense it stands opposed to a solid, whose parts do not yield, but constantly maintain the same relative situation. Elastic fluids are those which may be compressed into a smaller compass, but which on removing the pressure resume again their former dimensions; as air, and the various gases. Non-elastic fluids are those which occupy the same bulk under all pressures, or if they be at all compressible it is in a very trifling degree; such as water and other liquids.

Fly, in mechanics, is a heavy weight applied to some part of a machine, principally in order to render its motion uniform, though it is sometimes employed for the purpose of increasing the effect, as in the steam engine. It regulates the motion, because its momentum is not easily disturbed.

To find the weight of the rim or ring of a fly-wheel proper for a steam engine, multiply 1368 by the number of horses' power of the engine; divide the product by the diameter of the wheel in feet, multiplied by the number of revolutions per minute; the quotient is the weight of the ring in cwts. Thus, the weight of the rim of a fly-wheel for an engino of 20 horse power, the wheel to be 16 feet diameter, aud make 21 revolutions per minute, will be

$$\frac{1368 \times 20}{16 \times 21} = 81{\cdot}4 \text{ cwts. nearly.}$$

The fly-wheel of an engine for a corn or flour mill ought to be of such a diameter that the velocity of the circumference of the wheel may exceed the velocity of the circumference of the stones, to prevent, as much as possible, any tendency to back lash. The necessary weight and diameter of the wheel being found, suppose a breadth of rim, and the thickness to make the weight in cast iron will be found thus : dividing the required weight in lbs. by the area of the ring in inches multiplied by ·263. Thus, if it be required to know what thickness must a ring be to equal 81·4 cwts. when the outer diameter is 16 feet, and inner diameter 14 feet 8 inches. 81·4 cwts. = 9116·8 lbs., and by mensuration the area of the ring will be = 4624·43 inches; then

$$\frac{4624{\cdot}43 \times {\cdot}263}{9116{\cdot}8} = 7{\cdot}496 \text{ inches nearly.}$$

If the ring is to be of a cylindrical form, find the diameter of a circle having the same area as the cross-section of the ring found. Suppose the ring, in the last example, be required to be cylindrical, then 7·496 × 8 = 59·968 inches, cross sectional area of the ring found, and

$$\sqrt{\frac{59{\cdot}968 \times 452}{355}} = 8{\cdot}73 \text{ inches diameter nearly.}$$

As an approximate, multiply the required weight, in lbs., by 1·62; divide the product by the diameter of the wheel in inches, and the square root of the quotient will be the diameter of the cross section of the ring in inches; thus,

$$\sqrt{\frac{9116{\cdot}8 \times 1{\cdot}62}{16 \times 12}} = 8{\cdot}77 \text{ inches.}$$

Sometimes it is necessary to have the fly-wheel upon a second mover; for instance, there is a six-horse engine making 50 revolutions per minute, having a fly-wheel of 7 feet diameter and 9 cwt., but by the rule it ought to be 23·46 cwt. Now, a larger wheel cannot be got in, but the samo may be put upon a second motion—required the velocity that will increase its momentum equal to 23·46 cwt. on the first motion, 7 feet diameter $= 21{\cdot}9912$ feet circumference, and $21{\cdot}9912 \times 50$ revolutions $= 1099{\cdot}56$ feet velocity; then,

$$\overset{\text{cwt.}}{9} : \overset{\text{velocity.}}{1099{\cdot}56} :: \overset{\text{cwt.}}{23{\cdot}46} : \overset{\text{velocity.}}{2866{\cdot}1864} \div 21{\cdot}9912 = 130$$ revolutions per minute, nearly.

As 9 : 1099·56 : : 23·46 : 2866·1864 ÷ 21·9912 = 130 revolutions per minute, nearly.

To find the centrifugal force of a fly-wheel, multiply the decimal ·6136 by the diameter of the wheel in feet, and divide the product by the square of the time of one revolution; the quotient is the centrifugal force when the weight of the body is 1.

Example. Required the centrifugal force of a fly-wheel, 15 feet diameter, and making 40 revolutions per minute, the weight of the ring being 3 tons, will be $60 \div 40 = 1{\cdot}5$ time of one revolution; and

$$\frac{{\cdot}6136 \times 15}{1{\cdot}5^2} = 4{\cdot}09 \times 3 = 12{\cdot}27 \text{ tons},$$

the centrifugal force.

Focus is that point in the transverse axis of a conic section at which the double ordinate is equal to the parameter, or to a third proportional to the transverse and conjugate axis.

Force, in its most general and comprehensive sense, denotes whatever produces a change in the state of any body. Changes which are accompanied by motion or an alteration in the direction of motion, are said to be produced by mechanical forces; and those forces get different names according to their effects. Thus we say, the force of steam, the force of gunpowder, animal force, the force of impulse, the force of gravity, and a great many others; by which we mean that there are certain results arising from them in given cases; and when we say the force of steam, the force of gunpowder, or animal force, we are aware that the substance, or the animal, undergoes a change in itself at the same time that it appears to be the medium in operating a change upon something else. All forces, however various, are measured by the effects which they produce in like circumstances, whether the effect be creating, accelerating, retarding, or deflecting motions. The result of some general and commonly observed force is taken for unity, and with this any others may be compared, and their proportions represented by numbers or lines. Under this point of view they are considered by the mathematician; all else falls within the province of the metaphysician. When we say that a force is represented by a right line, A B, it is to be understood that it would cause a material point,

A________________B

situated at rest in A, to pass over the line A B, which is called the direction of the force, so as to arrive at B at the end of a given time, while another force would cause the same point to have moved a greater or less distance from A in the same time.

Mechanical forces may be reduced to two sorts; one of a body at rest, the other of a body in motion. The former is that which we conceive as residing in a body when it is supported by a plane, suspended by a rope, or balanced by the action of a spring, &c. being denominated pressure, tension, force; or *vis mortua*, *solicitatio*, *conatus movendi conamen*, and may always be estimated or measured by a weight, viz., the weight which sustains it. Thus, the ultimate standard to which all forces are referred is the gravitating or falling of bodies towards the earth. This has been adopted because it is the most constant and uniform in its operation.

The force of a body in motion is a power relating to that body so long as it continues its motion; by means of which it is able to remove obstacles lying in its way; to lessen, destroy, or overcome the force of any other moving body, which meets it in an opposite direction; or to surmount any the largest dead pressure or resistance, as tension, gravity, friction, &c. for some time; but which will be lessened or destroyed by such resistance as lessens or destroys the motion of the body. Concerning the measure of moving force it is allowed that the measure depends partly upon the mass of matter in the body, and partly upon the velocity with which it moves: the point in dispute is, whether the force varies as the velocity or as the square of the velocity. Descartes assumed the velocity produced in a body as the measure of the force which produces it. Leibnitz observed that a body which moves twice as fast rises four times as high against the uniform action of gravity; that it penetrates four times as deep into a piece of uniform clay; that it bends four times as many springs, or a spring four times as strong to the same degree; and produces a great many effects which are four times greater than those produced by a body which has half the initial velocity. If the velocity be triple, quadruple, &c., then the effects are 9 times, 16 times, &c. greater; and, in short, are proportional, not to the velocity, but to its square. He therefore affirmed that the force inherent in a moving body is proportional to the square of the velocity. This is a mere dispute about words, the one party taking one result of force as the measure and the other party taking another. To do so is perhaps quite natural, although it is certainly not worthy of being the foundation of a philosophical controversy.

If we call the force of gunpowder that which impels a cannon-ball with a given velocity, we mean one kind of force, and if we speak of it as driving the same ball a certain distance into the earth, or elevating it a certain way into the air, we mean another; and, though we have ascertained all the changes produced in the former, by altering the quantity and composition of the gunpowder, we have made no advance toward ascertaining the latter. A body moving with the same velocity has the same inherent force, whether this be employed to move another body, to bend springs, to rise in opposition to gravity, or to penetrate a mass of soft matter. Therefore these measures which are so widely different, while each is agreeable to a numerous class of facts, are not measures of this something inherent in the moving body which we call its force, but are the measures of its exertions when modified according to the circumstances of the case; or, to speak still more cautiously and securely, they are the measures of certain classes of phenomena consequent on the action of a moving body.

Laplace has shown, by a very ingenious investigation, how we may experimentally be convinced of the proportionality of force to the velocity; or, at least, that since the difference must be, if any, extremely small, it is highly improbable that there should be any difference whatever. It can be shown that if any considerable variation existed in this law, the relative motion of bodies on the earth's surface would be sensibly affected by the motion of the earth; that is, that the effect of a given force would vary very much, according as its direction coincided with, or was opposed to, the direction of the earth's motion.

The most general distinction of force is mechanical and chemical; the former refers to all those forces which change the shape of a body or its relative situation among other bodies, and the latter all those which alter its constitution or external structure. Force is also distinguished into motive and accelerative, or retardive, constant, variable, &c. Motive force, otherwise called momentum, or force of percussion, is the absolute force of a body in motion, &c., and is expressed by the product of the weight or mass of matter in the body multiplied by the velocity with which it moves. Motive force also denotes the force by which a system of bodies is put in motion, as it is the difference between the power or weight which produces the motion and the resistance or weight to which it is opposed. Accelerative force, or retardive force, is that which respects the velocity or rate of motion only, accelerating or retarding it; and it is denoted by the quotient of the motive force, divided by the mass or weight of the body. Constant force is such as remains and acts continually the same for some determinate time. Such, for example, is the supposed force of gravity, which acts constantly the same upon a body, while it continues at the same distance from the centre of the earth, or from the centre of force, wherever that may be. Constant or uniform forces produce uniformly accelerated motions. Variable force is that which is continually changing its effect and intensity, such as the force of gravity at different distances from the earth's centre. See the formulæ relating to variable forces, under the article *Acceleration*.

Forces are farther distinguished into central, centrifugal, &c., which see under the several articles.

Freezing, or **Congelation**, the transformation of a fluid body into a firm or solid mass, by the action of cold. The following are the freezing points of the undermentioned substances:

Sulphuric acid	45°
Mercury	39
Water	32
Nitric acid	19
Oil of turpentine	14
Brandy	7·9

Friction, the act of rubbing, or the resistance to the motion of machinery caused by the rubbing of the parts against one another. The determination of the amount of friction under different circumstances is one of the most important problems in practical mechanics, and we shall therefore lay before the reader a full account of the most recent and accurate information that has as yet been obtained on this subject. In doing so we will for the most part follow the paper of Mr Rennie, published in the Philosophical Transactions for 1829.

Amontons affirmed that friction was not augmented by an increase of surface, but only by an increase of pressure; that friction amounted to one-third of the pressure, the amount being the same both with wood and metals when unguents were interposed. He likewise concluded that friction increased or diminished with the velocity, and varied in the ratio of the weight and pressure of the rubbing parts, and the time and velocity of their motions. Parent suggested the determining the angle of equilibrium at which a body, resting on an inclined plane, commenced sliding; and Euler conceived it to depend upon the greater or less approximation of the asperities of the surface, brought into contact by pressure; and stated that when a body begins to descend an inclined plane the friction of the body will be to its weight or pressure as the sine of the plane's elevation to its cosine; but that when the body is in motion the friction is diminished one-half. Muschenbroek held that friction increased with the surface; and Bossut distinguished it into two kinds, the first being generated by the gliding and the second by the rolling of the surface of a body over another; and observed that it was affected by time, but followed neither the ratio of the pressure nor of the mass. It is to Coulomb, principally, that we are indebted for the knowledge we possess of friction.

The Academy of Sciences at Paris, being desirous of rendering the laws of friction and the effects resulting from the rigidity of cords applicable to Machines, Coulomb undertook, in the arsenal at Rochefort, a very extensive series of experiments, which he afterwards published in 1781, under the title of *Théorie des Machines simples, en ayant égard au Frottement de leurs Parties, et à la Roideur des Cordages.* This memoir is divided into two parts; the first treats of the friction of surfaces gliding over each other, and the second enters into an examination of the rigidity of cords and the friction of the rotary movements of axles. Coulomb, in examining the friction of plane surfaces gliding over each other, distinguishes it into two kinds; the first resulting from time and the second from velocity. The first may depend on four different causes, viz. the nature of the bodies in contact, the extent of surface, the pressure on the surface, and the time the surfaces have been in contact. The state of the atmosphere, he thinks, may have little influence. He considers that friction arises from the entangling of the asperities, which can only be disengaged by bending or breaking. From his experiments he was led to conclude that the friction of wood on wood without unguents was in proportion to the pressure, which attained its maximum in a few minutes after repose: that the effects of velocities were similar, but the intensities were much less to keep the body in motion than to detach it from a state of rest, oftentimes in the ratio of 22·95: that in the case of metals the results were likewise similar, but the intensity was the same, whether to disturb or maintain the motion of the body: that with heterogeneous surfaces, such as those of wood and metals gliding over each other, the intensity did not attain its limit sometimes for days. In general, however, with woods and metals without unguents, velocities were found to have very little influence in augmenting friction, except under peculiar circumstances.

Dr Vince endeavoured by some very ingenious experiments to determine the laws of retardation, together with the quantity and the effect of surface on friction; and was led to the conclusion that the friction of hard bodies in motion was a uniformly retarding force, but not so much as with cloth and woollen, which were found in all cases to produce an increase of retardation with an increase of velocity: that the quantity of friction amounted to about one-fourth of the pressure, and that it increased in a less ratio than the quantity of matter or weight of the body: that when the surfaces varied from 1·61 : 1 to 10·06 : 1, the smallest surface gave the least friction: and, finally, that friction was greatly influenced by cohesion.

Mr Rennie is the latest and most extensive experimenter on friction, and we shall exhibit his results in the form of tables. The apparatus consisted of a plane horizontal bed, but which might be elevated to any proposed angle; and the measure of the friction was obtained first by determining the weight on a scale requisite to draw a given load along the horizontal plane, and secondly by elevating the plane till the angle was such as to cause the effect of gravity to just overcome the friction. In the latter case, the angle being given, the cosecant of that angle will express the fraction of the weight which is equivalent to the friction.

Table of the Friction of Wood on Wood.

In these experiments a descending weight was made to draw another along a horizontal bed or plane.

Nature of the rubbing surface.	Mean of weight to friction.	Number of experiments from which the mean is taken.	Weights moved.	Weights which gave the least ratio.		Weights which gave the greatest ratio.	
				cwt.	prop.	cwt.	prop.
Red teak on red teak	8·82 to 1	13	from ½ cwt. to 13 cwt.	1	7·92	8	9·90
American live oak on American live oak	7·65 to 1	12	from ½ cwt. to 12 cwt.	8	6·98	3	9·15
Pine on pine	3·40 to 1	4	from ½ cwt. to 3 cwt.	3	3·01	1	4·01
Black beech on black beech	7·13 to 1	11	from ½ cwt. to 10 cwt.	4	6·45	2	8.00
Norway oak on Norway oak	7·67 to 1	9	from ½ cwt. to 8 cwt.	8	5·45	2	8.53
English oak on English oak	7·83 to 1	6	from ½ cwt. to 5 cwt.	1	7·46	4	8·14
Hornbeam on hornbeam	6·57 to 1	8	from ½ cwt. to 7 cwt.	7	4·68	2	7·38
Elm on elm	5·86 to 1	9	from ½ cwt. to 8 cwt.	1	5·07	5	6·38
Honduras mahogany on Honduras mahogany	5·96 to 1	12	from ½ cwt. to 11 cwt.	1	4·30	11	6·76
Yellow deal on yellow deal	2·88 to 1	6	from ½ cwt. to 5 cwt.	5	2·50	4	3·03
White deal on white deal	3·81 to 1	3	from ½ cwt. to 2 cwt.	½	2·98	2	4·94

Table of Friction of Wood on Wood.

In determining which, the bed on which the weights rested was inclined till the body slided.

Nature of the rubbing surface.	Weight on the surface.	Angle at which it moved.	Time in descending 11 inches.	Proportion.	Mean proportion.
Red teak on red teak	10	8°·00	18	7·116	7·617
	20	7 ·45	15	7·340	
	28	7 ·15	20	7·861	
	56	7 ·00	16	8·144	
American live oak on red teak . .	10	9 ·00	22	6·314	6·867
	20	8 ·00	24	7·116	
	28	8 ·30	20	6·691	
	56	7 ·45	25	7·348	
Black beech on black beech . . .	10	8 ·15	20	6·897	7·663
	20	7 ·20	17	7·770	
	28	7 ·40	19	7·429	
	56	6 ·40	21	8·556	
Norway oak on Norway oak . . .	10	8 ·00	19	7·116	7·966
	20	7 ·30	20	7·596	
	28	7 ·00	20	8·144	
	56	6 ·20	25	9·010	
English oak on English oak . . .	10	9 ·30	17	5·976	6·923
	20	8 ·30	17	6·691	
	28	7 ·40	18	7·429	
	56	7 ·30	20	7·596	
Elm on elm . . .	10	11 ·40	19	4·843	5·471
	20	10 ·30	18	5·396	
	28	10 ·00	19	5·671	
	56	9 ·30	19	5·976	
Hornbeam on hornbeam	10	10 ·00	20	5·671	6·349
	20	9 ·15	21	6·140	
	28	8 ·30	20	6·691	
	56	8 ·15	19	6.897	
Honduras mahogany on hornbeam .	10	12 ·00	22	4·705	4·753
	20	12 ·30	21	4·511	
	28	11 ·45	21	4·808	
	56	11 ·20	23	4.990	
Yellow deal on yellow deal . . .	10	15 ·00	10	4·732	3·501
	20	17 ·00	9	3·271	
White deal on white deal	10	18 ·00	10	3·078	3·794
	20	12 ·30	11	4·511	
Pine on pine . .	10	16 ·00	14	3·488	3·379
	20	17 ·00	11	3·271	

In reference to the two preceding tables of experiments Mr Rennie remarks "that there is a great deal of irregularity in the results; increase of pressure scarcely increasing the resistance. This may arise in some measure from the surfaces becoming condensed, and thus rendered less liable to abrasion. The soft woods present more resistance than the hard woods, yellow deal on yellow deal being the greatest, and red teak on red teak the least.

Table of the Friction of Metals on Metals, as depending on surface, the bodies being moved over a horizontal bed by a descending weight.

Cast Iron on Cast Iron.										
Laid flat, having an area of surface of 44 inches.						Laid edgewise, having an area of surface of $6\frac{3}{4}$ inches.				
Weight to be moved.	Weight required to move it.		Proportion.	Weight to one inch of area.		Weight required to move it.		Proportion.	Weight to one inch of area.	
lbs.	lbs.	oz.		lbs.	oz.	lbs.	oz		lbs.	oz
14	2	2	6·58	0	5·09	2	4	6·20	2	1·1
24	3	3	7·53	0	8·72	3	11	6·50	3	8·8
36	4	14	7·38	0	13·10	5	14	6·12	5	5·3
48	6	8	7·38	1	1·40	7	10	6·30	7	1·7
60	8	4	7·27	1	5·80	9	8	6 30	8	14·2
72	10	0	7·20	1	10·20	11	7	6 29	10	10 6
84	11	10	7·23	1	14·50	13	5	6·31	12	7·1
96	13	12	6·98	2	2·90	15	5	6 27	14	3·5
Hard Brass on Cast Iron; area of surface as above.										
14	1	14	7 4	0	$4\frac{2}{3}$	1	11	8·3	1	12
24	3	5	7·2	0	8	4	0	6 0	3	1
36	4	9	7·8	0	12	6	0	6·0	4	10
48	6	4	7·6	1	0	7	13	6·1	6	3
60	7	12	7·7	1	4	9	0	6·6	7	11
72	9	12	7·3	1	8	11	0	6·5	9	4
84	11	8	7·3	1	12	13	2	6·4	10	13
96	13	1	7 3	2	0	14	8	6·6	12	6
Yellow Brass on Cast Iron; area of surface as above.										
14	1	15	7·22	0	5·09	2	1	6·79	2	1·1
24	3	7	6·98	0	8·72	3	8	6 85	3	8·8
36	5	6	6·70	0	13·10	5	1	7·11	5	5·3
48	7	3	6·67	1	1·40	6	10	7 24	7	1·7
60	9	3	6·53	1	5·80	9	3	6·53	8	14·2
72	11	5	6·36	1	10·20	10	5	6·98	10	10·6
84	13	5	6·30	1	14·50	13	12	6·10	12	7·1
96	15	13	6 07	2	2·90	15	1	6·37	14	3·5
Tin on Cast Iron.										
Area of surf. 48 in.						Area of surf. $7\frac{3}{4}$ in.				
14	2	8	5·60	0	5·1	2	12	5·09	2	1·1
24	4	7	5·40	0	8·7	4	8	5·33	3	8 8
36	6	0	6 00	0	13·1	6	7	5·59	5	5·3
48	8	7	5 68	1	1·4	8	14	5·40	7	1·7
60	9	13	6·11	1	5·8	9	13	6·11	8	14·2
72	12	5	5·84	1	10·2	11	13	6·09	10	10·6
84	14	5	5·86	1	14 5	14	5	5·86	12	7·1
96	16	4	5·90	2	2·9	16	4	5·09	14	3·5

Hence it appears that the friction of

Cast iron upon cast iron laid flat, varies from	6·58 to	7·53
Cast iron upon cast iron laid edgewise	6·2	6·5
Hard brass upon cast iron laid flat	7·2	7·8
Hard brass upon cast iron laid edgewise	6·0	8·0
Yellow brass upon cast iron laid flat	6·09	7·22
Yellow brass upon cast iron laid edgewise	6·1	7·24
Tin upon cast iron laid flat	5·4	6·11
Tin upon cast iron laid edgewise	5·09	6·11

That the friction is nearly the same with cast iron and brass, whether the load be applied on the broad side or the narrow side of the plates, although the areas of the surfaces are to each other as 6·22 to 1. That tin, being a softer metal and more easily abraded, the friction increases when a load is applied above eight pounds per square inch, but remains nearly the same with the broad side as with a narrow side. Generally speaking, the friction is less with the broad side than with the narrow side.

In calculating the force of an engine, friction should never be overlooked. Though it varies so much with circumstances, that it is not yet reduced to certain rules, still the specific details we have given will enable the young mechanic to come tolerably near the truth in ascertaining its amount at each part of a machine according to the pressure, surface, and materials; and, as he goes along from the power to the resistance, he must consider these amounts as actual deductions from the advantage of the machine. It must be understood that the amount of friction stated in this section will apply only to machines that are well made; the loss of power that may be occasioned by bad workmanship is incalculable, and, as bad workmanship may exist when it is not perceived, no conjectural calculation should be relied on, when the real loss of power can be obtained by experiment.

The friction of a single lever is very trifling. The friction of the wheel and axle is in proportion to the weight, velocity, and the diameter of the axle; the smaller the diameter of the axle the less will be the friction. Pulleys have very great friction, on account of the smallness of their diameters in proportion to that of their axles, and their friction is greatly increased when they bear, as they are very apt to do, against their blocks, and when their centres and axles are worn untrue. The friction of bodies is in general proportionate to their weight, or the force with which their rubbing surfaces are pressed together; and is for the most part equal to between one-half and one-fourth of that force. Although friction increases with an increase of surface, yet this does not take place in direct proportion to that increase. It also increases, with some exceptions, in proportion to the velocity of bodies, particularly when very different substances are employed without an unguent.

Table of the Friction of Metals continued, the bodies being moved on a horizontal plane by a descending weight.

Nature of the bodies.	Area of rubbing surface.	Weights moved giving the greatest and least ratio.	Weights required to move the preceding.		Greatest and least proportion.	Weight to 1 inch area.	
	Inches.	lbs.	lbs.	oz.		lbs.	oz.
Brass on wrought iron . .	5·906	24	3	11	6·50	4	1·
		84	10	10	7·90	14	3·5
Cast iron on cast iron . .	6·75	24	3	0	8·00	3	8·9
		36	5	14	6·12	5	5·3
Soft steel on wrought iron .	5·90	84	17	5	4·85	14	3·5
		192	32	8	5·90	32	8·0
Brass on steel	5·90	60	9	11	6·19	10	2·7
		36	5	0	7·20	6	1·6
Brass on brass . . .	5·90	192	44	8	4·31	32	8·0
		24	3	8	6·85	4	1·0
Cast iron on wrought iron .	5·90	96	17	0	5·64	16	4·3
		72	17	5	6·36	12	3·2
Cast iron on soft steel . .	5·90	192	32	0	6·00	32	8·0
		48	7	2	6·73	8	2·1
Tin on tin	5·90	96	36	0	2·66	16	4·3
		14	3	10	3·86	2	5·9
Soft steel on soft steel . .	5·90	192	31	8	6·09	32	8·0
		48	6	13	7·04	8	2·1
Cast iron on hard brass . .	7·75	36	6	0	6·00	4	10·3
		14	1	11	8·29	1	12·9
Wrought iron on wrought iron	5·90	24	3	13	6·29	4	1·0
		192	27	0	7·11	32	8·0
Brass on cast iron . . .	6·75	84	13	12	6·10	12	7·1
		48	6	10	7·24	7	1·7
Tin on wrought iron . .	5·90	14	2	10	5·33	2	5·9
		48	7	14	6·09	8	2·1
Tin on cast iron	6·75	14	2	12	5·09	2	1·2
		60	9	13	6·11	8	14.2

From these statements it is inferred, 1. That the friction of metals varies with their hardness. 2. That the hard metals have less friction than the soft ones. 3. That without unguents, and within the limits of thirty-two pounds eight ounces per square inch, the friction of hard metals against hard metals may very generally be estimated at about one-sixth of the pressure. 4. That withiu the limits of their abrasiou the friction of metals is nearly alike. 5. That from 1·66 hundred weight per square inch to upwards of six hundred weight per square inch, the resistance increases in a very considerable ratio, being the greatest with steel on cast iron and the least with brass on wrought iron, their limits being as 30, 36, 38, and 44 hundred weight.

Table of the Friction of Axles, with and without Unguents.

Weight on the axle.	Weight required to move it.		Time in passing over $4\frac{1}{2}$ in.	Proportion.	Mean proportion.
Gun Metal on Cast Iron.					
Cwt.	lbs.	oz.	sec.		
1	16	0	90	7·00	5·94
2	30	0	..	7·46	
3	44	0	..	7·63	
4	60	12	..	7·37	
5	112	0	80	5·00	
6	134	0	90	5·01	
7	154	0	..	5·09	
8	175	0	..	5·12	
9	200	0	..	5·04	
10	233	0	..	4·70	
Yellow Brass on Cast Iron.					
10	272	0	90	4·11	4·11
Cast Iron on Cast Iron.					
10	173	8	90	6·45	5·92
11	228	0	—	5·40	
Cast Iron on Cast Iron with Blacklead.					
11	161	0	90	7·65	7·65
Gun Metal on Cast Iron with Blacklead.					
11	170	0	90	7·24	7·24

Weight on the axle.	Weight required to move it.		Time in passing over 4½ in.	Proportion.	Mean proportion.
Yellow Brass on Cast Iron with Blacklead.					
Cwt.	lbs.	oz.	sec.		
1	14	12	90	7·59	7·02
2	31	4	—	7·16	
3	47	8	—	7·07	
4	65	8	—	6·83	
5	84	0	—	6·66	
11	181	0	—	6·80	
Gun Metal on Cast Iron with Oil.					
11	218	8	90	5·63	5·63
Yellow Brass on Cast Iron with Oil.					
½	1	8	90	37·33	21·38
1	3	8	—	32·00	
2	7	0	—	32·00	
3	16	8	—	20·36	
4	24	8	—	18·28	
5	29	4	—	19·14	
10	193	8	—	5·78	
11	200	12	—	6·13	
Cast Iron on Cast Iron with Oil.					
10	131	1	90	8·54	8·67
11	140	0	—	8·80	
Cast Iron on Cast Iron with Hog's-lard.					
10	117	4	90	9·55	9·55
Yellow Brass on Cast Iron with Hog's-lard.					
½	1	10	90	34·46	20·99
1	3	1	—	36·57	
2	7	8	—	29·86	
3	23	0	—	14·60	
4	43	0	—	10·41	
5	47	8	—	11·78	
10	120	8	—	9·29	

Weight on the axle.	Weight required to move it.		Time in passing over 4½ in.	Proportion.	Mean proportion.
Gun Metal on Cast Iron with Hog's-lard.					
Cwt.	lbs.	oz.	sec.		
10	130	4	90	8·59	8·59
Yellow Brass on Cast Iron with Anti-attrition Composition.					
1	7	8	90	14·93	31·97
2	9	0	—	24·88	
3	10	8	—	32·00	
4	12	8	—	35·84	
5	14	8	—	38·62	
10	*190	0	—	5·89	
10	23	8	—	47·65	
10	20	0	—	56·00	
Yellow Brass on Cast Iron with Tallow.					
1	3	1	90	36·57	39·43
2	5	12	—	38·95	
3	8	5	—	40·42	
4	11	1	—	40·49	
5	13	12	—	40·72	
Yellow Brass on Cast Iron with Soft Soap.					
½	2	2	90	26·35	34·02
1	3	8	—	32·00	
2	6	0	—	37·33	
3	9	8	—	35·36	
4	12	12	—	35·13	
5	14	12	—	37·96	
Yellow Brass on Cast Iron with Soft Soap and Blacklead.					
½	5	8	90	10·18	18·55
1	9	3	—	12·19	
2	12	1	—	18·56	
3	14	4	—	23·57	
4	19	8	—	22·97	
5	23	8	—	23·82	

* In this experiment the axle had remained in a state of rest for forty-one hours, and it took 190 pounds to move it, but the axle being retouched with the composition, it required but 23 pounds 8 ounces.

It appears from an inspection of these tables that when no unguents were employed, and when the gun metal was loaded with variable weights from one to ten cwt., the friction varied within the limits of $\frac{1}{7.8}$ and $\frac{1}{4.7}$ of the pressure. The friction was greater with yellow brass than with cast iron, and the friction in all the three cases was reduced by using blacklead. When unguents were used with yellow brass and cast iron, the friction with the smaller weights was about one-thirty-seventh of the pressure, but with great weights of ten cwt. it increased to one-fifth or one-sixth. Cast iron on cast iron under similar circumstances gave less friction, and still less when hog's-lard was substituted for oil. Gun metal on cast iron gave less friction with hog's-lard than with oil. Yellow brass on cast iron, with anti-attrition composition, gave very irregular results; but generally the proportion was greater with less weights than with greater weights. Yellow brass on cast iron, with tallow gave the least friction; this unguent is therefore to be recommended as the best in this case. Yellow brass on cast iron, with soap, gave the next best result, and is therefore superior to oil.

Table of Friction, as depending on Velocity.

	Weight on the roller.		Weight required to move the roller.		Time in falling 21 feet.		Proportion.	Remarks.
	lbs.	oz.	lbs.	oz.				
Without Oil.	348	8	112	0	5		3·11	
	300	0	112	0	5		2·67	Began to grind.
	250	0	114	0	7		2·45	Grinding increasing with stopping.
	280	0	114	0	7		2·45	
	280	0	228	0	4½		1·22	
	224	8	112	0	6		2·00	
	224	8	112	0	4½		2·00	
	174	8	58	0	4		3 00	
	174	8	58	0	4		3·00	
	174	8	116	0	2		1·50	
	174	8	116	0	2		1·50	
	160	8	56	0	7		2·86	
	160	8	56	0	8		2·86	
	66	8	28	0	8		2·37	
	62	8	22	0	4		2·84	
	62	8	22	0	4		2·84	
	62	8	44	0	2½		1·42	
	62	8	44	0	2½		1·42	
	62	8	44	0	2½		1·42	
With Oil.	62	8	7	0	1st.	Whole	8·92	
	62	8	7	0	half.	height.	8·92	
	62	8	7	0	11	22	8·92	
	62	8	7	0	9	18	8·92	
	62	8	7	0	8	16	8·92	
	62	8	7	0	8	16	8 92	
	62	8	7	0	8	17	8·92	
	62	8	14	0	3	5	4·46	
	62	8	14	0	3	5	4 46	
	62	8	14	0	3	5	4·46	
	84	0	14	0	3½	7	6·00	
	84	0	14	0	3½	7	6·00	
	84	0	14	0	3½	7	6·00	
With Tallow.	272	8	42	0	14½	28	6·48	
	272	8	42	0	6½	13	6·48	
	272	8	42	0	6½	13	6·48	
	272	8	42	0	7½	14	6·48	

Frustum, in geometry, is the part of a solid next the base, left by cutting off the top or segment, by a plane parallel to the base. To find the solid content of the frustum of a cone or pyramid, add into one sum the areas of the two ends and the mean proportional between them, then $\frac{1}{3}$ of that sum will be a mean area, or the area of an equal prism, of the same area, or the area of an equal prism, of the same altitude with the frustum; and, consequently, that mean area being multiplied by the height of the frustum, the product will be the solid content of it. That is, if A denote the area of the greater end, a that of the less, and h the height; then $\frac{1}{3}(A + a + \sqrt{A\,a}) \times h =$ the solidity.

The curve surface of the zone or frustum of a sphere is had by multiplying the circumference of the sphere by the height of the frustum; and the solidity of the same frustum is found by adding together the squares of the radii of the two ends, and $\frac{1}{3}$ of the square of the height of the frustum; then multiplying the sum by the said height and by the number 1·5708; that is, $(R^2 + r^2\ \frac{1}{3}h^2) \times \frac{1}{2}ph$ is the solid content of the spheric frustum, whose height is h, and the radii of its ends R and r, p being = 3·1416.

Fuel. In our article coal we have made some remarks on the different species of that article of fuel; but it is necessary that some farther particulars of a more general nature be stated in this place. Respecting the quantity of steam produced by a given quantity of fuel no very accurate results have as yet been obtained. The annexed table, however, shows at one view those data which may be more implicitly relied upon:

Table showing the Quantity of Heat produceable from different kinds of Fuel.

Different kinds of Fuel experimented on.		Pounds of Water heated 1° by 1 pound of Fuel.	Pounds of Water at 52° converted into Steam at 220°.	Pounds of Fuel to transform a cubic foot of Water 52° into Steam 220°.
Newcastle or Swansea coal, according to Mr Watt .	from	6950	5·93	10·5
	to	10400	8.9	7·0
	mean	8675	7·4	8·75
Newcastle, according to Dr Black .		9230	7·9	7·9
Ditto. Wall's-end coal, Tredgold .		10050	8·6	7·25
Wednesbury coal, according to Mr Watt	from	5200	4·45	14·0
	to	7800	6.68	9·34
	mean	6500	5.56	11·67
Pinewood, (dry,) Count Rumford .		3618	3·1	20·02
Oakwood, (dry,) ditto.		5662	4.85	12·9
Compact peat from Dartmore, Tredgold		2400	2·05	30.5
Culm, Glasgow, ditto.		3330	2·85	22.0
Culm, Welch, ditto.		4175	3·56	17·5

According to Mr Gilbert, who experimented largely on this subject in the mining districts of Cornwall, seven pounds of coal will convert one cubic foot of water into steam; or, what amounts to the same thing, one bushel of coals will convert fourteen cubic feet of water from the ordinary temperature into steam. He also considers that the steam so formed will occupy 1330 times the bulk of the water; hence a bushel of coals will form 18620 cubic feet of steam. Now the weight of a cubic foot of water being 62·5 lbs., it follows that the space occupied with water would be 18620 × 62·8 = 1150410 lbs.; and, as the elastic force of steam at 212 is equal to 15 lbs. on the square inch, or 33·92 feet of a column of water, it follows that, a vacuum being produced, one bushel of coals would raise 1150410 lbs. to a height of 33·92 feet; or, what amounts to the same thing, 39361000 lbs. to the height of one foot. We subjoin a table of the quantity of coals required per hour for double-acting condensing engines from 6 to 100 horses' power.

Horses' Power.	Diameter of Cylinder.	Coals for each Horse's power in lbs.	Total Coals per Hour.
6	13·9	12·2	73
8	15·0	10·5	84
10	17·7	10·0	100
12	19·2	9·8	117
14	20·6	9·0	126
16	21·75	8·7	140
18	23·0	8·5	153
20	24·0	8·3	166
22	25·1	8·0	176
24	26·1	7·8	187
26	26·9	7·6	197
28	27·3	7·4	207
30	28·6	7·2	216
32	29·5	7·1	227
34	30·3	7·0	238
36	31·0	6·9	249
38	31·8	6·8	258
40	32·6	6·7	268
42	33·3	6·6	279
44	34	6·5	286
46	34·7	6·4	294
48	35·3	6·3	302
50	36	6·2	310
52	36·6	6·1	317
54	37.3	6·1	329
56	38	6·0	336
58	38·8	6·0	348
60	39·2	5·9	354
62	39·8	5·9	366
64	40·4	5·9	378
66	41·0	5·9	384
68	41·6	5·9	394
70	42	5·8	406
72	42·7	5·7	410
74	43·3	5·7	422
76	43·7	5·7	433
78	44·4	5·6	437
80	45	5·6	448
85	46·2	5·6	476
90	47·5	5·6	504
95	48·7	5·5	522
100	50	5·5	555

Funicular Machine (from *funiculus*, a rope, is a term used to denote an assemblage of cords, by means of which two or many powers sustain one or many weights.

Furnace, a contrivance for generating great quantities of heat. Furnaces are of different constructions according to the different purposes to which they are applied. In some cases it is not so much a great quantity of heat as a very intense heat that is required; as in the furnaces for smelting, casting, and forging metals. In other cases furnaces are constructed not so much with a view to obtain an intense heat, as to procure a great quantity and keep up a steady temperature: of this description are the furnaces for glass manufacture, and for the generation of steam for the steam engine.

The first object in the erection of a furnaco is to procure a sufficient supply of air for the support of the combustion of the fuel. It would appear from experiment and observation, that, under ordinary circumstances, about 200 cubic feet of common air are requisite for the complete combustion of one pound weight of good coal. When it is remembered that in some of óur large steam engine boilers not less than twenty tons of coals is consumed in an hour an estimate may be made of the great quantity of air that must pass through the fire in order to support combustion. Suppose there were only half a ton, or 10 cwt., then $212 \times 10 \times 200 = 224000$ cubic feet of air that must pass into the furnace in one hour, or 3733 feet per minute. How is so much air to be directed to the fire? by the action of the chimney ? The chimney is a long perpendicular tube, open at both ends, the under part of which is made to communicate with the roof of the place where the fuel is to be consumed. The office of the chimney in causing a draught or ensuring a regular supply of air to the fuel is not difficult of explanation. Air is expanded by heat, and according to the degree of its expansion it becomes specifically lighter, and will therefore have the greater tendency to ascend. The air above the fire being heated will ascend into the chimney, and thus form a column of light air whose tendency will be to rise up in the atmosphere. The ascent of the heated air in the chimney causes a sort of vacuum above the fuel, and, by the laws of the pressure of aeriform fluids the external air will be forced in, in order to supply the deficiency. In furnaces the opening for the ingress of air is so placed that all the air introduced must pass through the fuel, and thus contribute to the support of combustion. No opening is left on the upper side of the fuel except the chimney, otherwise the external air would rush in above the fire to supply the place of the rarified air and not touch the fuel; but the opening being made below the fuel all the air from without must pass through the fire before it can supply the place of heated air, which passes through the chimney. The same principles account for the phenomena of winds. The chimney of a furnace therefore creates a draught of fresh air through the fire, but it does more, it serves to carry away the impure air and also the smoke arising from combustion, and is therefore a most essential part of every furnace. For ordinary fire-places, where the heat does not require to be very intonse, and where, consequently, the supply of air of air does not require to be so rapid, a considerable quantity of the air that supplies the place of that which escapes up the chimney is allowed to enter between the fuel and the bottom of the chimney and never come in contact with the fire, and all the air which passes into the fire-place is useless for combustion excepting that which passes up through the fuel by the grating from the bottom and the little that enters the fire from the front. The draught from the bottom of a fire-place is also comparatively littlc, for the air which enters the chimney from above the fire cools the heated air, and thus retards the rapidity of its ascent.

The grating on which the fuel of a furnace rests is formed of iron rods, placed lengthwise, and parallel to each other. The spaces between the bars are generally from three-eighths to half an inch; the bars themselves are about an inch thick, with a swell in the middle for greater strength; they are loose, and made to rest on cross bars at each end, so that they may be removed at pleasure. It would appear that one foot of grating space is required for every two pounds of coal consumed in a furnace per hour, and it is obvious that the magnitude of the fire will depend upon thc extent of the grating. It is also worthy of remark that in the construction of furnaces the chimney should be placed as much as possible in the same perpendicular line with the grating, for then the air will be less obstructed in its natural tendency to rise in a perpendicular direction when heated. The tendency of the air in the chimney to rise will be proportionate to its temperature, wherefore every means ought to be employed to preserve the heat of the chimney, by constructing it of a bad conductor of caloric, such as brick; and, in order to facilitate the ascent of the hot air and smoke, the interior of the chimney should be smooth, straight, and perpendicular. Sudden bendings, or alterations in width create eddies and abstract the ascent of the hot air and smoke. The cylindrical form of the chimney is decidodly the most preferable, as it presents less cooling surface and greater area than any other form: the square chimney has, however, the recommendation of being more easily constructed. The chimney, whether circular or square, should be slightly tapered towards the top; for as the air ascends it becomes gradually cooler, and consequently diminished in bulk, and the width of the chimney should be regulated to this, so that it may be equally filled throughout.

A littlo reflection will show that the degree of draught, or the velocity with which the external air rushes up through the bottom of the grating, will depend upon the difference of the weight of the column of heated air within the chimney and a similar column of the air without. This difference will evidently increase with the height of the chimney. Thus, let there be a chimney of twenty feet high, and let the air within it be heated so as to be expanded to twice its ordinary bulk, then it is plain that the chimney contains a column only half as heavy as a like column of the external air of the ordinary temperature; wherefore the air from without will press up with a force equal to ten feet of the same area, or the cross section of the chimney. Calculations on this matter may therefore be easily made, if we know what proportion of air is expanded by given increments of heat. It has been determined by experiment that from 32° to 680° or the boiling point of Mercury, air expands uniformly by uniform increases of temperature, at the rate of a 488th part of its volume for every additional degree of heat; hence an increase of temperature of 488° would double its former volume and also double its tendency to ascend. From these data, by an easy investigation, it can be shown that the height of the preponderating column of external air will be $\frac{488 + t}{t \times h}$ where t is the number of degrees that the air in the chimney is heated above the external air, and h the height of the chimney. In using this formula, however, it is to be observed that the air cools gradually as it ascends the chimney, and the average or mean of the heats at bottom and top ought to be taken. But the most important point to determine is the velocity of the external air into the furnace, which on investigation will be found to increase with the square root of the height of the heated column, or, what may be substituted, the square root of the chimney's height; and, making allowances for friction, &c., a good approximating rule will be

$$6 \times \sqrt{\frac{488 + t}{t \times h}} = \text{velocity of the air into the grating.}$$

Thus, suppose the height of the chimney to be 40 feet, and that it is one square foot in width, the air within it being 350° higher in temperature than the external air, then we have

$$6 \times \sqrt{\frac{488 + 350}{350 \times 40}} = 6 \times \sqrt{16{\cdot}602} = 24{\cdot}444$$

feet per second of air that enters the grating. The velocity of the hot air up the chimney is a point which ought to be correctly ascertained, in order to guard against misconstruction. The rule for ascertaining this is

$$6 \times \sqrt{\frac{t \times h}{480}}$$

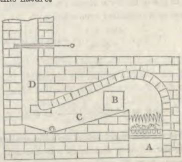
Thus, let the temperature of the air be 300 above that of the external air, and the height of the stalk or chimney 60 feet, then

$$6 \times \sqrt{\frac{300^{\circ} \times 60}{480}} = 6 \times \sqrt{37{\cdot}5} = 6 \times 6{\cdot}123 = 36{\cdot}738$$

feet per minute. When a very great draught is required, as in smelting iron and other ores, the chimney is not sufficiently powerful, and mechanical means are necessary to force a sufficient quantity of air into the fire: this is sometimes done by blowing-cylinders (see *Blowing*), and sometimes by fanners, revolving rapidly on an axis.

The common air furnace is mostly used for the melting of metals. the usual form of this kind of furnace is represented in the annexed figure. The charcoal, coke, or coal, is placed upon the grating in the centre of the figure, and the retort *c*, containing the metal to be melted, is placed in the centre of the fire. The chimney does not ascend perpendicularly from the fire, but communicates with it by a horizontal opening, the height of the chimney making up for the defect of indirect draught. There is an opening above the crucible for admitting and taking it out. The angle of the flue is often serviceable for placing a retort in, so that it may be heated. There are various forms of furnaces of this class, which are modified in shape according to the purposes for which they are designed; but they all act upon similar principles, and minute details regarding them would be inconsistent with a work of this nature.

The annexed cut represents an air furnace of the reverberatory kind: — A the ash-pit above which is the grate, B the door, C the hearth, and D the chimney.



In this sort of furnace the heat generated in the fire is not made to act immediately upon the crucible, but the fire-place is arched over and a horizontal flue passing along to about four times the length of the fire-place, and opens at the farther end into the bottom of the chimney. The flame and heated air are reflected or reverberated from the arched roof above the fire, and carried from thence along the flue to a retort placed at the bottom of the chimney. This kind of furnace, from the great heat which may be procured by it, is extensively used in the iron manufacture. The fuel proper for it is coal.

There is another class of furnaces much used in the arts, especially in lacquering and enameling, where the material to be acted upon requires to be kept free of the smoke or dust arising from the fire; of this kind of furnace is the common kitchen oven. The lacquering furnace will be described under our article *Lacquering*: such furnaces are called muffled furnaces.

Self-feeding Furnace. The attendance of a man (the stoker) is in most cases necessary to supply regularly the coals requisite for the maintenance of a constant heat in steam engine furnaces. Several contrivances have been made, in order that the constant attendance of the stoker may be dispensed with. Mr Brunton of Birmingham was the first who perfected an apparatus of this kind. A circular grating is made to revolve horizontally, carrying the ignited fuel beneath the whole of the under surface of the boiler; the axis on which the grating moves being turned by machinery connected with the engine. As to the velocity with which the grating turns, it may be stated that for a cylindrical boiler, five feet diameter, the grating is made to perform one revolution per minute. The coals fall upon the grating from a hopper above, so contrived that when the grating arrives at a certain point in each revolution the channel of the hopper is opened, and the proper quantity of coals fall upon the grating. The regulator lies upon a rim descending into a trough, thus forming a water or sand valve, for preventing any air from above from descending into the furnace. There is likewise a regulator connected with the damper, which increases or diminishes the quantity of coals permitted to escape from the hopper according to the strength of the fire. A simple and very effective self-regulating furnace has been extensively employed. There is a hopper near the mouth of the furnace, through the bottom of which coals, broken to a proper size, fall on two circular iron plates, revolving with great velocity being turned by the engine. The coals are thus thrown into the furnace in a regular manner, and the fire kept in a constant degree of intensity.

Fusee is a mechanical contrivance for equalizing the power of the main-spring of a watch; for, as the action of a spring varies with its distance from the quiescent position, the power derived from the force of a spring requires to be modified according to circumstances before it can become a proper substitute for a uniform weight, which is what it is intended to supply. In order, therefore, to correct this irregular action of the spring, the fusee on which the chain or catgut acts is made somewhat conical, so that its radius at every point may correspond with the strength of the spring.

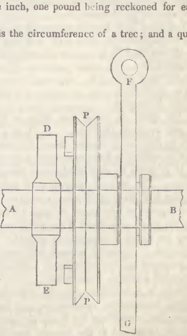
GAUGE, an instrument consisting of a stem, usually in the form of a square prism, with a small steel point, nearly at the end of one of the surfaces in the direction of its length, and just projecting enough to mark distinctly when pressed upon wood; the stem passes at right angles through a mortise in the middle of a piece of wood called the head. The head can be set at any distance required from the steel point, and secured by a small wedge passing through a mortise in one of its sides, and bearing upon the stem. The use of the gauge is to draw lines parallel to the arris of a piece of stuff, to serve as a guide for the saw, the plane, or the chisel. In drawing the line, it is necessary to keep that side of the head which is next the steel point rather firmly pressed against the edge of the wood. A guage made with two points projecting on the same side, and one of which, being moveable in a groove or mortise, can bo placed at any distance from the other, is called a mortise gauge; it is used alike in gauging mortises and tenons.

GAUGE-COCKS. There are inserted in the top of the boiler two tubes, near to each other, open at both ends, but furnished with stop-cocks at the top, which may be opened or shut at pleasure. One of these pipes has its lower orifice a little above the proper water level of the boiler, and the other pipe dips a little below that level; so that when the one cock is opened steam should escape, but when the other is opened water should escape, if the water in the boiler be at the proper level. Should the water be too low, steam will escape from both cocks: and if too high, water. These indications warn the attendant whether or not the feed-pipe is doing its duty.

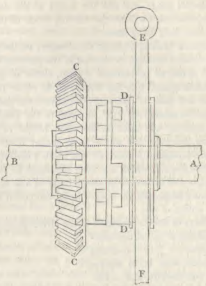
GAUGE, CONDENSER, an instrument for measuring the state of vapour in the condenser of the steam engine. This instrument consists of a bent iron tube, in the form of an inverted syphon, one leg of which is about twice the length of the other. The top of the longer leg opens into a pipe which communicates with the condenser, and furnished with a stop cock, by means of which the communication may be opened or closed at pleasure. Mercury is poured in at the shorter leg, which opens into the atmosphere, and the mercury carries a float with a stem which rises or falls according as the mercury rises or falls. When the pressure on the surface of the mercury, in both legs of the gauge, is equal, there will be no difference of level. By the exhaustion in the condenser the mercury rises as much in tho long leg as it falls in the short one; so that, the stem of the float being graduated into half inches, each division will be equivalent to one inch on the common barometer. The gauge should be made capable of indicating a steam pressure in the condenser of between two and three inches of mercury. Take the difference between the heights of the boiler or steam gauge and the condenser gauge, and add the height of the common barometer at the time, the result will be the moving force of the steam, deductions for friction, &c., being made.

Gauge Steam, a simple contrivance, on the principle of the barometer, for determining the amount of the pressure of steam. The common form is that of an inverted syphon, either of glass or iron, one leg of which is opened into the boiler, or to some tube connected with the boiler and near it. Mercury is put into the gauge, and it is plain that when the steam is at 212°, or equal to the pressure of the atmosphere, the mercury will stand at the same height in both legs of the tube. When, however, the steam is of greater elastic force than the atmospheric pressure the mercury will make a corresponding rise in that leg open to the air, which leg being graduated in inches the rise of the mercury, or the difference of the heights of the mercury will indicate the pressure in pounds per square inch, one pound being reckoned for each two inches of rise.

Girt, in timber measure, is the circumference of a tree; and a quarter of this is called the quarter-girt. The common practical rule is to square the quarter-girt, and multiply by the length of the tree for the content.



Gland, a contrivance for engaging or disengaging machinery, moved by belts or bands. A pulley P revolves upon a shaft A B, to which it requires sometimes to be connected, in order to drive some other part of the machinery. A cross piece, D E, called gland, is firmly fixed in the shaft, and one or more projecting pieces are fixed upon the wheel, parallel to the axis of the shaft, the wheel itself being made capable of being slided backwards or forwards to or from the gland by means of a handle F G. The part of the shaft on which the wheel slides is made square, so that when, by means of the handle, the wheel is moved forward to the gland, the projecting pieces are caught, and consequently the wheel turns with the shaft. The great objection to this contrivance is, that it produces a shock in the machinery at the moment of engaging, which renders it inferior to the fast and loose pulley. Another method of engaging and disengaging by the clutch may be here mentioned, which is superior to the gland in being less liable to fracture, as it may be made of any required thickness. A B is a shaft on which the wheel C C is capable of moving freely by means of a bush, being always kept in motion by being connected with the main shaft. The clutch, D D is made to slide freely upon the part of the shaft A which is square. The clutch is moved to or from the wheel by means of the handles E F, so that it may or may not be caught by the wheel, and thus engages or disengages the shaft. This contrivance is objectionable, like the gland, on account of the shock which is given to the machinery, when the clutch is brought into contact.



Globe, in geometry, a round solid body, which may be conceived to be generated by the revolution of a semicircle about its diameter. It is also called a sphere. See *Sphere.*

Glue is a tenacious cement, principally used by cabinet-makers, joiners, bookbinders, case-makers, and hatters. The substances from which glue is made are the shreds or parings of hides; the ears before they are immersed in the tanner's vats; the cuttings and raspings of horn, from the comb-maker and the button-maker; and the hoofs and horns of oxen, calves, and sheep from the butcher; the pelts of the hare, rabbit, beaver, &c.; parings of vellum and parchment from the leather-dresser, glover, &c. These substances are indiscriminately mixed together, and are purified from all grease and dirt by digestion in lime water, the greatest care being taken to remove every piece that is in the slightest degree putrescent. The materials are next steeped and washed in clean water, with frequent stirring, and are afterwards laid in heaps and the water pressed out. They are then boiled in a large brass kettle with clear water, the fat and dirt being constantly skimmed off as they rise, and when the whole is dissolved a little melted alum or finely powdered lime is added. After the skimming has been continued for some time, the whole is strained through baskets and suffered to settle, in order that the remaining impurities may subside and the fat rise to the top. The impurities and fat being removed, it is then returned into a clean kettle, and suffers a second evaporation and skimming. When it acquires a clear darkish brown colour, and a sufficient consistence, which is known by the appearances during ebullition, it is lifted out by a scoop into frames or moulds about six feet long, one foot broad, and two deep, where it is allowed to cool gradually. It is then cut by a spade into square cakes, and each of these is afterwards divided into three pieces, by an instrument like a bow, having a brass wire for its string. The pieces thus cut are dried in the open air, on a kind of net-work, generally old herring nets, fastened in moveable sheds of four feet square, each containing six or eight rows of net-work. When the glue is dry, each piece is rubbed gently with a wet cloth, to give it that glazed appearance which the London glue always possesses. The different pieces are then packed carefully up in separate rows in barrels or hogsheads, and are ready for sale. The best glue swells considerably, without melting, by three or four days' immersion in cold water, and recovers its dimensions and properties by drying. When glue looks thick and black, or has got frost in the drying, it should be melted over again with a sufficient quantity of fresh glue. Good glue is distinguished by its having a strong black colour, and by being free of cloudy and black spots when held between the eye and the light.

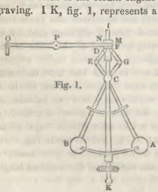
Glue must be steeped for several hours in cold water, when it will become swelled and softened. It must then be gently boiled till it is entirely dissolved and of a consistence not too thick to be easily brushed over wood. A quart of water may be used to half a pound of glue. In melting glue, the heat employed should not be more than is required to make water boil; and, to avoid burning it, the vessel containing it is suspended in another vessel containing only water. The glue should be thoroughly dissolved, and used boiling hot at the first or second melting; the wood should be warm and perfectly dry, and a very thin covering of glue be interposed at the juncture, and the surfaces to be joined, strongly pressed together, and left in that state, in a warm but not hot situation, till the glue is completely hard. The most essential of these are the hotness of the glue and the dryness of the wood. The faces of joints must be rubbed lengthwise one upon another two or three times. Glue, by repeated melting, becomes of a dark and almost black colour, and then its qualities are impaired; when newly melted it is of a light ruddy brown colour, nearly like that of the dry cake held up to the light, and while this colour remains, it may be considered fit for almost every purpose; and that glue which has been the longest manufactured is the best. A glue which does not dissolve in water may be obtained by melting common glue with the smallest possible quantity of water, and adding by degrees linseed oil rendered dry by boiling it with litharge; while the oil is added the ingredients must be well stirred to incorporate them thoroughly. A glue which will resist water, in a considerable degree, is made by dissolving common glue in skimmed milk.

Finely levigated chalk added to the common solution of glue in water, constitutes an addition which strengthens it, and renders it suitable for sign-boards, or other things which must stand the weather. A glue that will hold against fire or water may be prepared by mixing a handful of quick lime with four ounces of linseed oil: thoroughly levigate the mixture, boil it to a good thickness, and then spread it on tin plates in the shade; it will become exceedingly hard, but may be dissolved over a fire as ordinary glue, and is then fit for use.

Gnomon, in geometry, is the space included between the lines forming two similar parallelograms, of which the smaller is inscribed within the larger, so as to have one angle in each common to both.

Governor, a contrivance for regulating the motion of machines. A common form of the steam engine governor is shown in the annexed engraving. I K, fig. 1, represents a spindle kept in motion by the engine;

Fig. 1.



A B the centrifugal balls; C A and C B the rods which suspend the balls. These rods cross one another and pass through the spindle at C, where the whole are connected by a round pin put through the spindle and the rods at C, which serves as the point of suspension for the centrifugal balls or revolving pendulum. A part of the spindle above C is square, and nicely polished, so that the piece of brass, M, may slide easily upon it. The piece of brass M is round on the outside, and has an external groove turned upon the upper end of it to receive the lever N O, whose fulcrum is at P. This piece of brass is connected with the ball-rods by two short pieces and joints, D E F G. The construction of steam engine governors sometimes differs a little from that now described; but if this construction be understood there will be no difficulty in comprehending any other.

When the engine goes too fast, the balls fly off from the spindle and depress the end N of the lever, which partly shuts the throttle-valve, and diminishes the quantity of steam admitted into the cylinder; and, on the other hand, when the engine goes too slow, the balls fall down toward the spindle and elevate the end N of the lever, which partly opens the throttle-valve, and increases the quantity of steam admitted into the cylinder.

The usual velocity of the axis is thirty turns per second of time. It can be shown that the vertical distance between the plane in which the balls move and the point of suspension of the rods is equal to the length of a pendulum, making twice the number of vibrations that the balls make revolutions in the same time. Now, since the common velocity of the balls is thirty turns per second, therefore the length of the governor is the vertical distance between the plane of the balls; and the point of suspension will be equal to the length of a second's pendulum, that is, 39·14 inches. From this it follows that to find the height for any other number of revolutions,

$$\frac{35226}{\text{revolutions per second}}; \quad \text{or}$$

$$\left(\frac{375}{2 \times \text{revolutions per minute}}\right)^2 = \text{the length.}$$

From these rules it will be found that when the revolutions are 20 per second the length will be 88·065 inches; and also when the revolutions are 38 per minute the length is 24·305 inches. From these calculations it is not difficult to determine the requisite range of the slide of the governor. The greatest change of velocity should not, under ordinary circumstances, exceed one-tenth more or one-tenth less than the mean at which the engine ought to work. Suppose that at the proper motion of the engine the governor makes thirty-eight revolutions per minute, its height then will be, as before stated, 24·305; wherefore, the tenth of this being 2·4305, we have $24{\cdot}305 + 2{\cdot}4305 = 26{\cdot}7355$ = the greatest height, and $24{\cdot}305 - 2{\cdot}4305 = 21{\cdot}9745$; and the entire range will therefore be $26{\cdot}7355 - 21{\cdot}9745 = 4{\cdot}861$ inches, or very nearly 5 inches. A shorter process will be to take one-fifth of the medium height for the range; thus,

$$\frac{24 \cdot 305}{5} = 4 \cdot 861, \text{ the same as before.}$$

The length or the distance between the point of suspension and plane of revolution of the balls being given, to find the times of revolution per minute:

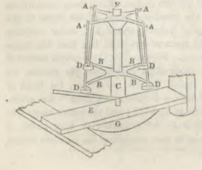
$$\frac{1}{2}\left(\frac{375}{\sqrt{\text{length}}}\right). \text{ Thus 36 inches being given}$$

$$\text{Then } \frac{1}{2}\left(\frac{375}{\sqrt{36}}\right) = \frac{1}{2}\left(\frac{375}{6}\right) = 31 \cdot 25 \text{ rev. per min.}$$

The governor ought to be so adjusted that when at the medium height, the throttle should be entirely open. The stay on which the balls rest when they fall in, ought to be of such a length that the rods which suspend the balls make angles of about 30° with the upright axis. The other rods may with advantage be so arranged as to make more acute angles with the axis than is represented in the figure. According to the size of the governor, the weight of each of the balls may be from 30 to 80 lbs.

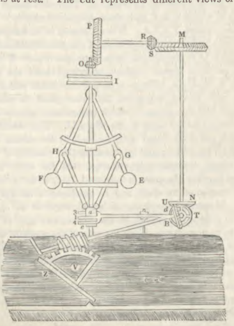
Governor for a Wind-mill.—In a wind-mill, when the velocity is increased by the irregular action of the wind, the corn is sometimes forced rapidly through the mill without being sufficiently ground. There is a contrivance for preventing this, similar to the governor of a steam engine, but which was much earlier in use, and called in some parts of England a lift-tenter. By means of the centrifugal force of one or more balls, which fly out as soon as the velocity is augmented, and allow a lever to rise with them, the upper millstone is made to descend and bring it a little nearer to the lower one.

The construction of Lift-tenters for Windmills.—This machine, and part of the stone-spindle and framing with which it is connected, are represented in the annexed cut. To the stone spindle there are fixed four arms, A A A A, and there are four similar arms, B B B B, firmly attached to the hollow cylinder C, which is loose on the spindle F G. The pendulums D D D D, are hung above to the arms A A A A, and through holes toward their lower extremities pass the arms of the loose cylinder. When the mill is at rest the pendulums hang vertically; but, by their centri-



fugal force, when the mill is in motion they hang obliquely; and that obliquity is increased in proportion to the velocity, and proportionately raises the loose cylinder C. This cylinder C acts on the one end of the lever E, which has a connexion with the clove upon which the bridge of the stone-spindle rests, and accordingly raises or depresses the upper millstone in proportion as the wind blows weak or strong.

Water-wheel Governors.—Governors are sometimes applied to water-wheels, and made on various constructions. We shall describe a construction which has for several years been at work in Cartside cotton-mill, erected under the direction of the late Robert Burns, Esq. It has a revolving pendulum which receives its motion from the mill, and in proportion as the machinery moves faster or slower the centrifugal force acts upon the governor, and raises or depresses an iron cross, which, acting on a lever, reverses the motion by the wheel work, which operates upon a sluice so as to enlarge or lessen the passage of the water to the water-wheel; this sluice is made on the principles of the throttle-valve, that it may be moved by a small power. So long as the machinery is moving at a proper velocity this wheel-work of the sluice apparatus remains at rest. The cut represents different views of this ma-



chine, and some of its parts detached. The same letter in all the figures refers to the same part. The revolving pendulum, E F G H, receives its motion from the mill work by means of a rope giving motion to a pulley, I. The upright shaft, M N, is kept in constant motion by the the wheel work O P R S. The wheel N acts constantly into the two bevelled wheels T and U, and makes them move in contrary directions. They are loose on the shaft when the mill is going at its proper speed: but if the mill moves either too fast or too slow, the one of these wheels, by means of a clutch, Q, in a way to be described, is connected with, and carries round the lying shaft D C; and, by a pair of bevelled wheels, communicates motion to the oblique shaft, B W; which again, by a screw, X, and quadrant-wheel, Y, moves the sluice, Z; and, by making it stand more or less oblique, alters the area of the passage for the water. It will appear evident that the box *a* will be raised or depressed in proportion as the balls E and F, of the revolving pendulum E F G H, are removed further or brought nearer to the centre of motion; for when the velocity is greatest, the balls E and F, by their centrifugal force, will extend themselves furthest from the centre of motion, and raise the box *a*. To the box *a* is fixed a cross *b c*. There is a forked lever, *d q e*, the fulcrum of which is at *f*, and which turns horizontally. This forked lever has four prongs, 1 2 3 4. When the mill is at its proper speed, the cross works within the prongs 1 and 2; in this situation of the forked lever the clutch Q is disengaged from both the wheels T and U, and they move on their bushes without carrying round the lying shaft. The clutch is made to slide on a part of the shaft which is square. When the mill moves too quick the cross gland is raised, and in turning round hits the prong 3, which immediately causes the lever to throw the clutch into the arms of the wheel U. This wheel then carries the clutch and shaft round with it; and, by the means already described, acts on the sluice; and by lessening the quantity of water falling on the wheel, diminishes its velocity. On the other hand, when the mill goes too slow the cross is depressed, and, striking the prong 4, reverses the motion of the shaft, and so produces a contrary effect on the sluice. Moreover, the train of wheel work is so calculated as very much to reduce the motion at the sluice, and this is found from experience to be necessary. Were the area of the aperture too suddenly changed, the effect on the water wheel would be too violent. Every time the mill is stopped it is proper to lift the wheel R out of gear. The centre on which the sluice turns should be one-third of its height from the bottom, in order that the pressure of the water above the centre may balance that below. At *m* there is an upright shaft, which is worked by hand when required.

Grain, a small weight, being the 480th part of an ounce troy weight, or apothecaries' weight; and very nearly the 7,000th part of a pound avoirdupois.

Grating. The most efficient mode of supplying fuel with air, in a steam engine furnace, is by causing the current to pass through an iron grating on which the coals are laid, the grating being placed above a pit which receives the ashes. It is important to determine the proper area of grating, in order that the admission of air may be proportionate to the requisite combustion, for which purpose Tredgold has given the following formula:

$$\frac{2}{\sqrt{h}}$$

where h, = the height of the bottom of the chimney above the bottom of the ash-pit. Thus if the height from the ash-pit to where the smoke enters the chimney be 4 feet, we have

$$\frac{2}{\sqrt{4}} = \frac{2}{2} = 1 \text{ foot},$$

the area of grating for each horse's power:—the area of the bars being equal to the area of the openings, and this is the usual proportion in practice. For wood and peat the area is double of that for coal, but the bars are also double the breadth. The bars are usually made thicker towards the middle, to ensure strength: they are commonly six inches in depth, and for coal furnaces three-fourths of an inch in breadth; their length being one-third that of the boiler. The height between the bottom of the bars and the bottom of the ash-pit varies from four feet to four feet six inches, and between the top of the bars and the bottom of the boiler about eighteen inches for a twenty horse power boiler; the depth of curvature of which may be taken about six inches. The bars lie loosely in niches in the bearers, so that they do not shake; but each may be taken out at pleasure, the depth of these niches being usually five inches; and, to ensure strength, a bearer passes along the middle, which leaves less stress upon the bearers at each end. The bearers are supported upon brick work.

Gravity. The attraction of gravitation differs from the attraction of cohesion in this respect, that it is exerted at all distances and by every particle of matter upon every other particle. The gravitating power of a body is always proportionate to its quantity of matter; and all the heavenly bodies are retained in their places by the due balance of their action on each other. An effect of gravity, or gravitation, familiar to all mankind, is the tendency of bodies to fall to the earth. This tendency is always towards a point, which is either accurately or very nearly in the centre of the earth; consequently bodies fall every where perpendicularly to the surface. The pressure of bodies to attain, in all cases, the lowest situation possible, or that nearest the centre of the earth, is what constitutes their weight. All substances having a certain degree of gravity, they consequently all have weight. Even smoke and vapours are possessed of it, the reason of their rising from the earth being the same as that which causes a piece of wood to swim in water, viz., they are lighter than an equal bulk of the atmosphere or fluid in which they are disengaged, and therefore their falling to the ground is as effectually resisted as the falling of a stone supported by the hand. Since the gravitating force is proportionate to the quantity of matter, the most compact and the most loose, the greatest and the smallest bodies, descend through equal spaces in equal times, unless they fall through a resisting medium, which operates most upon those which have the greatest extension for their weight. A guinea and a feather being dropt at the same instant from the top of a house, no one will be at a loss to say which would soonest reach the ground; but in the exhausted receiver of an air pump these two bodies fall together. The guinea, containing more solid matter than the feather, requires more force to put it in motion; but the attractive power being proportioned to the quantity of matter its velocity is not greater than that of a body which requires less force to put it in motiou. Another proof that the gravity of bodies is proportionate to their quantity of matter is derived from experiments on the motion of pendulums. When the lengths of pendulums are equal, and they vibrate in equal arcs, they always acquire equal velocities at the corresponding points of those arcs, and their vibrations are consequently performed in times exactly equal, however different the bulk and texture of the material of which they are composed. The resistance of the air must be understood to be excluded in this experiment, because it acts unequally on different bodies, as already exemplified in the guinea and feather experiment.

In all places equally distant from the centre of the earth, the force of gravity is nearly equal. The earth is, however, not a perfect globe, but a little depressed on two opposite sides, partly like an orange. These depressed parts are at the poles, and the polar diameter of the earth has been found to be about thirty-four miles shorter than the equatorial one. The surface of the earth at the equator being therefore seventeen miles further from the centre than at the poles, the force of gravity there is less than at the poles. It is for this reason that a pendulum calculated to swing seconds in the polar regions must be shortened before it will swing seconds at the equator; and that bodies at the equator lose one-two hundred and thirtieth part of the weight which they would have at the poles. The power of gravity, at any given place, is greatest at the earth's surface, from whence it decreases both upwards and downwards, but not both ways in the same proportion. The force of gravity upwards decreases as the square of the distance from the centre increases; so that at a double distance from the centre above the surface the force would only be one-fourth of what it is at the surface. The surface of the earth is, in round numbers, four thousand miles from the centre; if, then, a body at the surface weighs four pounds, and falls through sixteen feet in a second of time, it will at double this distance from the centre weigh but one pound, and will fall through but four feet in a second of time. Below the surface of the earth the power of gravity diminishes in such a manner that its intensity is in the direct ratio of the distance from the centre, and not as the square of the distance: so that at the distance of two thousand miles, which is half a semi-diameter from the centre, the force would be but half what it is at the surface: at one-third of a semi-diameter the force would be one-third, and the same ratio is applicable to all other distances. But although the force of gravity, strictly speaking, varies in the manner just stated, in receding from the surface, its operation at short distances is considered uniform, a quarter or even half a mile bearing so small a proportion to the earth's radius that the difference is too insignificant to be noticed in calculations.

As the power of gravity appertains to every particle of matter, and the gravitating power of entire bodies consists of that of all their parts, under certain circumstances the gravity of a part of the earth somewhat counteracts that of the whole earth. Thus, the attraction of a lofty mountain is found to draw a plumb line at the foot of it a little out of the perpendicular, so that in such a situation it does not tend to the centre of the earth.

The spaces described in different times by a falling body are to each other as the squares of the times from the beginning of the descent; or, which produces the same result, they are as the squares of the velocities acquired at the end of those times. The motion of a falling body being uniformly accelerated by gravity, the same cause uniformly retards the motion of a body thrown directly upwards. A body projected perpendicularly, with a velocity equal to that which it would have acquired by falling from any height, will ascend to the same height before it loses all its velocity. See *Accelerated Motion*.

Gravity and weight, it ought to be understood, are not interchangeable terms. Gravity is a power of which weight is the effect. Gravity has a constant tendency to impress on every particle of bodies a certain velocity, which would cause them to fall if they were not supported: weight is the resistance necessary to destroy this velocity, or produce this support.

Gravity, specific, is the relative gravity of any body or substance, considered with regard to some other body which is assumed as a standard of comparison, and this standard, by universal consent and practice, is rain water, on account of its being less subject to variation in different circumstances of time, place, temperature, &c. than any other body. By a fortunate coincidence, at least to English philosophers, it happens that a cubic foot of rain water weighs 1000 avoirdupois ounces; and, consequently, assuming this as the specific gravity of rain water, and comparing all other bodies with this, the same numbers that express the specific gravity of bodies will denote the weight of a cubic foot of each in avoirdupois ounces.

In bodies of equal magnitudes the specific gravities are directly as the weights, or as their densities. In bodies of the same specific gravities the weights will be as the magnitudes. In bodies of equal weights the specific gravities are inversely as the magnitudes. The weights of different bodies are to each other in the compound ratio of their magnitudes and specific gravities. Hence it is obvious that of the magnitude, weight, and specific gravity of a body, any two of these being given, the third may be found.

Exam. 1. The weight of a marble statue being 748 lbs. avoirdupois, required the number of cubic feet, &c., which it contains, the specific gravity of marble being 2742. Since a cubic foot of marble weighs 2742 ounces we have

As $2742 : 748 \times 16 :: 1 : 4{\cdot}36$ feet.

Exam. 2. Required the weight of a block of granite whose length is 63 feet and breadth and thickness each 12 feet, the specific gravity of granite being 3500. Here $63 \times 12 \times 12 = 9072$ feet: then again as $1 : 9072 :: 3500 : 31752000$ ounces: or 885 ton, $18\frac{3}{4}$ cwt.

A body immersed in a fluid will sink if its specific gravity be greater than that of the fluid: if it be less, the body will rise to the top, and be only partly immerged: and if the specific gravity of the body and fluid be equal, it will remain at rest in any part of the fluid in which it may be placed. When a body is heavier than a fluid it loses as much of its weight when immersed as is equal to a quantity of the fluid of the same bulk or magnitude. If the specific gravity of the fluid be greater than that of the body, then the quantity of fluid displaced by the part immerged is equal to the weight of the whole body. And hence, as the specific gravity of the fluid is to that of the body, so is the whole magnitude of the body to the part immerged. The specific gravities of equal solids are as their parts immerged in the same fluid. The specific gravities of fluids are as the weights lost by the same immerged solid.

To find the specific gravity of a body. This may be done generally by means of the hydrostatic balance, which is contrived for the easy and exact determination of the weights of bodies, either in air or when immersed in water or other fluid, from the difference of which the specific gravity of both the solid and fluid may be computed.

1. *When the body is heavier than water.* Weigh it both out of water and in water; then say, As the weight lost in water is to the whole or absolute weight, so is the specific gravity of water to that of the body.

2. *When the body is lighter than water.* In this case attach to it a piece of another body heavier than water, so that the mass compounded of the two may sink together. Weigh the denser body and the compound body separately, both out of the water and in it; and find how much each loses in the water by subtracting its weight in water from its weight in air; and subtract the less of these remainders from the greater; then use this proportion, As the last remainder is to the weight of the light body in air, so is the specific gravity of the water to the specific gravity of the body.

3. *When the specific gravity of a fluid is required.* Take some body of known specific gravity; weigh it both in and out of the fluid, and find the loss of weight in the fluid, by taking the difference of these two; then say, As the whole or absolute weight is to the loss of weight, so is the specific gravity of the solid to the specific gravity of the fluid.

For the method of finding the specific gravity of fluids by means of an hydrometer, see *Hydrometer*.

Table of the Specific Gravity of Metals

Antimony,	in a metallic state, fused	6·624	Lead,	ore, black	5·770
	glass of	4·946		, brown	6·974
	sulphur of	4·064		, white	7·236
Bismuth,	cast	9·823		, red, or red lead spar	6·027
	native	9·822		, yellow, molybdenated	11·352
	ore, in plumes	4·371	Mercury,	solid, 40 deg. below 0 Fahr.	15·632
Brass,	common cast	7·824		at 32 deg. of heat	13·619
	cast, not hammered	8·396		at 60 deg.	13·580
	wire-drawn	8·544		at 212 deg.	13·375
Copper,	cast	8·788	Nickel,	cast	7·807
	wire-drawn	8·878	Platina,	crude, in grains	15·602
	pyrites	4·080		purified	19·500
	ore, Cornish	5·452		the same hammered	20·337
	, white	4·500		rolled	22·069
	, grey	4·500		wire-drawn	21·042
	, yellow	4·300	Silver,	cast, pure	10·474
	, blue	3·400		cast, pure, hammered	10·511
	ore, prismatic	4·200		Parisian standard	10·175
	, foliated, florid red	3·950		shilling, George III.	10·534
	, radiated, azure	3·231	Steel,	soft	7·833
	, emerald	3·300		hardened, but not tempered	7·840
Gold,	pure cast	19·258		tempered, but not hardened	7·816
	the same hammered	19·362		tempered and hardened	7·818
	22 carats, fine, standard	17·486	Tin,	pure Cornish	7·291
	20 carats, fine, trinket	15·709		the same hardened	7·299
Iron,	cast	7·207		Molacca, fused	7·296
	bars	7 788		, hardened	7·307
	pyrites, cubic	4·702	Tungsten		6·066
	ore, specular	5·218	Uranium		6·440
	, micaceous	5·070	Wolfram		7·119
	, prismatic	7·355	Zinc,	in its usual state	6·862
Lead,	cast	11·352		pure and compressed	7·191
	litharge	6·300		sulphate of	1·900
	ore, cubic	7·587			

WOODS.

Alder	·800	Jasmin, Spanish	7·70
Apple-tree	·793	Juniper	5·56
Ash	·845	Lemon tree	7·03
Bay tree	·822	Lignum-vitæ	13·33
Beech	·852	Lime tree	6·04
Box, Dutch	·912	Logwood	9·13
French	1·328	Mahogany	10·63
Brazilian, red	1·031	Maple	7·50
Campechy	·913	Mastic tree	8·49
Cedar, American	·561	Medlar	9·41
Indian	1·315	Mulberry	8·97
Palestine	·613	Oak, heart of, 60 years old	11·70
Wild	·596	dry	9·32
Cherry tree	·715	Olive tree	9·27
Citron	·726	Orange tree	7·05
Cocoa,	1·040	Pear tree	6·61
Cork	·240	Pomegranate tree	13·54
Cypress	·644	Poplar	3·83
Ebony, Indian	1·209	, white, Spanish	5·29
American	1·331	Plum tree	7·55
Elder	·695	Quince tree	7·05
Elm	·671	Sassafras	4·82
Filbert	·600	Vine	13·27
Fir, yellow	·657	Walnut	6·71
white	·569	Willow	5·85
male	·550	Yew, Spanish	8·07
female	·498	Dutch	7·88
Hazel	·600		

STONES, EARTHS, &c.

Alabaster, yellow	2·699	Granite, Aberdeen, blue kind	2·625
stained brown	2·744	Cornish	2·662
veined	2·691	Egyptian, red	2·654
Dalias	2·611	, grey	2·728
Malaga	2·876	beautiful red	2·761
Malta	2·699	Girardmor	2·716
Oriental, white	2·730	violet, of Gyromagny	2·685
, semi-transparent	2·762	Dauphiny, red	2·643
Piedmont	2·693	, green	2·684
Spanish Saline	2·713	, radiated	2·668
Valencia	2·638	Semur, red	2·638
Ambergris	·926	Bretagne, grey	2·738
Amianthus, long	·909	, yellowish	2·619
short	2·313	Carinthia, blue	2·956
Asbestos, ripe	2·578	Grindstone	2·143
starry	3·073	Gypsum, opaque	2·168
Borax	1·714	semi-transparent	2·306
Brick	2·000	fine ditto	2·274
Chalk, British	2·784	cuneiform, crystallized	2·306
Biançon, coarse	2·727	rhomboidal	2·311
Spanish	2·790	ditto, ten faces	2·312
Coal, Cannel	1·270	Hone, white, razor	2·876
Newcastle	1·270	Jet, a bituminous substance	1·259
Staffordshire	1·240	Lime-stone, green	3·182
Scotch	1·300	, arenaceous	2·742
Cutler's-stone	2·111	, white fluor	3·156
Emery	4·000	, compact	2·720
Flint, black	2·582	, foliated	2·837
veined	2·612	, granular	2·800
white	2·594	Manganese,	7·000
Egyptian	2·565	grey ore, striated	4·756
Glass, flint	2·933	grey foliated	3·742
white	2·892	red, from Kapnick	3·233
bottle	2·732	black	3·000
green	2·642	scaly	4·116
St Gobin	2·488	sulphuret of	3·950
Leith, crystal	3·139	phosphate of	2·699
fluid	3·329	Marble, African	2·708

STONES, EARTHS, &c.

Marble, Biscayan, black	2·695
Brocatelle	2·650
Campanian, green	2·742
Carrara, white	2·717
Castilian	2·700
Egyptian, green	2·668
French	2·649
Grenada, white	2·705
Italian, violet	2·858
Norwegian	2·728
Parian, white	2·838
Pyrenean	2·726
Red	2·724
Roman violet	2·755
Siberian	2·718
Siennian	2·678
Switzerland	2·714
Valencia	2·710
Mill-stone	2·484
, phosphoric	1·714
Porcelain China	2·385
Limoges	2·341
Seves	2·146
British	
Portland-stone	2·570
Pumice-stone	·915
Paving-stone	2·416
Purbeck-stone	2·601
Porphyry red	2·765
green	2·676
red, from Cordone	2·754
green from ditto	3·728
red from Dauphiny	2·793
Pyrites, copper	4·954
ferruginous, cubic	3·900
, round	4·101
, of St Domingo	3·440
Rotten-stone	1·981
Salt	2·130

Serpentine, opaque, green Italian	2·430
, veined, black & olive	2·594
, red and black	2·627
, semi transparent, grained	2·586
, fibrous	3·000
, from Dauphiny	2·669
Slate, common	2·672
new	2·854
black stone	2·186
fresh polished	2·766
Stalactite, opaque	2·478
, transparent	2·324
Stone, Bristol	2·510
Burford	2·049
common	2·520
Clicard, from Brachet	2·357
Ouchain	2·274
Notre-Dame	2·378
Oriental blue	2·771
paving	2·416
Portland	2·570
pumice	·915
Purbeck	2·601
prismatic basaltes	2·722
rag	2·470
rotten	1·981
rock of Chatillon	2·122
Siberian blue	2·945
St Cloud	2·201
St Maur	2·034
touch	2·415
Sulphur, native	2·033
melted	1·991
Talc, black	2·900
crayon	2·089
German	2·246
Muscovy	2·792
yellow	5·623

LIQUIDS.

Acetic Acid	1·007
Acetous acid, red	1·025
, white	1·014
Alcohol, commercial	·837
highly rectified	·829
Ammonia, liquid	·897
muriate of	1·453
Beer, pale	1·023
brown	1·034
Benzoic acid	1·018
Cyder	1·018
Ether, acetic	·866
muriatic	·730
nitric	·909
sulphuric	·739
Fluoric acid	1·500
Formic acid	·994
Milk of cows	1·032
Muriatic acid	1·194
Nitric acid	1·271
, highly concentrated	1·583
Oil of Almonds, sweet	·917
Cloves, essential	1·036
Cinnamon, essential	1·044
Filberts	·916
Hemp-seed	·926

Oil of Lavender, essential	·894
Linseed	·940
Olives	·915
Poppies	·924
Rape-seed	·919
Turpentine, essential	·870
Whales	·923
Spirits of Wine, commercial	·837
, highly rectified	·829
Sulphuric Acid	1·841
, highly concentrated	2·125
Turpentine, liquid	·991
Vinegar, distilled	1·010
Water, rain	1·000
distilled	1·000
sea	1·026
Wine, Burgundy	·992
Bourdeaux	·994
Champaigne, white	·998
Canary	1·033
Constance	1·082
Madeira	1·038
Malaga	1·022
Port	·997
Tokay	1·054

RESINS, GUMS, ANIMAL SUBSTANCES, &c.

Ambergris	·926	Gum Seraphic	1·201
Aloes, socotrine	1·380	Tragacanth	1·316
hepatic	1·359	Gunpowder, in a loose heap	·836
Assafœtida	1·328	shaken	·932
Bark, Peruvian	·785	solid	1·745
Bees-wax, white	.969	Honey	1·450
yellow	·965	Indigo	·769
Butter	·942	Ivory	1·826
Camphor	·989	Lard	·948
Copal, Chinese	1·063	Madder-root	·765
Madagascar	1·060	Mastic	1·074
Opaque	1·140	Myrrh	1·360
Fat, Beef	·923	Olibanum	1·173
Mutton	·924	Opium	1·336
Veal	·934	Scammony of Aleppo	1·235
Hog's	·937	Smyrna	1·274
Galbanum	1·212	Spermaceti	·943
Gambouge	1·222	Sugar, white	1·606
Gum Ammoniac	1·207	Tallow	·942
Arabic	1·452	Tragacanth	1·316
Bdellium	1·372	Wax of Bees, white,	·969
Euphorbia	1·124	, yellow	·965
Scammony, of Aleppo	1·235	Shoemakers'	·897
Smyrna	1·274		

GASES.

In the following Table atmospheric air is supposed to be 1·000.

Atmospheric, or common air	1·000	Muriatic acid gas	1·278
Ammoniacal gas	·590	Nitrous gas	1·094
Arsenical hydrogen gas	·529	Nitrous acid gas	2·427
Azote	·969	Nitrous oxide	1·614
Carbonic acid	1·520	Oxygen, mean	1·104
Carbonic oxide	·960	Phosphuretted hydrogen	·870
Carburretted hydrogen	·491	Steam	·690
Chlorine	·470	Sulphuretted hydrogen	1·777
Chloro-carbonic gas	3·389	Sulphurous acid	2·193
Chloro-cyanic vapour	2·111	Vapour of alcohol	2·100
Cydrogen	1·806	absolute alcohol	1·613
Euchlorine	2·409	hydriotic ether	5·475
Fluoboracic	2·371	iodine	8·620
Fluosilicic acid gas	3·574	muriatic ether	2·219
Hydrogen	·074	oil of turpentine	5·013
Hydriodic acid gas	4·443	sulphuret of carbon	2·645
Hydrocyanic vapour	·948	sulphuric ether	2.586

GUDGEON, the extremity of a lying or horizontal shaft, that runs in the collar. Every gudgeon, in order to avoid unnecessary friction, should be made as small in diameter as possible, consistently with the requisite strength and durability. The cube root of the weight of a water-wheel in hundred weights, is nearly equal to the diameter in inches of a cast-iron gudgeon sufficiently strong to support such wheel. For wooden water-wheels, multiply the diameter in feet by the width also in feet, to which add the square of half the diameter: the cube root of the sum will be nearly equal to the diameter of the gudgeon in inches. It has been inferred from experiment that gudgeons of the same size, of cast and of wrought iron, are capable, at a medium, of sustaining weights without flexure, in the proportion of 9 to 14. The following table, to show the proportionate diameters of east-iron and wrought-iron gudgeons, has been drawn up on this principle :—

Table of Cast and Wrought Iron Gudgeons.

1	2	3	4
Diameter of cast-iron gudgeons in inches.	Cube of diameter of cast-iron gudgeons, or the cwts. which the gudgeons may sustain.	Cube of diameter of wrought iron gudgeons.	Diameter of wrought iron gudgeons in inches and parts.
1·	1·	·6428571	·863054
1·25	1·953125	1·2555803	1·063340
1·5	3·375	2·1696427	1·252921
1·75	5·359375	3·4453125	1·514825
2·	8·	5·1428571	1·709976
2·25	11·400625	7·3289732	1·912933
2·5	15·625	10·0446428	2·154435
2·75	20·796875	13·3694196	2·351335
3·	27·	17·3571420	2·571282
3·25	34·328125	22·0670803	2·802039
3·5	42·875	27·5625	3·018294
3·75	52·734375	33·9006696	3·239612
4·	64·	41·1420571	3·448217
4·2	76·765625	49·3493303	3·659306
4·5	91·125	58·5803571	3·881936
4·75	107·171875	68·896	4·101566
5·	125·	80·357	4·308870
5·25	144·763125	93·023	4·530655
5·5	166·375	106·955	4·747459
5·75	190·109375	122·213	4·959675
6·	216·	138·857	5·180101
6·25	244·140625	156·948	5·394690
6·5	274·625	176·545	5·609376
6·75	307·546875	197·709	5·828476
7·	343·	220·500	6·041377
7·25	381·078125	244·979	6·257324
7·5	421·875	271·205	6·471274
7·75	465·484375	299·240	6·686882
8·	512·	329·143	6·903436
8·25	561·515625	360·975	7·120367
8·5	614·125	394·795	7·337234
8·75	669·921875	430·664	7·553688
9·	729·	468·643	7·769462
9·25	791·453125	508·791	7·984344
9·5	875·375	562·741	8·257263
9·75	926·859375	595·837	8·415541
10·	1000·	642·857	8·631103
10·25	1076·890625	692·287	8·845085
10·5	1157·625	744·187	9·061309
10·75	1242·296875	798·619	9·279308
11·	1331·	855·643	9·493599

Columns 1 and 2 are the same as those calculated for cast-iron gudgeons. Column 3 contains numbers in the proportion of 9 to 14 less than those in column 2. Column 4 contains the cube root of column 3, or the diameters of wrought-iron gudgeons, having the same strength as those of cast-iron in column 1. In order to find the diameter of a wrought-iron gudgeon of the same strength with one of cast-iron of 3 inches in diameter: look on the first column for 3, and on the same line in the fourth column will be found 2·571282; that is, a little more than $2\frac{1}{2}$ inches, the diameter required of the wrought-iron gudgeon. The numbers in the third column, being the cube of those in the fourth, another use may be made of this part of the table. For, supposing the fourth column to represent cast-iron gudgeons, the third column will represent the hundred-weights which cast-iron gudgeons of those diameters should sustain.—See *Shaft.*

Gun Metal, a species of brass employed in casting ordinance, and for some of the smaller parts of machinery. This alloy should consist of 9 parts of copper, and 1 of tin, but no zinc. It answers very well for valves.

Table of the Weight, in lbs., of a foot, in length, of Gun Metal.

Side of the square or diameter.	Square.	Hexagon.	Octagon.	Circle.
$\frac{1}{2}$	·875	·756	·728	·686
$\frac{3}{4}$	1·967	1·711	1·648	1·554
1	3·500	3·027	2·915	2·747
$1\frac{1}{4}$	5·467	4·732	4·553	4·294
$1\frac{1}{2}$	7·875	6·814	6·559	6·184
$1\frac{3}{4}$	10·717	9·275	8·928	8·417
2	14·000	12·113	11·662	10·993
$2\frac{1}{4}$	16·717	15·333	14·749	12·916
$2\frac{1}{2}$	21·875	18·928	18·207	17·178
$2\frac{3}{4}$	26·467	22·904	22·032	20·786
3	31·500	27·261	26·222	24·738
$3\frac{1}{4}$	36·967	31·993	30·772	29·034
$3\frac{1}{2}$	42·875	37·107	35·693	34·273
$3\frac{3}{4}$	49·217	42·605	40·971	38·654
4	56·000	48·464	46·616	43·981
$4\frac{1}{4}$	63·217	54·715	52·629	49·651
$4\frac{1}{2}$	70·875	61·341	59·003	55·664
$4\frac{3}{4}$	78·967	68·344	65·740	62·020
5	87·500	75·729	72·845	68·722
$5\frac{1}{4}$	96·467	83·492	80·307	75·764
$5\frac{1}{2}$	105·875	91·633	88·140	83·153
$5\frac{3}{4}$	115·717	100·152	96·337	90·884
6	126·000	109·053	104·895	98·959
$6\frac{1}{4}$	136·717	118·328	113·816	107·376
$6\frac{1}{2}$	147·875	127·984	123·111	116·140
$6\frac{3}{4}$	159·467	138·019	132·758	125·244
7	171·500	148·431	142·775	134·694
$7\frac{1}{4}$	183·967	159·222	153·153	144·487
$7\frac{1}{2}$	196·875	170·394	163·898	154·623
$7\frac{3}{4}$	210·217	181·744	175·010	165·105
8	224·000	193·872	186·483	175·927
$8\frac{1}{4}$	238·217	206·178	198·320	187·096
$8\frac{1}{2}$	252·875	218·862	210·541	198·607
$8\frac{3}{4}$	267·967	231·927	223·090	210·462
9	283·500	245·367	236·019	222·659
$9\frac{1}{4}$	299·467	259·189	249·312	235·200
$9\frac{1}{2}$	315·875	273·392	262·969	248·087
$9\frac{3}{4}$	332·717	287·969	276·993	261·317
10	350·000	302·928	291·382	274·890
$10\frac{1}{4}$	367·717	318·258	306·131	288·802
$10\frac{1}{2}$	385·875	333·977	321·247	303·065
$10\frac{3}{4}$	402·467	350·066	336·724	317·667
11	423·500	366·541	352·572	332·615
$11\frac{1}{4}$	442·968	383·393	368·781	347·907
$11\frac{1}{2}$	462·875	400·617	385·350	363·538
$11\frac{3}{4}$	483·217	418·124	402·290	379·519
12	504·000	436·212	419·567	395·839

GYRATION, the act of turning round a fixed centre.

GYRATION, CENTRE OF. If any body or system of bodies be revolving round a fixed axis there is a certain point in which if the mass of the whole body or system of bodies were collected the momentum of inertia would be the same as that of the body or system of bodies; or, what amounts to the same thing, the sum of the products of the mass of each body × the square of its distance from the axis of motion will be equal to the sum of all the bodies × the square of the distance of the point before mentioned from the axis of motion. This point is called the centre of *Gyration*. The centre of gyration may also be defined such a point in any revolving body or system of bodies that if all the mass were collected in it the angular velocity would be the same. In general if P be the weight or power giving rotation to the body or system whose weight is w, the distance of the power from the axis of motion being r, and of the centre of gyration from the axis of motion d; then f being the accelerating force we have

(A) $$f = \frac{P \times r^2}{P \times r^2 + w \times d^2}$$

and when the power acts over a pulley the formula becomes

(B) $$f = \frac{P \times r_2}{w \times d^2}$$

The distance of the centre of gyration from the axis of motion, for the more common forms of bodies used in engineering are as follow:— In a circular wheel of uniform thickness $d = \frac{r}{2} \times 1{\cdot}4142$, and the same rule holds good for the circumference of a circle revolving about the diameter, but for the plane of a circle revolving about the diameter, the rule is $d = \frac{r}{2}$. In a solid sphere revolving on its diameter $d = r \times {\cdot}6324$. In a circular ring the radii of which are R and r, revolving about the centre we have

$$d = \sqrt{\left(\frac{R^2 + r^2}{2}\right)}$$

In a cone revolving about its vertex

$$d = \sqrt{\frac{(2{\cdot}4 \times a^2 + 0{\cdot}6\, r^2)}{2}}$$

but for a cone revolving round its axis $d = r \times 0{\cdot}1783$. In a straight lever, the arms of which are R and r, the rule is

$$d = \sqrt{\left(\frac{R^3 + r^3}{3\,(R + r)}\right)}$$

In a paraboloid, the radius of whose base is R, we have $d = R \times \sqrt{0{\cdot}333}$. The application of these theorems to actual cases is not difficult. Suppose we have a cylinder whose weight is 60 lbs. which is put in motion round its axis by means of a weight of 30 lbs. acting at the end of a string coiled round the cylinder, then by the theorem

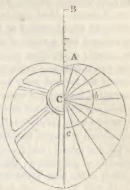
$$f = \frac{P \times r^2}{P \times r^2 + w \times d^2}$$

H

Hammer, a well-known instrument used for driving nails, etc. Hammers are faced with steel, in a state of considerable hardness. Their handles are almost always made of nearly a uniform thickness in every part, or if they differ from such figure it is not for any specific purpose. Hence the vibrations of the hammer head are communicated to the hand, to which they occasion very unpleasant sensations, and the workman is tired before he has exerted his strength. If the handle of the hammer, at a little distance from its upper end, be made considerably smaller for a short space than in any other part, the alteration will be found a decisive improvement. Such a hammer will, as it is technically termed, fall well; diminishing, at the same time, the workman's fatigue and convincing him that his blows are solid and effectual. In hammers for chipping iron the head need not be more than sixteen ounces in weight and the handle about twelve inches long. In a hammer of any given shape, calculated to give the hardest blows with the least weight, and, consequently with the least fatigue, the quantity of iron in the head should be equal on the opposite sides of a line supposed to be drawn perpendicular to the centre of the face. Hammers, therefore, made for the purpose of drawing nails, with claws, which lean backwards from this line, are not calculated to produce the best effect in striking. Clockmakers, tin-plate workers, and braziers, polish the face of their planishing hammers by rubbing them upon a soft board covered with a mixture of oil and finely washed emery. Watchmakers and silversmiths take still more pains with theirs, selecting them free from every flaw, removing every scratch, and giving them an exquisite lustre with colcothar or putty. These various artists, also, for their respective purposes, require them to be made of a numberless variety of shapes, convex, concave, cylindrical, etc.

Hardness, or **Rigidity**, that quality in bodies by which their parts so cohere as not to yield inward, or give way to an external impulse, without instantly going beyond the distance of their mutual attraction; and therefore are not subject to any motion, in respect to each other, without breaking the body.

Heart Wheel, a contrivance for converting an uniform circular motion into an uniform rectilinear motion. It is much employed in the machinery of the cotton and flax manufacture, and is formed after the following manner. Draw a line AB equal in length to the required extent of the alternating rectilinear motion, and divide this line into any number of equal parts, the more the better. From the centre, C, round which the heart wheel is to move, with any distance (which need not be great) describe the semicircle, A *b c*, and divide it into the same number of equal parts as the line AB. From the centre draw radii passing through each of these points, and extend them a considerable way beyond the circumference. Next from the centre C take the distance to the first division on the line AB, and lay off that distance on the first radius, passing through the division on the semicircle, then take the second, third, fourth, &c. divisions from the centre C in succession on the line AB, and lay them off successively on the second, third, fourth, &c. radii, then will a line drawn through all these points on the radii be the face of one half of the wheel. The other half is formed after the same manner. The curve of the face of the wheel is in this case the spiral of Archimedes, but the alternating rectilinear motion may be made to follow any given law besides that of uniformity, by changing the nature of the curvature of the face of the wheel, which may be easily done by making the divisions on the line AB increase or diminish from the centre or the ends, and constructing the figure in other respects as before.



HEAT. The term heat is employed either to signify the sensation of warmth or the cause of that sensation. It is matter of dispute among philosophers whether the cause of the phenomena of heat be a subtile fluid, capable of penetrating all substances, or a peculiar vibration, rotation or other kind of motion. It would be inconsistent with the nature of this work to enter into the merits of the various arguments in support of either hypothesis; we will therefore confine ourselves to a view of its more important mechanical properties.

Heat penetrates all bodies, nor is it possible to abstract it entirely from any body whatever. Heat may communicate from one body to another; thus, if a drop of ice be put into a cup of boiling water, the ice will melt in consequence of the heat of the boiling water being transferred to the ice, and the whole will ultimately become of one degree of heat. And, also, if a number of substances of different degrees of heat be placed in a vessel where there is no original source of heat, such as a fire, the whole of the substances will acquire ultimately one temperature, so that the thermometer will stand at the same height when placed on any of them. Heat may be communicated from a hot body to a cold one either by actual contact or by radiation. Thus, when a bar of hot iron is plunged into a vessel of cold water, the temperature of the water will be raised; or, in other words, the heat of the bar will be imparted to the water until an equilibrium be restored: that is, until the temperature of the bar and water be the same; and this takes place by the actual contact of the bar and water. But a hot body may communicate heat to a cold one although not in contact; for, if a hot iron ball be placed in the focus of a large parabolic reflector, opposite which there is a similar reflector, placed at several feet distance, and so as to receive the reflected rays of the first mirror; and there be placed in the focus of the second mirror a quantity of gunpowder; then the gunpowder will be inflamed in consequence of the heat given out by the iron ball, propelled from thence on to the first mirror, reflected from that to the second, and by this last concentrated into the focus where the gunpowder is laid. It is plain that in this experiment the heat is not communicated by contact from the ball to the gunpowder, as they are at a distance from each other of several feet. It may be imagined that the heat of the ball is communicated to the particles of the air immediately surrounding it, and from these to the next, and so on till the heated air reaches the first mirror, and then by the ordinary laws of reflection to the second, and from thence to the focus where the gunpowder is placed, and that thus the transfer of heat may in this case as well as the former be said to take place by actual contact. But the same experiment will succeed in the exhausted receiver of an air pump, where no air intervenes between the hot ball and the powder. This distinctly proves that hot bodies give out their heat, by, as it were, propelling it from their surface; this is called radiation. In some cases heat is communicated from a warm to a cold body solely by contact; in other instances solely by radiation, and in others by contact and radiation conjointly. The laws of the heating and cooling of bodies are extensively applicable in the arts and manufactures, and therefore for the use of the practical engineer we shall lay down in this place a short and connected view of the subject.

Two circumstances, principally, influence the transfer of heat from one substance to another. These are, 1st. the proximity or nearness of the one substance to the other; and, 2d. the conducting power of the substances: these two circumstances influencing the rapidity of the transfer. Thus a solid will, other things being the same, transfer its heat less rapidly to another solid than to a gas, with which it is enveloped, and less rapidly to a gas than a fluid in which it is plunged, as the points of contact are more numerous in this last than in any of the former cases. When bodies touch each other at their surfaces only the question becomes one of *conduction*, the rapidity of transfer depending on the velocity with which heat passes through the substances in contact. But, supposing the amount of contact to remain the same, the rapidity of transfer will depend, as before observed, on the conducting power of the substances; that is, on the celerity with which heat passes through them. The following tables exhibit the relative conducting power of different substances:—

Substance.	Conducting power.	Substance.	Conducting power.
Gold	100	Tin	30·38
Platinum	98·1	Lead	17·96
Silver	97·3	Marble	2·34
Copper	89·82	Porcelain	1·22
Iron	37·41	Brick earth	1·13
Zinc	36·37		

	Conducting power.		Conducting power.
Water	10	Oak	32·6
Ebony wood	21·7	Pear tree	33·2
Apple tree	27·4	Birch	34·1
Ash	30·8	Silver fir	37·5
Beech	32·1	Alder	38·4
Hornbeam	32·3	Scotch fir	38·6
Plum tree	32·5	Norway spruce	38·9
Elm	32·5	Lime	39·0

It is extremely probable that the conducting power of gases or aeriform fluids is even less than that of liquids, although the precise ratio is very difficult to ascertain. The conducting power of solids does not seem to follow implicitly any particular law, yet the conducting power seems in general to increase, but not in strict ratio with the density. Liquids are less perfect conductors than solids; and, as stated above, gases are still less perfect than liquids. It is to the perfection of the relative conducting power of bodies that they communicate sensations of different intensities of heat, although they be of the same temperature. Thus if a piece of iron and a piece of glass be heated to the same temperature, so that when the thermometer is applied to each it will stand at the same point; we will, when we touch the iron and then the glass, imagine, from the sensation by the hand, that the glass is considerably warmer than the iron; because the latter is a much better conductor of heat than the former, and will consequently convey the heat more rapidly from the body than the former. So a marble mantel-piece will to the feel seem much colder than the timber of the chair on which we sit, although the thermometer indicates the same temperature in each; because the wood is a much worse conductor of heat than marble.

The transfer of heat, as was remarked above, depends also on radiation, and we will next attend to the laws of this mode of diffusing or commuuicating heat. It is well known that when air is heated it has uniformly a tendency to ascend, so that one might be led to suppose that when a heated body is held at a considerable distance above the hand we would not feel any of its heat, since it would be all carried upwards; but this is not the case, for we can easily prove by trial that the heat is propelled, or radiated, in all directions; upwards, downwards, sideways, and obliquely. If a hot body be suspended in a vacuum, then will a thermometer, held at small distances from its surface in any direction, indicate the same temperature; so that the radiation must be equal in all directions. The radiating power of different substances is very dissimilar: and of the same substance the radiating power varies with the conducting power of the gas in which it is placed. The following table shows the relative radiating powers of the following substances, that of water being 100:—

	Seconds.		Seconds.
Lamp-black	100	Plumbago	75
Writing-paper	98	Isinglass	75
Sealing-wax	95	Tarnished lead	45
Crown-glass	90	Clean lead	19
China-ink	88	Iron, polished	15
Ice	85	Tin-plate	12
Red-lead	80	Gold, silver, and copper	12

The radiating power of any substance varies with the nature of its surface: thus iron does not radiate so well when its surface is clear and polished as when it becomes rough by corrosion. A piece of tin plate does not radiate heat well when its surface is clear and free of scratches, but if it be smeared over with tallow, isinglass, or wax, its radiating power increases to a considerable amount. In general it would appear that velocity of radiation depends more upon the nature of the surface than the substance of a radiating body. A metallic surface appears adverse to radiate, independently of polish, for a highly polished plate of glass radiates better than an equally polished plate of iron. Scratching seems to increase the power of radiation, by multiplying the number of radiating points. Colour also seems to affect in a considerable degree the power of radiation, for if the bulb of a delicate thermometer be successively covered by equal weights of differently coloured wool, and placed in a glass tube heated by immersion in water at a temperature of 180° Fah., and then cooled down to 50 in cold water, the time of cooling for black wool will be 21 minutes, for red wool 26 minutes, and for white wool 27 minutes; the velocity of radiation increasing with the darkness of the colour.

Having now considered the general laws of conduction and radiation, we will be better enabled to investigate the nature of the cooling of bodies, by the transfer of their heat, by either or both of these ways. When a hot body is enveloped in solid substances its heat is withdrawn solely by communication, and the velocity of cooling is dependent entirely on the conductive power of the enveloping substances. When the hot body is immersed in a liquid, the velocity of cooling depends in some measure upon the conducting power of the liquid, but in addition it also depends upon the facility with which the particles move among themselves. In an elastic fluid the cooling takes place both by communication and radiation, and in a vacuum by radiation alone. By the phrase *velocity of cooling* is meant the number of degrees of heat (indicated by the thermometer) lost by a hot body in a given time, as a minute or second; and by the phrase the *law of cooling*, the relation which the velocities of cooling, in successive intervals, bear to each other. Newton supposed that while the times of cooling are in an arithmetical progression that the velocities are in a geometrical progression; as, for instance, if a body be heated to an excess of 1000 degrees above the surrounding atmosphere; and if it lose 100 degrees during the first second, that is, one-tenth of the whole excess, then will it lose one-tenth of the remainder during the next second, that is, one-tenth of 900, or 90 degrees; and, during the third second it would lose one-tenth of the remainder, that is, one-tenth of 810, or 81 degrees, and so on; so that during the first five successive seconds the velocities of cooling would be 100, 90, 80, 72·9 and 65·6 degrees, a geometrical progression, the ratio of which is 1·111. This law was found to hold sufficiently true when the temperature of the heated body was not much above that of the surrounding medium, but not otherwise. The following table exhibits the rate of cooling of a mercurial thermometer in vacuo. The first column gives the temperature (centigrade), and the second the degrees lost per minute at the corresponding temperature:—

240	10·69
220	8·81
200	7·40
180	6·10
160	4·89
140	3·88
120	3·02
100	2·30
80	1·74

According to Newton's law, the velocity of cooling at 200 degrees ought to be twice that at 100 degrees, but from the table we find that it is actually three times.

Excess of temperature of the thermometer.	Velocity of cooling water at 0°.	Ditto., water at 20°.	Ditto., water at 40°.	Ditto. water at 60°.	Ditto., water at 80°.
240	10·69	12 40	14·35		
220	8·81	10·41	11·98		
200	7·40	8·58	10·01	11·64	13·45
180	6·10	7·04	8·20	9·55	11·05
160	4·89	5·67	6·61	7·68	8·95
140	3·88	4·57	5·32	6·14	7·19
120	3·02	3·56	4·15	4·84	5·64
100	2·30	2·74	3·16	3·68	4·29
80	1·74	1·99	2·30	2·73	5·18
60		1·40	1·62	1·88	2·17

The velocity of the cooling of a thermometer in a vacuum, for a constant excess of temperature, increases in a geometrical progression, while the temperature of the surrounding medium increases in an arithmetical progression; and the ratio of this geometrical progression is the same, whatever be the excess of temperature considered, as may be seen on inspecting the last table drawn up from the experiments of M. M. Dulong and Petit. Commonly the geometrical progress requires to be diminished by a constant quantity, in consequence of the heat radiated back from the inner surface of the surrounding vessel. The velocity of cooling other things being equal, seems to increase with the extent of surface and proximity; and of two bodies of the same temperature, form, and material, but different in size, the smaller will cool more rapidly than the larger. The following table shows the number of seconds that the bulb of a thermometer took to cool down from 70 to 10 degrees of Reumur, when placed in the substances mentioned:—

Surrounded with	Seconds.	Surrounded with	Seconds.
Air, it cooled in .	570	16 grs. of Fine lint .	1032
16 grs. of raw silk ,	1284	— Beaver's fur	1296
— Ravellings of taffety . .	1169	— Hare's fur .	1315
— Sowing silk, cut	917	— Eider down .	1305
— Wool . .	1118	— Charcoal .	937
— Cotton .	1046	— Lamp-black .	1117
		— Wood ashes	927

The presence of heat, in different degrees, not only changes the bulk but likewise the form of substances. By heat bodies are in general increased in bulk or expanded. Heat, in fact, seems to exert a force opposed to cohesion, for its effect in expanding bodies or separating their particles seems to be greatest in those substances in which there is the least cohesion. Thus solids, in which the cohesive power is strong, are less expanded by equal increments of heat than liquids, in which the attraction of cohesion is less intense, and liquids are less expanded by equal additions of heat than gases or aeriform fluids, which last cohesion is very weak. In general equal increments of heat will expand the same bodies equally, but different bodies in different degrees, unless the form or chemical composition of the substance suffer a change by the addition of caloric.

Many philosophers have turned their attention to the expansion of solids by heat, and the following general principles may be drawn from their experiments:—Equal increments of heat do not expand different substances in the same degree. A body that has been heated from the freezing to the boiling point, i. e. from 32⁰ to 212⁰ Fah. will increase in bulk, but will recover its original size if allowed to cool down again to 32⁰. The expansion of the more permanent solids, or solids not easily fused, is pretty uniform for equal increments of heat from 32⁰ to 212⁰; but beyond this point, i. e. 212⁰, the law does not hold, for equal increments of temperature produce greater expansion, and this difference becomes the more remarkable as the temperature becomes higher. Indeed from the experiments of M. M. Dulong and Petit, we are led to infer that between 32⁰ and 212⁰ the expansion is not uniform, but follows a like law of increase; but the deviation from uniformity is so small that for all practical purposes it may without fear of error be neglected. The following table will exhibit the results of tho best experiments on the expansion of solids by heat.

Dimensions which a bar takes at 212⁰ *whose length at* 32⁰ *is* 1.000000.

Glass Tube	1·00083333	Iron	1·00115600
Do.	1·00077615	Do.	1·00125800
Do.	1·00082800	Soft-forged iron	1·00122045
Do.	1·00086130	Round iron, wire-drawn	1·00123504
Do.	1·00081166	Iron wire	1·00144010
Plate Glass	1·00089089	Iron	1·00118203
Do. crown glass	1·00087572	Bismuth	1·00139200
Do. do.	1·00089760	Annealed gold	1·00146000
Do. do.	1·00091751	Gold	1·00150000
Do. rod	1·00080787	Do. procured by parting	1·00146606
Deal		Do. Paris standard unannealed	1·00155155
Platina	1·00085655	Do. do. annealed	1·00151361
Do.	1·00088420	Copper	1·00191000
Do.	1·00099180	Do.	1·00172244
Do. and glass	1·00110000	Do.	1·00171222
Palladium	1·00100000	Do.	1·00191880
Antimony	1·00108300	Do.	1·00171821
Cast-iron prism	1·00110910	Brass	1·00178300
Cast-iron	1·00111111	Do.	1·00186671
Steel	1·00118990	Do.	1·00188971
Steel Rod	1·00114479	Brass scale, supposed from Hamburgh	1·00185540
Blistered steel	1·00112500		
Do.	1·00115000	Cast brass	1·00187500
Steel not tempered	1·00107875	English plate brass, in a rod	1·00189280
Do. do. do.	1·00107956	Do. do. in a trough form	1·00189490
Do. tempered yellow	1·00136900	Brass	1·00191880
Do. do. do.	1·00138600	Brass wire	1·00193000
Do. at a higher heat	1·00123956	Brass	1·00216000
Steel	1·00118980	Copper 8, tin 1	1·00181700
Hard Steel	1·00122500	Silver	1·00189000
Annealed steel	1·00122000	Do.	1·00210000
Tempered steel	1·00137000	Do.	1·00212000

Table of dimensions which a bar, &c. continued.

Do. of cupel	1·00190974
Do. Paris standard	1·00190868
Silver	1·00208260
Brass 16, tin 1	1·00190800
Speculum metal	1·00193300
Spelter solder; brass 2, zinc 1	1·00205800
Molacca tin	1·00193766
Tin from Falmouth	1·00217298
Fine pewter	1·00228300
Grain tin	1·00248300
Tin	1·09284000
Soft solder; lead 2, tin 1	1·00250800
Zinc 8, tin 1, a little hammered	1·00269200
Lead	1·00284836
Do.	1·00286700
Zinc	1·00294200
Zinc, hammered out half inch per foot	1·00301100
Glass from 32° to 212°	1·00086130
Do. from 212° to 392°	1·00091827
Do. from 392° to 572°	1·00010111

It is remarkable in looking over the foregoing table that those metals which are most expansible are also those that are most easily fused by heat, and thus there would seem to be some relation between the power of expansibility and the melting point. From the experiments of Dulong and Petit, it would appear that beyond 212° glass expands in a greater degree than mercury. The expansion of a cube is not quite correctly three times that of the linear expansion, but so nearly so that the small difference may be neglected in practice. The following table exhibits the quantity of expansion of iron for different temperatures.

Temp.	Length of an iron rod.	1st. dif.	2d. dif.	3d. dif.
40°	0·999632			
22	0·999721	89		
4	0·999811	90	1	
14	0·999904	93	3	2
32	1·000000	96	3	0
50	1·000102	102	6	3
68	1·000211	109	7	1
86	1·000328	117	8	1
104	1·000453	125	8	0
122	1·000588	135	10	2
140	1·000734	146	11	1
158	1·000892	158	12	1
176	1·001063	171	13	1
194	1·001247	184	13	0
212	1·001446	199	15	2

We come now to speak of the expansion of liquids by increments of heat. Different liquids do not expand in the same degree from equal increments of heat. Mercury expands much less than water, and this last still less than alcohol. It would seem that in liquids equal additions of heat do not produce equal increments in bulk, but that the expansions go on in increasing ratio, that is, they are proportionally greater at high than at low temperatures. Thus in the case of mercury if it be heated from 32° half way to the boiling point, i. e. to 106°, the quantity of expansion will not be so great as when heated from 106° to 212° the boiling point; for although the two intervals of temperature contain the same number of degrees, yet the quantity of expansion in the first will be to that in the second as 14 to 15. The following table exhibits the quantity of expansion of different liquids whose temperatures have been raised from 32° to 212°.

	Expansion.		Expansion.
Mercury . .	0·020000	Water .	0.04332
Do. . .	0·018870	Do. . . .	0·0460
Do. . .	0·018000	Muriatic acid .	0·0600
Do. . .	0·017000	Nitric acid . .	0·1100
Do. . .	0·01851	Sulphuric acid .	0·0600
Do. . .	0·01810	Alcohol . .	0·1100
Do. . .	0·0181800	Sulphuric æther	0·0700
Do. . .	0·0180180	Fixed oils . .	0.0800
Do. . .	0·0184331	Oil of turpentine	0·0700
Do. . .	0·0188700	Water saturated with common salt .	0·05198
Do. . .	0·015432	Do. . . .	0·0500
Do. . .	0·015680		
Mercury . .	0·0158280		

The following table exhibits the relative expansion of different liquids at various temperatures; the degrees being marked according to the three thermometers most commonly in use.

Mercury.			Olive Oil.	Es. Oil of Chamomile.	Oil of thyme.	Alcohol.	Brine.	Water.
R.	Cent.	Fahr.						
80°	100°	212°	80°	80°	80°	80°	80°	80°
75	93¾	200¾	74·6	74·7	74·3	73·8	74·1	71
70	87·5	189½	69·4	69·5	68·8	67·8	68·4	62
65	81	178¼	64·4	64·3	63·5	61·9	62·6	53·5
60	75	167	59·3	59·1	58·3	56·2	57·1	45·8
55	68¾	155¾	54·2	53·9	53·3	50·7	51·7	38·5
50	62½	144½	49·2	48·8	48·3	45·3	46·6	32
45	56¼	133¼	44·0	43·6	43·4	40·2	41·2	26·1
40	50	122	39·2	38·6	38·4	35·1	36·3	20·5
35	43¾	110¾	34·2	33·6	33·5	30·3	31·3	15·9
30	37½	99½	29·3	28·7	28·6	25·6	26·5	11·2
25	31¼	88¼	24·3	23·8	23·8	21·0	21·9	7·3
20	25½	77	19·3	18·9	19·0	16·5	17·3	4·1
15	18¾	65¾	14·4	14·1	14·2	12·2	12·8	1·6
10	12½	54½	9·5	9·3	9·4	7·9	8·4	0·2
5	6¼	43¼	4·7	4·6	4·7	3·9	4·2	0·4
0	0½	32	0·0	0·0	0·0	0·0	0·0	0·0
5	6¼	20¾				3·9	4·8	
10	12½	9½				7·7	8·1	

Some liquids exhibit a singular phenomenon, of which water is a notable instance. There is a certain point at which this liquid is more dense than at any other, and it will expand if either heated beyond this point or cooled below it. The point in question is called the point of maximum density, and in the case of water it has been found to be 39° 38 Fah. The following table will exhibit the degree of expansion for different temperatures both above and below this point.

Temperature.		Ess. gravity of water.	Volume.
Cent.	Fah.		
0	32	0·9998918	1·0001082
1	33·8	0·999938	1·0000617
2	35·6	0·9999717	1·0000281
3	37·4	0·9999920	1·0000078
4	39·2	0·9999995	1·0000002
4·1	39·38	1·	1·
5	41·0	0·9999950	1·0000050
6	42·8	0·9999772	1·0000226
7	44·6	0·9999472	1·0000527
8	46·4	0·9999044	1·0000954
9	48·2	0·9998497	1·0001501
10	50	0·9997825	1·0002200
11	51·8	6·9997030	1·0002970
12	53·6	0·9996117	1·0003888
13	55·4	0·9995080	1·0004924
14	57·2	0·9993922	1·0006081
15	59·0	0·9992647	1·0007357
16	60·8	0·9991260	1·0008747
17	62·6	0·9989752	1·0010259
18	64·4	0·9988125	1·0011888
19	66·2	0·9986387	1·0013631
20	68	0·9984534	1·0015490
21	69·8	0·9982570	1·0017560
22	71·6	0·9980489	1·0019549
23	73·4	0·9978300	1·0021746
24	75·2	0·9976000	1·0024058
25	77	0·9973587	1·0026483
26	78·8	0·9971070	1·0029016
27	80·6	0·9968439	1·0031662
28	82·4	0·9965704	1·0034414
29	84·2	0·9962864	1·0037274
30	86	0·9959917	1·0040245

The expansive force of frozen water is truly remarkable, as has been proved by numerous experiments, the most celebrated of which was that of the Florentine academicians, who burst a hollow brass ball whose cavity was only one inch diameter, by introducing water and then freezing it. It has been calculated that the force necessary to produce this effect must have amounted to 2772 lbs. avoirdupois. Fused iron, antimony, zinc, and bismuth, are also expanded, on congelation, but mercury is a remarkable instance of the reverse.

Aeriform or gaseous substances expand proportionally more than solids, by equal additions of heat, in consequence of the comparatively small cohesive force that draws these particles together. It would seem that in the same gas expansion takes place proportionally to the increase of heat. Dr Dalton states that 1000 cubic feet of air heated from 32° to 212° Fah. became 1325 cubic feet, but this last number according to Gay Lussac is 1375, and according to Mr Crichton, of Glasgow, it should be 1374·8. According to Dalton the expansion of air for an increase of 1° will be $\frac{1}{483}$, whereas Gay Lussac would make it $\frac{1}{480}$, and Crichton, $\frac{1}{480 \cdot 25}$. Dr Thomson thinks Crichton's estimate the most correct, but Gay Lussac's is more easily employed in calculation, and the difference between these two is so trifling that it may be neglected. From these statements we may easily calculate the bulk of any given quantity of air, at any temperature, provided we know the bulk of the same quantity of air at any other given temperature. For instance, taking Gay Lussac's estimate, i. e. $\frac{1}{480}$, we have the following rule: if we wish to know the bulk of air at a temperature above 32°, that at 32° being given. Subtract 32 from 480, and to the remainder add the degrees indicating the temperature of the air, these two sums will form the first and second terms of a proportion of which the third is the bulk of the air at 32°, and the fourth that at the higher temperature. Thus let the given temperature be 60°, then $480 - 32 = 448$, to this add first 32 and then 60, we get 480 and 508 as the two first terms of the proportion, and calling the bulk of the air at $32° = 100$ cubic feet, then $480 : 508 :: 100 : 105{\cdot}832$; and the same rule holds good if both temperatures be above 32°. The following general rules will often be found useful.

Let P′ be the volume of gas at any temperature above 32°, T′ the number of degrees above that point, and P its volume at 32°. Then $P' = P. \left(1 + \frac{T'}{480}\right) = P\left(\frac{480 + T'}{480}\right)$ and if P is unknown, its value, deduced from the last equation, may be calculated from the formula $P = P'. \left(\frac{480}{480 + T'}\right)$.

It frequently happens, in the employment of Fahrenheit's thermometer, that when P′ for the above formula is known, it is not P itself which is wanted, but the volume of gas at some other temperature, as at 60° F. This value may be obtained without first calculating what P is. Thus, retaining the value of P′ and T′ as in the preceding formula, let P″ be the corresponding quantity of gas, at some other temperature, the degrees of which above 32° may be expressed by T″. Now $P'' = \frac{(480 + T'')}{480} \times P$; but as P is unknown, let its value in P′ be substituted. Thus, $P'' = \left(\frac{480 + T''}{480}\right) \times \left(\frac{P' \; 480}{480 + T'}\right)$; which gives $P'' = \frac{480^2 P' + 480 \, T'' P'}{480^2 + 480 \, T'} = \frac{P' \, 480 \, (480 + T'')}{480 \, (480 + T')} = \frac{P' \, (480 + T'')}{480 + T'}$.

Suppose, for example, a portion of gas occupies 100 divisions of a graduated tube at 48°, how many will it fill at 60° F.? Here $P' = 100$; $T' = 48 - 32$ or 16; $T'' = 60 - 32$, or 28. The number sought, or the $P'' = \frac{100 \times 508}{496} = 102{\cdot}42$.

The rate of expansion of atmospheric air at temperatures exceeding 212° has been examined by Dulong and Petit, and the following table contains the result of their observations.

Temperature by the Mercurial Thermometer.		Corresponding volumes of a given volume of air.
Fahrenheit.	Centigrade.	
— 33	— 36..	0·8650
32	0..	1·0000
212	100..	1·3750
302	150..	1·5576
392	200..	1·7389
482	250..	1·9189
572	300..	2·0976
M. boils 680	360..	2·3125

All bodies are either solid, fluid, or aeriform, according to the relation of the cohesive and repulsive forces among the particles. Heat has a tendency to destroy cohesion, and therefore by the addition of heat the form, or rather state, of all bodies may be changed from a solid to a liquid, and from a liquid into a gas. Thus the solid *ice* may, by the addition of heat, be converted into the liquid water, and that again may be converted into the gaseous form *steam*; by diminishing the heat of *steam* it will be converted intc water, and by diminishing the quantity of heat in water it will be converted into ice. The temperature at which solids are converted into liquids is called the melting point, or point of fusion; and the point at which liquids solidify is called their point of congelation: both of these points are the same in the same body under the same circumstances, but different in different bodies.

The following table shows the melting points of various substances.

Substance.	Melting point.	Substance.	Melting point.
Cast iron	3479	Spermaceti	112
Gold	2590	Phosphorus	108
Silver, one-fourth gold	2050	Tallow	92
Copper	2548	Olive oil	36
Silver, one-tenth gold	1920	Ice	32
Silver	2233	Milk	30
Silver	1830	Vinegar	28
Brass	1869	Sea water	27·5
Antimony	810	Blood	25
Zinc	648	Wines	20
Lead	606	Turpentine	14
Bismuth	497	Vitriol	1
Tin	442	Mercury	39
Sulphur	218	Nitric acid	45·5
Bees'-wax, bleached	142	Salpetre	46

When a sufficient quantity of heat is applied to a liquid it rises in an aeriform state, denominated vapour. Vapours and gases bear a resemblance to each other in their form; but it is the distinguishing characteristic of vapours that they may be converted into the form of liquids by a moderate pressure, without diminishing the temperature, or by moderately diminishing the temperature without increasing the pressure. Gases resist all condensation at moderate temperatures or pressures. Were we able to apply sufficient heat there is reason to believe that all bodies whatever might be converted into vapour, but some substances resist even being fused by the most intense heat we have yet been enabled to produce; such substances are said to be *fixed in the fire*, and those that are not are said to be *volatile*. Most solids pass into liquids before they are converted into vapour, but a few, such as sal ammonia and arsenic, pass immediately into the state of vapour from that of the solid. Vapours occupy much more space than the solids or liquids. Thus one cubic foot of water at its point of greatest density, when converted into vapour will occupy 1696 cubic feet; and it has been found that vapours expand by the same law as gases, by uniform increments of heat, that is, provided the quantity of vapour remains the same; they expand $\frac{1}{480}$ of their bulk for each degree of Fahrenheit's thermometer; and the volume or space occupied by both vapour or gas is in the inverse ratio of their pressure upon it.

Evaporation goes on in all liquids at common temperatures, but so gently that it is not perceptible, excepting after the liquid has been exposed for a considerable time, when it will be found diminished in bulk. The rapidity of this insensible evaporation is different in different substances. Thus alcohol evaporates more quickly, ceteris paribus, than water. Evaporation increases with the extent of surface, and also with the temperature and the dryness of the surrounding air. It also increases when the air is put in motion, and also by a diminution of the atmospheric pressure.

Scientific men have differed concerning the cause of evaporation. It was once supposed to be owing to chemical attraction between the air and water, and the idea is at first view plausible, since a certain degree of affinity does to all appearance exist between them, it is nevertheless impossible to attribute the effect to this cause.

When the heat is considerable, evaporation goes on perceptibly, and the phenomenon of ebulition takes place; the temperature at which this takes place under the ordinary pressure of the atmosphere is called the boiling point. The following table exhibits the boiling points of various substances as determined by creditable experimenters.

Ether	sp. gr. 0·7365 at 48°	100
Carburet of sulphur		112
Alcohol, sp. gr.	0·813	173·5
Nitric acid	1·500	210
Water		212
Saturated sol. of Glaub. salt		213·3
Ditto sugar of lead		215·6
Ditto sea salt		224·3
Muriate of Lime	1 water 2	230
Ditto	35·5 ditto 64·5	235
Ditto	40·5 ditto 59·5	240
Muriatic acid	1·094	232
Ditto	1·127	222
Ditto	1·047	222
Nitric acid	1·45	240
Ditto	1·42	248
Ditto	1·40	247
Ditto	1·35	242
Ditto	1·30	236
Ditto	1·16	220
Rectified petroleum		306
Oil of turpentine		316
Sulph. acid. sp. gr.	1·30	240
Ditto	1·408	260
Ditto	1·520	290
Ditto	1·650	350
Ditto	1·670	360
Ditto	1·699	374
Ditto	1·730	391
Ditto	1·780	435
Ditto	1.810	473
Ditto	1·819	487
Ditto	1·827	501
Ditto	1·833	515
Ditto	1·842	545
Ditto	1·847	575
Ditto	1·848	590
Ditto	1·849	605
Ditto	1·850	620
Ditto	1·848	600
Phosphorus		554
Sulphur		570
Linseed oil		640
Mercury (Dulong 662°)		656

The boiling point of a liquid varies with the pressure of the atmosphere, increasing uniformly with the pressure. The boiling point of water at a pressure equal to thirty inches of mercury, or 15 lbs. per square inch, is 212° Fah., and by careful experiments it has been found that the boiling point sinks below 212°, or rises above it in the ratio of 0·88 of a degree, for every half inch of difference of the height of the mercurial column below or above 30 inches. Thus if the barometer stand at 25 inches, which is 10 half inches below 30, we have $0{\cdot}88 \times 10 = 8{\cdot}8$, which taken from 212 leaves 203·2 degrees, the corresponding boiling point; and at a pressure of 36 inches the boiling point would be $6 \times 2 \times 0{\cdot}88 = 10{\cdot}56$, which added to 212 gives 222·56 degrees the boiling point. From this it can be easily shown by simple proportion that a change of one-tenth of an inch in the barometer will vary the temperature of the boiling point by 0·176 of a degree. This article has already extended to such a length, that we will be obliged to refer to our article *Steam* for further particulars regarding this important department of the doctrine of heat. See *Steam*.

Although the thermometer should stand at the same height when put into different liquids, this is no proof that they contain the same quantities of heat. If two glasses of unequal capacities be filled with the same sort of water at the same temperature, it is manifest that the water in the larger vessel must contain the greatest quantity of heat. This obvious fact leads naturally to the inquiry whether equal quantities of different materials contain the same quantities of heat, while the thermometer indicates equality of temperature. Whether a pound of water, for example, contains as much heat as a pound of mercury of the same temperature. If equal quantities of water are mixed together, the one at 100 and the other at 200, the temperature of the mixture will be 150°, the mean between the two: but if a cubic foot of water, at any temperature, be mixed with a cubic foot of mercury at some other temperature, the mixture will not be a mean between the two; thus if the water be at 40° and the mercury at 100, the temperature of the mixture will not be 70°, which is the mean, but 60°; and if the water had been 100 and the mercury 40°, the temperature would have been 80°. Thus it appears that equal quantities of the same substance, when mixed, give a temperature the mean of the two, the hot portion losing just as much as the cold portion gained; thus the cold water, in the first case cited above, gained 25, exactly what the hot water lost; but in the second case the mercury lost 40° when the water gained only 20; and in the third case the water lost 20° whereas the mercury gained 40, showing that the same quantity of heat that will raise the same quantity of mercury a certain number of degrees will raise an equal quantity of water only half that amount. But if we take them by weight, instead of bulk, it will require 23 times as much heat to raise a given weight of water a certain number of degrees as it would an equal weight of mercury. The quantity of heat necessary to raise the temperature of a body a certain number of degrees is called its *Specific heat.*

The phrase *specific heat* is often confounded with *capacity for heat.* The definition of the former will be understood from what has been said above. The capacity of bodies for heat are the absolute quantities of heat contained in them at equal temperatures.

The reader must have been struck with the singular fact which we have been endeavouring to describe, that it requires different quantities of heat to raise the temperature of different substances the same number of degrees: thus to raise water and mercury from a temperature of 32° to 212°, the former would require 33 times as much heat as the latter. Now the question naturally arises, where does all this great quantity of heat that has been given to the water go, seeing that it is not indicated by the thermometer? Dr Black, who first observed these phenomena, was of opinion, that heat exists in two different states in the same substance; viz., in a free and in a latent or hidden state; the former passing readily from one substance to another, affecting the senses, and likewise the height of the thermometer, this species he conceived to be only united to the body by mechanical combination. The other species of heat he conceived to be chemically combined, and only to become apparent by a change of the condition of the body, and to be in fact latent or concealed. This serves to explain the phenomena, but can be regarded in no other light than an hypothesis. Dr Turner suggests that sensible heat should be employed instead of free or uncombined heat, and insensible for latent heat; these phrases serving to state the fact without reference to any hypotheses.

During the process of liquifaction a large portion of heat becomes insensible. Mix a quantity of water at 32° with an equal quantity at 172°, the temperature of the mixture will be the mean, that is 102°. Mix a pound of ice at 32° with a pound of water at 172°, the heat of the water will liquify the ice, but the temperature of the mixture will not be 102°, but 32°, showing that 140° had passed from the ice and become insensible during the process of liquification. This insensible heat that seems all to go for the purpose of causing fluidity, is frequently called the heat of fluidity. We have seen that 140 degrees are necessary for forming ice into water without altering the sensible heat. The following is a list of the heat of fluidity of several substances, as determined by Irvine.

Sulphur,	143·68
Spermaceti	145
Lead	162
Bees wax	175
Zinc	493
Tin	500
Bismuth	550

Quantities of heat also become latent during the process of evaporation, as in the process of liquification. Thus Watt found long ago that it required nearly six times as much heat to convert water at 212° into steam at 212°, as it did to raise water from 32° to 212°.

Dr Ure gives the subjoined numbers as representing in degrees of Fahrenheit's thermometer, the insensible heats of the corresponding vapours.

Vapour of Water at 212	9670°
Alcohol	442
Ether	302 379
Petreleum	177·87
Turpentine, oil of	177·87
Nitric acid	531·99
Liquid ammonia	837·28
Vinegar	875

The following Table shows the power of various species of fuel.

Species of fuel.	Effect in lbs. of water heated one degree by one lb. of fuel.	Effect in lbs. of water converted into steam of 220°.	Quantity to convert a cubic foot of water into low pressure steam.	Quantity to convert a cubic foot of water into steam, allowing 10 per cent. for loss.
Caking coal	9800 lbs.	8·4 lbs.	7·45 lbs.	8·22 lbs.
Coke	9000 —	7·7 —	8·1 —	9·00 —
Splint coal	7900 —	6·75 —	9·25 —	10·28 —
Oak wood, dry	6000 —	5·13 —	12·2 —	13·6 —
Ordinary oak	3600 —	3·07 —	20·31 —	22·6 —
Peat compact, of ordinary dryness	3250 —	2·8 —	22·5 —	25·0 —

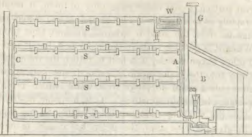
General Effects of Heat corresponding to certain Temperatures.

	Fahr.
Extremity of the scale of Wedgwood	32277°
Greatest heat of an air furnace, 8 inches in diameter, which did not soften Nankeen porcelain	21877
Chinese porcelain softened, best sort	21357
Cast iron, thoroughly melted	20577
Hessian crucible melted	20577
Bristol porcelain not melted	18627
Cast iron begins to melt	17977
Greatest heat of a common smith's forge	17327
Plate glass furnace (strongest heat)	17197
Bow porcelain vitrifies	16807
Chinese porcelain softened, inferior sort	16677
Flint glass furnace (strongest heat)	15897
Derby porcelain vitrifies	15637
Stoneware baked in	14337
Welding heat of iron, greatest	13427
Welding heat of iron, least	12777
Cream-coloured ware baked in	12257
Flint glass furnace (weak heat)	10177
Working heat of plate glass	8487
Delft ware baked in	6407
Fine gold melts	5237
Settling heat of flint glass	4847
Fine silver melts	4717
Swedish copper melts	4587
Brass melts	3807
Heat by which enamel colours are burnt on	1857
Red heat fully visible in day light	1077
Iron red hot in twilight	884
Heat of a common fire (Irvine)	790
Iron bright red in the dark	752
Zinc melts	700
Quicksilver boils (Irvine)	672
Quicksilver boils (Dalton)	660
Quicksilver boils (Crichton)	655
Linseed oil boils	600
Lead melts (Guyton, Irvine)	594
Sulphuric acid boils (Dalton)	590
The surface of polished steel acquires a deep blue colour	580
Oil of turpentine boils	560
Sulphur burns	—
Phosphorus boils	554
Bismuth melts (Irvine)	476
The surface of Polished steel acquires a pale straw colour	460
Tin melts (Crichton, Irvine)	442
A compound of equal parts of tin and bismuth melts	283
Nitric acid boils	242
Sulphur melts	226
A saturated solution of salt boils	218
Water boils (the barometer being at 30 inches;) also a compound of 5 of bismuth, 3 of tin, and 2 of lead, melts	212
A compound of 3 of tin, 5 of lead, and 8 of bismuth, melts	210
Sodium fuses (Gay Lussac and Thenard)	194
Alcohol boils	174
Bees' wax melts	142
Potassium fuses (G. Lussac and Thenard)	136
Spermaceti melts	133
Phosphorus melts (Thenard)	109
Phosphorus melts	100
Ether boils	98
Medium temperature of the globe	50
Ice melts	32
Milk freezes	30
Vinegar freezes at about	28
Strong wine freezes at about	20
A mixture of 1 part of alcohol and 3 parts of water freezes	7
A mixture of alcohol and water in equal quantities freezes	— 7
A mixture of 2 parts of alcohol and 1 of water freezes	— 11
Melting point of quicksilver (Cavendish)	— 39
Liquid ammonia crystallizes (Vauquelin)	— 42
Nitric acid, S. G. about 1.42, freezes, (Cavendish)	— 45
Sulphuric ether congeals (Vanquelin)	— 47
Natural temperature observed at Hudson's Bay	— 50
Ammoniacal gas condenses into a liquid (Guyton)	— 54
Nitrous acid freezes (Vauquelin)	— 56
Cold produced from diluted sulphuric acid and snow, the materials being at the temperature of — 57	— 78½
Greatest artificial cold yet measured (Walker)	— 91

HEATING OF FACTORIES. Heat is sent from one general focus to be distributed through very large buildings or manufactories, and as it is unconfinable, and radiates and escapes in every foot of its progress, it is necessary that the source should be as near as possible to the place of delivery.

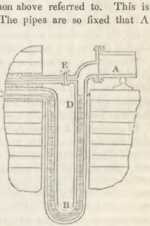
The annexed figure is a section of a silk manufactory belonging to Messrs. Shute and Co., of London, situated at Watford, Herts, and is described by the late ingenious Mr Tredgold, in his *Treatise on the Warming and Ventilating Buildings*. The arrangement is very simple. B is the boiler and furnace house outside the building, the smoke being conveyed away through the funnels and chimney G. A is the main steam pipe up which the steam ascends from the upper part of the boiler.

Into this first pipe are inserted the longitudinal pipes suspended near the ceiling of each room, marked S S S S; each of these pipes has a valve



to regulate the supply of steam, and a siphon at the other extreme, the construction and purpose of which may be thus described. C is a small pipe for returning the water of condensation to the boiler from the upper three floors, that collected from the steam pipe of the lower floor, being used for washing and other purposes. In order to accumulate the water of condensation the longitudinal pipes, it will be seen, are placed at a slight degree of inclination down towards the pipe C, so that as the water is formed in these pipes, it runs gently down towards the further end, there enters the descending small water pipe C, whence it passes again to the bottom of the boiler, retaining still considerable heat. Mr Tredgold observes, that the power of making a good arrangement in this case was extremely limited, the mill being already full of machinery, but the advantages of it are still great, which he thus enumerates: 1. A considerable reduction in the rate of insurance. 2. The absence of all smoke, dust, and ashes, which had been found very injurious to the silk in the former way of warming. 3. A saving of fuel, and of time and labour in attending to the fires. 4. An equable heat instead of the partial one of the stoves, and a regular supply of fresh air into the mill warmed by the main pipe A. 5. The labour proceeds without interruption and in a comfortable temperature. 6. The children are free from chaps and chillblains in the winter season owing to their having warm distilled water for washing. The mill is 106 feet 4 inches by 33 feet; the upper story, 8 feet high, is warmed by a pipe of 3 inches diameter; the next story, 8 feet 8 inches high, is warmed by a pipe of 4 inches; the next, 9 feet high, by a pipe also 4 inches; the next or lower story, 9 feet high, by a pipe of 5 inches diameter. The building is supplied with water from a cistern at W.

It remains for us to explain the nature and uses of the siphon above referred to, and not shown in the figure; this will appear in the course of the following general observations. In every part of the distributing apparatus it is necessary to prevent any considerable quantity of water collecting, for when steam is admitted into the pipes, &c. and meets with a great surface of cold water remaining in them, it condenses the steam so rapidly as to endanger the boiler and pipes, should they not be firm enough to resist the sudden external pressure thus brought upon them. When it is possible to have the boiler at a lower level than the pipes and other steam vessels, it is best to return the water of the condensed steam into the boiler again, because it not only saves fuel, but also requires only a small supply of fresh water, which is an object of some importance in certain situations. It is, however, desirable in some cases to allow the water of condensation to collect in the pipes, and to continue to give out heat after the steam has ceased to flow into the pipes. Stop-cocks may in these cases be employed, and which afterwards allow the water to be educted from the pipes: the same cocks also serve for letting the air out of the pipes when the steam is first admitted, but, when the water is returned into the boiler, the advantage of this supply of heat cannot be reserved; and in these cases a self-acting apparatus is commonly employed for taking off the water of condensation, one kind of which is the siphon above referred to. This is represented by the accompanying cut. The pipes are so fixed that A is the lowest point of a longitudinal pipe; thus any quantity of water that may be formed in the pipe will flow into the siphon ABC at A, and run to waste, or otherwise, at C, the water in the legs of the siphon acting as a trap to the steam in the pipe A. The length of the leg AB of the siphon should not be less than is equivalent to the force of the steam in the pipes, and must, therefore, be determined accordingly. For example, when the steam is worked at the rate of 10 pounds per square inch, the column of water should not be less than ten feet, and even with this pressure there will be considerable oscillations unless a valve be placed somewhere intermediate, as at D. When the legs are both filled with water, and at rest, this valve should be open so as to close whenever the water has a tendency to return into the pipe. The siphon should also be large enough to take away with ease all the water formed by condensation; at the same time it should not be too large,



because there would then be a loss of heat in the leg AB, from its being filled with steam; and in all cases the siphon should be carefully protected against freezing. In connection with the siphon it is usual to place a cock for letting the air out of the pipe instead of the stop-cock above referred to; such a one is shown at E, and it is kept to range with the lower part of the pipe, because the air being heavier than steam it will occupy only the lower portion of it.

The usual diameter of the heating pipe for the common size of spinning factories, is 9 inches. Heating by air is now in general abandoned. The quantity of coals for heating by steam, a cotton-mill, of 4 flats, each 120 feet long by 40 broad, is 1429 lbs. per day; and to heat by air to the temperature for spinning coarse Nos. requires 1782 lbs.

Hemisphere, one-half of a globe or sphere, formed by a plane passing through the centre.

Heptagon, a figure having seven angles and seven sides. When the sides and angles are equal, it is called regular; when not, irregular.—*Properties*. The angle at the centre $= 51^\circ\frac{3}{7}$. The angle of the polygon $= 128\frac{4}{7}$. The area, when the side is 1, $= 3{\cdot}6339126$. And, therefore, when the side is any other number, the rule for the area is, Side ^{2} $\times$ 3·6339126.

Heterogeneous, signifies something whose parts are of different kinds, in opposition to *homogeneous*. Heterogeneous bodies, are of unequal density and composition.

Hexaedron, the cube, one of the five regular or Platonic bodies; and so called from its having six faces.—The square of the side or edge of a hexaedron, is one-third of the square of the diameter of the circumscribing sphere; and hence the diameter of a sphere is to the side of its inscribed hexaedron as $\sqrt{3}$ to 1.

In general, if l, s, and S, be put to denote respectively the linear side, the surface, and the solidity of a hexaedron or cube, also r the radius of the inscribed sphere, and R the radius of the circumscribed one; then we have these general formulæ.

1. $l = 2r = \frac{2}{3}\mathrm{R}\sqrt{3} = \sqrt{\frac{1}{6}s} = \sqrt[3]{s}$.
2. $s = 24r^2 = 8\mathrm{R}^2 = 6l^2 = 6\sqrt[3]{s^2}$.
3. $\mathrm{S} = 8r^3 = \frac{8}{9}\mathrm{R}^3\sqrt{3} = l^3 = \frac{1}{6}s\sqrt{\frac{1}{6}s}$.
4. $\mathrm{R} = r\sqrt{3} = \frac{1}{2}l\sqrt{3} = \frac{1}{2}\sqrt{\frac{1}{2}s} = \sqrt{\frac{3}{4}}\sqrt[3]{s}$.
5. $r = \frac{1}{3}\mathrm{R}\sqrt{3} = \frac{1}{2}l = \frac{1}{2}\sqrt{\frac{1}{6}} = \frac{1}{2}\sqrt[3]{s}$.

From which equations all those quantities may be found, if any one of them be given.

Hexagon is a figure of six sides and angles. It is regular, when both sides and angles are equal: irregular, when these are unequal.

To describe a regular Hexagon on a given line.—On the given line describe an equilateral triangle, and from the vertex as a centre, and with a radius equal to the given line describe a circle; the given line applied to the circumference will cut it in the angles of the Hexagon. To inscribe a hexagon on a circle: apply the radius to the circumference.

Angle at the centre $= 60°$
Angle at the circumference $= 120°$
Area to side $1 = 2·5980762$.
Area to any side $(s) = s^2 \times 2·5980762$.

Table of Diagonals of Hexagons.

Short diameter.	Long diameter or diagonal.	Short diameter.	Long diameter or diagonal.	Short diameter.	Long diameter or diagonal.
¼	·288	2⅜	2·740	6	6·923
⅜	·432	2½	2·884	6¼	7·211
½	·577	2⅝	3·029	6½	7·499
⅝	·721	2¾	3·173	6¾	7·787
¾	·865	2⅞	3·317	7	8·075
⅞	1·009	3	3·461	7¼	8·363
1	1·153	3¼	3·750	7½	8·651
1⅛	1·298	3½	4·038	7¾	8·939
1¼	1·442	3¾	4·327	8	9·227
1⅜	1·586	4	4·615	8¼	9·515
1½	1·730	4¼	4·903	8½	9·803
1⅝	1·875	4½	5·192	8¾	10·091
1¾	2·019	4¾	5·480	9	10·379
1⅞	2·163	5	5·769	9¼	10·667
2	2·307	5¼	6·057	9½	10·955
2⅛	2·452	5½	6·346	9¾	11·243
2¼	2·596	5¾	6·634	10	11·531

High Pressure Engine. The simplest form of the steam engine is the non-condensing, or high-pressure engine. In this engine the condensing apparatus is dispensed with, and steam being admitted into the cylinder, at a high temperature, and consequently high pressure, and having acted on the piston, is allowed to escape into the open air. A part of the force of the steam is of course expended in overcoming the pressure of the atmosphere, and it is only that portion of the steam's elastic force that exceeds 15 lbs. to the square inch that is effective in moving the engine. The surplus pressure is usually from 30 to 40 lbs. on the circular inch. In Perkin's engine, a strong vessel called a *generator* is kept full of water, heated to a high temperature; portions of the water are successively forced out, and he relies on the heat already in the water to produce from it the requisite amount of steam. See

Steam Engine for particulars as to the mode of operation and proportions of the various parts of the high-pressure engine.

HOGSHEAD, an English measure of 63 gallons.

HOMOGENEAL, or HOMOGENEOUS, is a term applied to various subjects to denote that they consist of similar parts, or of parts of the same nature and kind; in contradistinction to heterogeneous.

HOMOGENEAL NUMBERS, are those of the same kind and nature.

HOMOGENEAL SURDS, are such as have one common radical part, as $\sqrt[3]{27}$, and $\sqrt[3]{3}$.

HOMOLOGOUS, a term applied to the corresponding sides of similar figures, which are said to be homologous, or in proportion to each other. Thus, the base of one triangle is homologous to the base of another similar triangle; and in similar triangles, the sides opposite to equal angles are homologous. Equiangular, or similar triangles, have their homologous sides proportional. All similar triangles, rectangles, and polygons, are to each other as the squares of their homologous sides.

HORIZONTAL WHEEL. A horizontal wheel with oblique floats, sometimes called in this country a *tub wheel*, is turned by a current of water discharged against the floats, moving in a horizontal direction. This method is said to be in common use on the continent of Europe, and but seldom employed in England. It is a disadvantageous mode of applying power, and is only recommended in corn-mills by its simplicity, the mill-stones being turned directly by the axis of the water wheel, without the intervention of other wheels, or geering. In the same manner, another kind of *tub wheel*, which is a sort of inverted cone furnished with spiral floats on its inside, is made to revolve horizontally, by discharging into it a current of water from above.

HORIZONTAL WIND-MILL. This name is given to those wind-mills which turn on a vertical axis. Various methods are employed in their construction, in most of which the wind acts by its direct impulse, as in an undershot water wheel. In the most common forms, the sails, like float-boards, present their broadside to the wind on the acting side of the wheel, but are folded up, or turned edgewise on the returning side. Those wheels, however, are found to be greatly inferior to the vertical wind-mill, in the amount of work which they are capable of performing, and at the present day they are little used.

As wind is the most uncertain of all the moving agents, and fails totally in times of calm, it is not common to depend upon this power in large works, provided other moving forces can be obtained. The steam engine has in many cases superseded it, but it is still used in certain places for grinding corn, pumping water, and driving inferior machinery. Upon the ocean it is a locomotive engine of incalculable importance.

HORSES. Horses are often employed as movers of machinery by their draught. A horse draws with greatest advantage when the line of draught is not horizontal, but inclines upward, making a small angle with the horizontal plane. The force of a horse diminishes as his speed increases. The following proportions are given by Professor Leslie, for the force of the horse employed under different velocities. If his force when moving at the rate of two miles per hour, is represented by the number 100, his force at three miles per hour will be 81,—at four miles per hour 64,—at five miles 49,—and at six miles 36. These results are confirmed very nearly by the observations of Mr Wood. In this way the force of a horse continues to diminish, till he attains his greatest speed, when he can barely carry his own weight.

Various estimates have been made of a horse's power by Desaguliers, Smeaton, and others; but the estimate now generally adopted as a standard for measuring the power of steam engines, is that of Mr Watt, whose computation is about the average of those given by the other writers. The measure of a horse's power, according to Mr Watt, is, that he can raise a weight of 33000 pounds to the height of one foot in a minute.

In comparing the strength of horses with that of men, Desaguliers and Smeaton consider the force of one horse to be equal to that of five men; but writers differ on this subject.

When a horse draws in a mill or engine of any kind, he is commonly made to move in a circle, drawing after him the end of a lever which projects like a radius from a vertical shaft. Care should be taken that the horse-walk, or circle, in which he moves, be large enough in diameter; for since the horse is continually obliged to move in an oblique direction, and to advance sideways as well as forward, his labour becomes more fatiguing, in proportion as the circle in which he moves becomes smaller.

In some ferry boats and machines, horses are placed on a revolving platform, which passes backward under the feet, whenever the horse exerts his strength in drawing against a fixed resistance, so that the horse propels the machinery without moving from his place. A horse may act within still narrower limits, if he is made to stand on the circumference of a large vertical wheel, or upon a bridge supported by endless chains which pass round two drums, and are otherwise supported by friction wheels. Various other methods have been practised for applying the force of animals, but most of them are attended with great loss of power, either from friction, or from the unfavourable position of the animal.

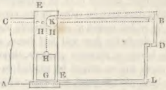
HYDRODYNAMICS treats of the state and forces of liquids, at rest or in motion. It is divided into hydrostatics and hydraulics.

Hydrostatics is the science which treats of the weight, pressure, and equilibrium of liquid fluids. The particles in liquids are freely movable among each other, so as to yield to the least disturbing force; but though it was formerly believed that the liquid fluids are incompressible, recent experiments have shown that they may be indefinitely condensed by pressure. The fundamental truth, on which the whole science of hydrostatics rests, is equality of pressure. All the particles of fluids are so connected together, that they press equally in every direction, and are continually pressed upon; each particle presses equally on all the particles that surround it, and is equally pressed upon by them; it equally presses upon the solid bodies which it touches, and is equally pressed by those bodies. From this, and from their gravity, it follows, that when a fluid is at rest, and left to itself, all its parts rise or fall so as to settle at the same level, no part standing above or sinking below the rest. Hence, if we pour water or any other liquid into a tube bent like the letter U, it will stand at the same height in both limbs, whether they are of the same diameter or not, and thus a portion of the liquid, however small, will resist the pressure of a portion however large, and balance it. In a common tea-kettle, for instance, water poured into the body of the vessel will rise to the same level in the nose as in the vessel; and if poured into the nose, the same will also be true, and the small column of water in the nose balances the whole column in the body of the vessel, and will continue to do so, however large the one, and however small the other may be. From this fact two important conclusions follow, derived both from reasoning and from daily experience. The one is, that water, though, when unconfined, it can never rise above its level at any point, and can never move upwards, will, on being confined in close channels, rise to the height from which it came, that is, as high as its source; and upon this principle depend all the useful contrivances for conveying water by pipes, in a way far more easy, cheap, and effectual than by those vast buildings, called *aqueducts*, by which the ancients carried their supplies of water in artificial rivers over arches for many miles. In this case, the stream must have been running down all the way, and consequently a fountain fed from it at its termination, could not furnish the water at the same height as its source. The other conclusion is not less true, but far more extraordinary, and, indeed, startling to belief, if we did not consider the reasoning upon which it is founded; it is that the pressure of the water upon any object against which it comes, is not in proportion to the body or bulk of the water, but only to the size of the surface, on or against which it presses, and its own height above that surface. Thus, in a tunnel-shaped vessel, the pressure on the bottom is not proportioned to the whole body of water in the vessel, but only to a column of the fluid equal in diameter to the bottom. The general rule for estimating the pressure of any fluid, is to multiply the height of the fluid by the extent of the surface on which it stands; and this by the weight of some known portion of the fluid. Thus the weight of a cubic foot of water is very nearly 1000 ounces avoirdupois; and supposing that a basin containing water up to the height of 10 feet, has a base whose area is 100 square feet, we have $1000 \times 100 \times 10 = 1{,}000{,}000$ ounces the whole pressure on the bottom, which gives for the pressure on one square foot of the bottom 10,000 ounces, or 625 lbs. If any portion of the fluid is supported by a tube above the remainder, the pressure on the bottom of the vessel will be the same as if the water was throughout at the same height as that in the tube, so that the height of the tube is multiplied by the extent of the bottom of the vessel, to determine the whole pressure. And thus it is that the pressure on the bottom of the forementioned basin being only covered by a thin stratum of water but that connected with the water in a tube ten feet in height. In this way a small quantity of water may be made to give a great pressure. This principle of equal pressure has been called the *hydrostatic paradox*, though there is nothing in reality more paradoxical in it than that one pound at the long end of a lever should balance ten pounds at the short end; it is, indeed, but another means, like the contrivances called *mechanical powers*, of balancing different intensities of force by applying them to parts of an apparatus which move with different velocities. This law of pressure is rendered very striking in the experiment of bursting a strong cask by the action of a few ounces of water. Suppose a cask already filled with water, and let a long tube be screwed tightly into its top, which tube will contain only a few ounces of water; by filling this tube the cask will be burst. The explanation of the experiment is this; if the tube have an area of a fortieth of an inch, and contain half a pound of water, this will produce a pressure of half a pound upon every fortieth of an inch over all the interior of the cask. The same effect is produced in what is called the *hydrostatic bellows*. The tube is made to communicate with an apparatus constructed like a common bellows, but without a valve. If the tube holds an ounce of water, and has an area equal only to one thousandth of that of the top board of the bellows, an ounce of water in the tube will balance weights of a thousand ounces resting on the bellows. The hydrostatic or hydraulic press of Mr Bramah, (see *Bramah's press*), is constructed on this principle. The uses to which this power may be applied, are of great variety and extent, but this branch of art seems to be yet in its infancy. Upon the tendency of all the parts of fluids to dispose themselves in a plain or level surface, depends the making of *levelling* instruments, or instruments for ascertaining whether any surface is level, or any line horizontal; for finding what point is on the same level with any given point, and how much any point is above or below the level of any other point.

We have thus far spoken of the pressure of liquids upon a horizontal or level surface, in which case it is only necessary to multiply the height of the fluid by the extent of the surface, and the weight of the bulk is equal to the pressure upon the surface. But if the surface is not horizontal, a different rule must be applied; for then the pressure is equal to the weight of the bulk, found by multiplying the extent of the surface into the depth of the centre of gravity of the surface. In this manner we can find the pressure upon a dam; we must take half the depth of the water, and multiply it by the superficial extent of the dam; this gives the bulk of water whose weight is the pressure on the dam. The pressure against the upright sides of a cylinder filled with water, may be found by multiplying the curve surface under water by the depth of its centre of gravity, which is half the depth of the water. The increase of pressure in proportion to the depth of the fluid, shows the necessity of making the sides of pipes or masonry, in which fluids are to be contained, stronger in proportion to their depth. It is therefore needless to make them equally thick and strong from the top downwards. If they are thick enough for the great pressure below, they will be thicker than is required for the smaller pressure above. The same is true in regard to flood-gates, dams, and banks.

When a solid body is plunged in any liquid, it must displace a quantity of that liquid exactly equal to its own bulk. Hence by measuring the bulk of the liquid so displaced, we can ascertain, precisely the bulk of the body; for the liquid can be put into any shape, as that of cubic feet or inches, by being poured into a vessel of that shape divided into equal parts. This is the easiest way of measuring the solid contents of irregular bodies, when a body is plunged into a liquid, if it be of the same weight as the liquid, it will remain in whatever part of the fluid it is placed; if it be heavier, it will sink to the bottom; if lighter, it will rise to the top. If any body, therefore, be weighed in the air, and then weighed in a liquid, it will lose as much in weight as an equal bulk of the liquid weighs. In this manner we determine the relative weights of all bodies, or the proportion which they bear to each other in weight, which is called their *specific gravity*. Suppose a mass of gold, for instance, to have a certain weight in the air; it would lose, on being weighed in water, about a nineteenth of its weight; that is, the gold would be nineteen times heavier than water. The instrument used for this purpose is called the *hydrostatic balance*, (See *Balance*), and affords the easiest and most accurate method of comparing all substances, whether solid or fluid. This operation may be performed with substances lighter than water, by attaching them to a stiff pin, fastened to the bottom of the scale, or by suspending some heavy substance of a known weight. The same principle also enables us to ascertain the specific gravities of different fluids; for, if the same substance be weighed in two fluids, the weight which it loses in each is as the specific gravity of that fluid. (See *Hydrometer*.)

Mr Thom of Rothsay has employed the principle of floating bodies in the regulation of the height of water in mill dams. The accompanying wood cut shows a section of one of his contrivances for this purpose, called a self-regulating sluice.



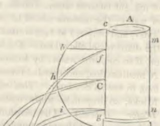
The waster sluice. This sluice, when placed upon any river, canal, reservoir, or collection of water, prevents the water within the embankment from rising above the height we choose to assign to it; for whenever it rises to that height, the sluice opens and passes the extra water; and whenever that extra water is passed, it shuts again; so that whilst it saves the banks at all times from damage by overflow, it never wastes any water we wish to retain. A C B L, part of a canal, river, stream, or collection of water. B C, high water mark, or the greatest height to which the water is to be allowed to rise. BD, a sluice, or folding dam, which turns on pivots at D. E F, a hollow cylinder, having a small aperture in its bottom, to which is joined F L, a small pipe always open. I I I I, small holes in cylinder EF, on the line of high water mark. G H, another cylinder, waterproof, that moves up and down freely within cylinder E F; and the weight of which keeps the sluice B D shut by its connexion with B K H, a chain fixed to cylinder G H at H, thence passing over pulley K, and having its other end fixed to sluice B D at B. When the water in the canal, river, or pond, rises to the line B C, it passes into cylinder E F, at the small holes I I I I; and this lessens the weight of cylinder G H so much that the pressure of the water in front of sluice B D throws it open. When the water subsides, so as not to enter these holes, the cylinder is emptied by the tube F L; and then the weight of cylinder G H shuts the sluice as before. The dimensions and weight of this cylinder must of course correspond with the weight of the column of water pressing upon sluice B D. This sluice is here represented with the pivots on which it turns at its under edge, but they may be placed either at the upper or under edge as circumstances render advisable. The upper edge is also here represented on a level with high water mark, but if necessary, it may be placed anywhere between that and the bottom of the pond, or aqueduct, or right below, as on an aqueduct bridge, or similar situation. The cylinders may also be placed on the outside of the dam or embankment, by having a pipe to communicate between them and the water within; but in whatever situation the sluice or cylinders may be placed, the pipe that communicates between the cylinders and the water within the embankment must always have its opening there exactly at the level of high water mark, or at the greatest height to which the water thereiu is to be permitted to rise. On this principle a self-acting dam may be raised in any river or stream, up to high water mark, by which means a considerable reservoir will be obtained, whilst during floods the dam will fold down, and no new ground be overflowed. In lawns, or pleasure grounds, through which streams or rivulets flow, these sluices might be applied to advantage; for by placing one on the bank of each pond, the water within would always be kept at the same height, whether the weather were wet or dry; and hence flowers or shrubs might be planted close to the water's edge, or in it, (as best suits their respective habits,) and their position with regard to water, would always be the same.

If a single drop of water, or any liquid of a like degree of fluidity, be pressed upon a solid surface, it will wet that surface, and adhere to it, instead of keeping together and running off. This shows that parts of the liquids are more attracted by the parts of the solids than by one another. In the same manner, round the glass in which a liquid is contained, its surface will be seen to be higher than in the centre. If the vessel be less than the twentieth part of an inch in diameter, the liquid will rise in it the higher in proportion to the smallness of the diameter. This is called *capillary attraction*, and tubes of this kind are called *capillary tubes*. See *Capillary Tubes*; see also *Pumps*, *Siphons*, *Springs*.

Hydraulics is that branch of hydrodynamics which has for its object the investigation of the motions of liquids, the means by which they are produced, the laws by which they are regulated, and the force or effect which they exert against themselves or against solid bodies. This subject naturally divides itself into three heads: 1. the effects which take place in the natural flowing of fluids through the various ducts or channels which convey them; 2. the artificial means of producing motion in fluids, and destroying their natural equilibrium by means of pumps and various hydraulic engines and machines; and 3. the force and power which may be derived from fluids in motion, whether that motion be produced naturally or artificially.

The particles of fluids are found to flow over or amongst each other with less friction than over solid substances; and as each particle is under the influence of gravitation, it follows that no quantity of homogeueous fluid can be in a state of rest, unless every part of its surface be on a level, that is, not a level plane, but so far convex as that every part of the surface may be equally distant from the centre of the earth. As the particles of all liquids gravitate, any vessel containing a liquid will be drawn towards the earth with a power equivalent to the weight it contains, and if the quantity of the fluid be doubled, tripled, &c., the gravitating influence will be doubled, tripled, &c. The pressure of fluids is, therefore, simply as their heights,—a circumstance of great importance in the construction of pumps and engines for raising water. As liquids gravitate independently, if a hole be made in the bottom of the vessel, the liquid will flow out, those particles directly over the hole being discharged first. Their motion causes a momentary vacuum, into which the particles tend to flow from all directions, and thus the whole mass of the water, and not merely the perpendicular column above the orifice, is set in motion. If the liquid falls perpendicularly, its descent will be accelerated in the same manner as that of falling solid bodies. (See *Mechanics*.) When water flows in a current, as in rivers, it is in consequence of the inclination of the channel, and its motion is referable to that of solids descending an inclined plane; but, from want of cohesion among its particles, the motions are more irregular than those of solids, and involve some difficult questions. The friction between a solid and the surface on which it moves can be accurately ascertained; but this is not the case with liquids, one part of which may be moving rapidly and another slowly, while another is stationary. This is observable in rivers and pipes, where the water in the centre moves with greater rapidity than at the sides, so that a pipe does not discharge as much water in a given time, in proportion to its magnitude, as theoretical calculation would lead us to suppose. As water, in descending, follows the same laws as other falling bodies, its motion will be accelerated; in rivers, therefore, the velocity and quantity discharged at different depths would be as the square roots of those depths, did not the friction against the bottom check the rapidity of the flow. The same law applies to the spouting of water through jets or adjutages. Thus, if a hole be made in the side of a vessel of water, the water at this orifice, which before was only pressed by the simple weight of the perpendicular column above it, will be pressed by the same force as if the water were a solid body descending from the surface to the orifice; that is, as the square root of the distance of those two points; and, in the same way, water issuing from any other orifices, will run in quantities and velocities proportionate to the square root of their depths below the surface. Now, the quantity of water spouting from any hole in a given time, must be as the velocity with which it flows: if, therefore, a hole A be four times as deep below tho surface as a hole B, it follows that A will discharge twice as much water in a given time as B, because two is the square root of four. A hole in the centre of such a column of water, will project the water to the greatest horizontal distance (or range), which will be equal to twice the length of the column of which the orifice is the centre. In like manner, two jets of water, spouting from holes at equal distances above and below the central orifice, will be thrown equal horizontal distances. The path of the spouting liquid will always be a parabola, because it is impelled by two forces, the one horizontal, and the other (gravitation) perpendicular.

To prove this by experiment, let two pipes of equal size, *m* and *n*, be fixed into the side of the vessel A, but so that the pipe *n* is placed four times deeper below the surface *c* than the pipe *m*. (In this case the orifices *fCg* are supposed to be closed.) If the surface of the water in the vessel be kept at the same height by a constant supply being poured in, and if two vessels, one of which would hold a pint, be placed under the pipe *m*, and the other which would contain a quart under the pipe *n*, both vessels will be filled in the same time from their respective pipes.



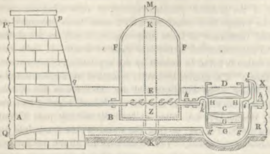
Wherefore the quantities of water passing through equal holes in the same time, are as the square roots of their depths. The horizontal distance to which a fluid will spout from a hole made in the side of an upright vessel may be determined in the following manner. Let the vessel A be filled with water to the height of the surface, and let *d k a* be a horizontal plane upon which the jets fall; on *c d*, as a diameter describe a semicircle *c h d*, whose centre C shall be the central height of the column of fluid in the reservoir A; then if holes be made in the reservoir at the points *f* C *g*, and lines drawn from them to the semicircle perpendicular to the diameter of the semicircle, or the side of the vessel as at *f b*, C *h*, and *g i*; the distance to which water will spout from the holes *f* C *g*, will be proportionate to the length of line which cuts the semicircle. As C *h* is the longest line which can be drawn within the semicircle, the water spouting from C will reach the greatest horizontal distance *a*, and that range, if in vacuo, would be equal to twice the length of line drawn from the point of discharge to the semicircle. Though water will rise in pipes as high as the surface of the head from which it is supplied; yet in perpendicular jets it can never rise so high, because of the resistance of the air, and the friction of the adjutage. The best kind of adjutage is the end of the tube covered with a thin plate, in which is made a smooth hole much less than the bore of the tube. In such an adjutage the water will ascend in a regular shape, and find little friction in passing through the thin plate.—See *Discharge*.

The second division of the subject, mentioned in the beginning of this article, is of the greatest practical utility, as embracing an account of the various pumps and machines which have been employed to raise water; and numerous as these may appear, it will be found that they may all be comprehended under four general heads: 1. those machines in which water is lifted in vessels by the application of some mechanical force to them. The earlier hydraulic machines were constructed on this principle, which is the simplest; such are the Persian wheel, consisting of upright buckets attached to the rim of a wheel, moving in a reservoir of water; the buckets are filled at bottom, as they pass through the water, and emptied at top, so that the water is raised a height equal to the diameter of the wheel. The wheel may be turned by living power, or, if in running water, by fastening float boards to the circumference. A modification, and decided improvement on the Persian wheel has been long in use in Scotland. This wheel was the invention of Mr George Micke, an ingenious millwright of Alloa, in Clackmannanshire. (See *Water Wheel*.) The Archimedian screw, the bucket-engine or chain-pump, and the rope-pump of Vera, are modifications of the same principle. See *Water Works*.

2. The next class of machines are those in which the water is raised by the pressure of the atmosphere, and comprises all those machines to which the name of *pump* is more particularly applied. These act entirely by removing the pressure of the atmosphere from the surface of the water, which may thus be raised to the height of about thirty-two feet. Whenever it becomes necessary to raise water to greater heights, the third class of machines, or those which act by compression on the water, either immediately or by the intervention of condensed air, are employed. All pumps of this description are called *forcing-pumps*. Although atmospheric pressure is not necessary in the construction of forcing-pumps, it is, in most cases, resorted to for raising the water, in the first place, into the body of the pump, where the forcing action takes place. In machines of this kind the water may be raised to any height. —See *Water Works*.

3. The next class of hydraulic machines for raising water, consists of such engines as act either by the weight of a portion of the water which they have to raise, or of any other water that can be used for such purpose, or by its centrifugal force, momentum, or other natural powers; and this class, therefore, includes some very beautiful and truly philosophical contrivances, too numerous for us to describe. The Hungarian machine, the centrifugal pump, and the water-ram, are among the number.

The large pipe AB called the body of the ram, passes through the side of the reservoir PQ, from which the fall of water is obtained. It has a trumpet mouth at one end A, and at the other end an opening



HH, which can be closed by valves C or D. When these valves are open, the water will issue at H H with a velocity due to the height AP; but when the internal valve C is closed, as in the figure, the water is prevented from issuing. When the valve C opens, it descends into the position shown by the dotted lines G G, being guided between three or four stems *g g*, which have hooks at the lower ends for supporting the valves. In this case the water has a free passage between these stems, and the width of the passage can be increased or diminished by the screws with which the stems are fixed. The valve C is made of metal, and has a hollow cup or dish of metal attached to its lower surface. The seat HH of the valve is wider than the diameter of the pipe AB. It consists of a short cylinder or pipe screwed by its flanch *h h* into the opening of the upper surface of the head R of the ram; and the cylinder is so formed as to have an inverted cup or annular space *i i* round the upper part of it for containing air, which cannot escape when it is compressed by the water. A small pipe *k l*, leading from this annular space to the open air, is furnished with small valves, *k l*, one of which, *k*, opens inwards to admit the air into *i i*, but to prevent its return, while the other valve, *l*, admits a certain quantity of air, and then shuts and prevents any further entrance. The valve D is exactly the same as C, only it descends as in the figure when it shuts, and rises when it opens. The upper part of the head of the ram at E is made flat, and has several valves which allow the water to pass freely from the pipe AB, but prevent its return. On each side of the head of the ram, at the part opposite to these valves is a hollow enlargement, shown by the dotted lines K, forming a circular bason, through the centre of which the pipe ABR passes. The pipe is hero made flat instead of circular, for forming the seats of the valves, and the bason K K is covered with an air vessel FF. This air vessel communicates all round the pipe B, with the bason KK, and with the vertical pipe M. The machine being thus constructed, let us suppose the pipe A B R full of water, and the valve C to be opened, the water will lift the valve D, and escape with a velocity due to the height of the reservoir. In a short time, the water having acquired an additional velocity, raises the valve G, which shuts the passage, and prevents the escape of the water. The consequence of this is, that all the included water exerts suddenly a hydrostatical pressure on every part of the pipe, compressing at the same time the air in the annular space *i i*, which by its elasticity diminishes the violence of the shock. This hydrostatical pressure opens the valves at E, and a portion of the water flows into the air vessel F, and condenses the air which it contains. The valves at E now close, preventing the return of the water into the pipe, and the water recoils a little in the tube with a slight motion from B to A, in consequence of the reaction or elasticity of the compressed air in *i i*, and also of the metal of the pipe, which must have yielded a little to the force exerted upon it in every direction. The recoil of the water towards A produces a slight aspiration within the head R of the ram, which causes the valve D to descend by its own weight, and prevent the water X which covers it from descending into the tube. The air, however, passes through the pipe *l k*, opens the valve *k*, and a small quantity is sucked into the annular space *i i*; but the quantity is very small, as the valve *k* closes as soon as the current of air becomes rapid. During the recoil towards A, the valve C, being unsupported, falls by its own weight; and when the force of recoil is expended by acting on the water in the reservoir PQ, the water begins again to flow along ABR, and the very same operation which we have described is repeated without end, a portion of water being driven into the air vessel F at every ascent of the valve C. The air in this vessel being thus highly compressed, will exert a force due to its elasticity upon the surface of the water in the vessel F, and will force it up through the pipe M to a height which is sufficient to balance the elasticity of the included air.

The small quantity of air which is drawn into the annular space *i i* through the air tube *l k* at each aspiration, causes an accumulation of air in the space *i i;* and when the aspiration of recoil takes place, a small quantity of air passes from *i i*, and proceeds along the pipe till it arrives beneath the valves at E, and lodging in the small space beneath the valves, it is forced into the air vessel at the next stroke, and thus affords a constant supply of air to the vessel. The valves make in general from fifty to seventy pulsations in a minute.

When the fall of water, or PQ, is five feet, and the pipe AB six inches in diameter, and fourteen feet long, a machine with its parts proportioned as in the figure will raise water to the height of 100 feet. It will expend about seventy cubic feet per minute in working it, and will raise about two and a third cubic feet per minute to the height of 100 feet. For another form of this machine see *Water Works*.

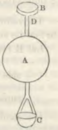
The third general division of the subject relates to the means by which motion and power may be obtained from liquids, and includes the general consideration of water-wheels and other contrivances for moving machinery. Motion is generally obtained from water, either by exposing obstacles to the action of its current, as in water-wheels, or by arresting its progress in movable buckets, or receptacles which retain it during a part of its descent.

Water-wheels have three denominations, depending on their particular construction, on the manner in which they are set or used, and on the manner in which the water is made to act upon them; but all water-wheels consist, in common, of a hollow cylinder or drum, revolving on a central axle or spindle, from which the power to be used is communicated, while their exterior surface is covered with vanes, float-boards, or cavities, upon which the water is to act. The undershot wheel is the oldest construction of this kind: it is merely a wheel, furnished with a series of plane surfaces or floats projecting from its circumference, for the purpose of receiving the impulse of the water which is delivered under the wheel. As it acts chiefly by the momentum of the water, the positive weight of which is scarcely called into action, it is only proper to be used where there is a great supply of water always in motion. It is the cheapest of all water-wheels, and is more applicable to rivers in their natural state than any other form of the wheel; it is also useful in tide-currents, where the water sets in opposite directions at different times, because it receives the impulse equally well on either side of its floats. In the overshot wheel, the circumference is furnished with a series of cavities or buckets, into which the water is delivered from above. The buckets on one side, being erect, will be loaded with water, and the wheel will be thus set in motion; the mouths of the loaded buckets, being thus turned downwards by the revolution of the wheel, will be emptied, while the empty buckets are successively brought under the stream by the same motion, and filled. The breast-wheel differs from this in receiving the water a little below the level of the axle, and has floats instead of buckets. In these two wheels, the weight and motion of the water are used, as well as its momentum, and a much greater power is, therefore, produced with a less supply of water than is necessary for the under-shot wheel. In order to permit these wheels to work with freedom, and to the greatest advantage, it is necessary that the *back* or *tail* water as it is called, or that which is discharged from the bottom of the wheel, should have an uninterrupted passage off; for otherwise it accumulates, and forms a resistance to the float-boards. One of the simplest methods of removing it consists of forming two drains through the masonry, each side of the water-wheel, so as to permit a motion of the upper water to flow down into the tail, in front of the wheel. The water, thus brought down with great impetuosity, drives the tail-water before it, and forms a hollow place, in which the wheel works freely, even if the state of the water be such that it would otherwise form a tailing of from twelve to eighteen inches. The drains may be closed whenever the water is scarce. Numerous other contrivances are in use, which our limits will not permit us to describe. See *Breast, Over-shot and Under-shot, Water Wheel.*

In Barker's centrifugal mill, the water does not act, as in the contrivances above noticed, by its weight or momentum, but by its centrifugal force and the reaction that is produced by the flowing of the water on the point immediately behind the orifice of discharge. It consists of a revolving vertical tube, which receives the water at the top, and at the bottom of which is a horizontal tube, extending on each side of it, and having apertures opening in opposite sides, near the ends. The water spouting from these apertures keeps up a constant rotatory motion, by reaction.

HYDROMETER, an instrument, which, being immersed in fluids, as in water, brine, beer, brandy, determines the proportion of their densities or their specific gravities. The hydrometer will sink in different fluids in an inverse proportion to the density of the fluids. The weight required to sink a hydrometer equally far in different fluids, will be directly as the densities of the fluids. Each of these two facts gives rise to a particular kind of hydrometer; the first with the graduated scale, the second with weights. The latter deserves the preference. There are various instruments used as hydrometers; one is a glass or copper ball, with a stem, on which is marked a scale of equal parts or degrees. The point to which the stem sinks in any liquid being ascertained and marked on this scale, we can tell how many degrees any other liquid is heavier or lighter, by observing the point to which the stem sinks in it. Another kind is formed by preparing a number of hollow glass beads, of different weights, and finding which bead will remain stationary in any liquid, wherever it is placed. An instrument of great delicacy, which will even detect any impurity in water too slight to be detected by any ordinary test, or by the taste, consists of a ball of glass three inches in diameter, with another joining it, and opening into it one inch in diameter. A wire, about ten inches long and one-fortieth of an inch in diameter, divided into inches and tenths, is screwed into the larger ball. A tenth of a grain, placed on the top of the wire will sink it a tenth of an inch. Now it will stand in one kind of water a tenth of an inch lower than in another, which shows that a bulk of one kind of water, equal to the bulk of the instrument (which weighs 4000 grs.), weighs one tenth of a grain less than an equal bulk of the other kind of water; so that a difference in specific gravity of one part in 40,000 is detected. The areometer is more simple and accurate. A glass phial, about two inches in diameter, and seven or eight long, is corked tight; into the cork is fixed a straight wire, one twelfth of an inch in diameter, and thirty inches long. The phial is loaded with shot, so as to sink in the heaviest liquid, leaving the wire just below the surface. The liquor is then placed in a glass cylinder, three or four feet long, with a scale of equal parts on the side, by which the point to which the top of the wire sinks is marked. This instrument is so delicate, that the sun's rays, falling upon it, will cause the wire to sink several inches; and it will rise again when carried into the shade.

Nicholson made an improvement by which the hydrometer is adapted to the general purpose of finding the specific gravity both of solids and fluids. A is a hollow ball of copper, B a dish affixed to the ball by a



short slender stem D; C is another affixed to the opposite side of the ball by a kind of stirrup. In the instrument actually made, the stem D is of hardened steel 1-40 of an inch in diameter, and the dish C is so heavy as in all cases to keep the stem vertical when the instrument is made to float in any liquid. The parts are so adjusted, that the addition of 1000 grains in the upper dish B, will just sink it in distilled water, at the temperature of 60° of Fahrenheit's thermometer, so far that the surface shall intersect the middle of the stem D. Let it now be required to find the specific gravity of any fluid. Immerse the instrument in it, and by placing weights in the dish B cause it to float, so that the middle of its stem D shall be cut by the surface of the fluid. Then, as the known weight of the instrument, added to 1000 grains, is to the same known weight added to the weight used in producing the last equilibrium, so is the weight of a quantity of distilled water displaced by the floating instrument, to the weight of an equal bulk of the fluid under examination. And these weights are in the direct ratio of the specific gravities. Again, let it be required to find the specific gravity of a solid body, whose weight is less than 1000 grains. Place the instrument in distilled water, and put the body in the dish B. Make the adjustment of sinking the instrument to the middle of the stem, by adding weight in the same dish. Subtract those weights from 1000 grains, and the remainder will be the weight of the body. Place now the body in the lower dish C, and add more weight in the upper dish B, till the adjustment is again obtained. The weight last added will be the loss the solids sustain by immersion, and is the weight of an equal bulk of water. Consequently the specific gravity of the solid is to that of water, as the weight of the body to the loss occasioned by the immersion.

Hypotenuse, or Hypothenuse in Geometry, is that side of a right-angled triangle which is opposite to the right angle, the square of which is equal to the sum of the squares of the other two sides.

Hypothesis, a proposition or principle which is supposed or taken for granted, in order to draw conclusions for the proof of a point in question.

I

Icosahedron, in geometry, one of the regular platonic bodies, comprehended under twenty equal triangular sides or faces.

Let s represent the side; then will surface equal $= 5\,s^3\sqrt{3} = 8{\cdot}66025403\,s^2$ and solidity $= \frac{5}{6}\,s^3\,\frac{7+3\sqrt{5}}{2} = 2{\cdot}1816950\,s^3$.

The radius of the sphere circumscribing an Icosahedron being given, to find its side or linear edge, surface, and solidity.

Let R represent the given radius, then will

$$\text{side} = R\sqrt{\left(\frac{10-2\sqrt{5}}{5}\right)}$$

$$\text{surface} = 2\,R^2\,(5\sqrt{3}-\sqrt{15})$$

$$\text{solidity} = \tfrac{2}{3}\,R^3\sqrt{(10+2\sqrt{5}.)}$$

Or putting r to represent the radius of the inscribed sphere, we shall have

$$\text{side} = r\sqrt{(42-18\sqrt{5})}$$

$$\text{surface} = 2r^2\,(7\sqrt{3}-3\sqrt{15})$$

$$\text{solidity} = 10r^3\,(7\sqrt{3}-3\sqrt{15})$$

Or writing s for the side, we have radius of circumscribing sphere

$$= \tfrac{1}{2}\,s\sqrt{\left(\frac{5+\sqrt{5}}{2}\right)}$$

radius inscrib. sphere

$$= \tfrac{1}{2}\,s\sqrt{\left(\frac{7+3\sqrt{5}}{6}\right)}.$$

Impact, the single instantaneous blow or stroke communicated from one body in motion, to another either in motion or at rest.

IMPENETRABILITY, that quality of a body which prevents it from being pierced.

IMPETUS, the product of the mass and velocity of a moving body, considered as instantaneous, in distinction from *momentum*, with reference to time, and *force* with reference to capacity of continuing its motion.

INCIDENCE, in mechanics, is used to denote the direction in which a body, or ray of light, strikes another body; and is otherwise called inclination. In moving bodies their incidence is said to be perpendicular or oblique, according as their lines of motion make a straight line, or an angle at the point of contact.

Angle of Incidence, generally denotes the angle formed by the line of incidence, and a perpendicular drawn from the point of contact to a plane or surface on which the body or ray impinges.

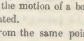
Thus if a body impinges on the plane at a point, and a perpendicular be drawn, then the angle made by this perpendicular and the incident ray is generally called the angle of incidence, and the complement of this the angle of inclination.

INCLINATION, denotes the mutual approach or tendency of two bodies, lines, or planes, towards each other, so that the lines of their direction make at the point of contact an angle of greater or less magnitude.

INCLINED PLANE. A plane which forms an angle with the horizon. The force which accelerates the motion of a heavy body on an inclined plane, is to the force of gravity, as the sine of the inclination of the plane to the radius, or as the height of the plane to its length. If $f =$ force accelerating the body on an inclined plane, of which the inclination is i, and if $g =$ force of gravity, $f = g$ sine i. Hence the motion of a body on an inclined plane, is a motion uniformly accelerated.

If two bodies begin to descend from rest, and from the same point, the one on an inclined plane, and the other falling freely to the ground, their velocities at all equal heights above the surface will be equal. Hence the velocity acquired by a body in falling from rest through a given height, is the same, whether it fall freely, or descend on a plane any how inclined. The space through which a body will descend on an inclined plane, is to the space through which it would fall freely in the same time, as the sine of the inclination of the plane to the radius.

When a power acts on a body, on an inclined plane, so as to keep that body at rest; then the weight, the power, and the pressure on the plane, will be as the length, the height, and the base of the plane, when the power acts parallel to the plane; that is,



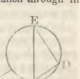
The weight	will be as	AC
The power		BC
The pressure on the plane		AB

When the power does not act parallel to the plane, then from the angle C of the plane, draw a line perpendicular to the direction of the power's action; then, the weight, the power, and the pressure on the plane, will be as AC, CB, AB.

When the line of direction of the power is parallel to the plane, the power is least.

If two bodies, on two inclined planes, sustain each other, by means of a string over a pulley, their weights will be inversely as the lengths of the planes.

The diameter of a circle perpendicular to the horizon, and any chord terminating at either extremity of that diameter, are fallen through in the same time. Thus a body will fall through the diameter E A in the same time that it would descend the inclined plane ED, or the plane DA, each of these being chords of the same circle.



The velocities which bodies acquire by descending along chords of the same circle, are as the lengths of those chords. If a body descend over a series of inclined planes, at each of the angular points, where it passes from one plane to another, it loses a part of the velocity it had acquired, proportional to the versed sine of the inclination of the planes. If v be the velocity it has acquired when it comes to any angle φ, $v \times$ vers. φ is the velocity lost. Any angle being given, it may be divided into angles, so small, that the sum of the versed sines of these angles shall be less than any given magnitude. Hence the number of planes may be so increased, and their inclination to one another so diminished, that though the change of direction between the first and the last be ever so great, the loss of velocity in the descending body shall be less than any given quantity. Therefore, if the body descend in a curve, it will suffer no loss of velocity.

INDICATOR, an instrument for ascertaining the amount of the pressure of steam and the state of the vacuum throughout the stroke of a steam engine. Boulton and Watt long employed an instrument of this kind, the nature of which was for a long time not generally known. Of late an instrument acting upon the same principle and equally accurate, has been made by Mr M'Naught, of Glasgow, which we shall describe under our article *Tell Tale*.

INERTIA, is the term which designates the passiveness of matter, which, if at rest, will for ever remain in that state until compelled by some cause to move; and, on the contrary, if in motion, that motion will not cease, or abate, or change its direction, unless the body be resisted. That a body at rest will not move of itself, will be readily admitted; but its tendency to continue the motion once communicated to it, contradicting our ordinary experience, requires a little explanation. We can indeed produce no species of motion which will fully illustrate the proposition by experiment; but the conclusion seems undeniable, when we consider the effect produced by diminishing the obstructions to a body in motion. These obstructions are, gravitation, the resistance of the air, and friction. Gravitation, operates according to established laws, unsusceptible of change or modification by human art; most of the resistance of the air may be removed by means of the air-pump, but experiments with this machine can only be of small extent; the last-named obstruction to motion, viz. friction, is therefore the only one we have in general the power of diminishing; and yet in proportion as this one is diminished, we find the motion communicated to a body by a given impulse, so much increased that we cannot hesitate to consider the action of gravitation and the resistance of the air, combined with the friction yet undestroyed, as the sole causes of its ever ceasing. If a ball be projected along a rough pavement, it will soon stop; if projected on a level floor, the same force will send it much further; and on a surface perfectly plane, hard, and smooth, a ball also perfectly hard and smooth, as well as globular, would be carried perhaps five hundred yards, by the same force that would scarcely carry it twenty yards upon the rough pavement. So far, also, as reasoning confirms the explanation given of the inertia of matter, it seems as absurd to suppose that matter once put in motion can stop without a cause, as that when at rest it can move without a cause.

INERTIÆ, VIS. See *Vis Inertiæ*.

INSCRIBED FIGURE, is one which touches all the sides of another figure internally. To inscribe a circle in any triangle or regular polygon: Bisect two of the angles, the intersection of the bisecting lines will be the centre of the circle, and its radius will be the perpendicular drawn from that point to any of the sides.

INTERIOR ANGLE OF A POLYGON, that which is formed internally by the meeting of any of the sides of the figure.

INTESTINE MOTION of the parts of a body, is that which takes place amongst the component parts.

INTRADOS, the interual curve of the arch of a bridge.

INVOLUTE CURVE, is that which is traced out by the end of a thread that is coiled round another curve. This species of curve is frequently used in the formation of the teeth of wheels.

IRON is intrinsically the most valuable of all the metals. In treating of this metal, we shall adopt the following order: its ores; their reduction to the metallic state; mechanical properties, and other particulars.

Ores of Iron. Iron exists in nature under four different states—the native state; that of an oxide; in combination with combustible bodies, particularly with sulphur; and, finally, in the state of salts, as the sulphate, phosphate, and carbonate, of iron. Natural malleable iron is a rare production of this globe, nearly all that has ever been found upon it having come to us from the atmosphere.

It would be inconsistent with the nature of this work to enter into minute details of the chemical history of iron ores and salts. Of the ores there are at least fifteen, but as only four of them are employed in the manufacture of cast and malleable iron we shall omit all the others in our description.

Magnetic Iron Ore, or *Oxydulated Iron*, is of an iron-black colour, more intense than belongs to metallic iron; its powder is of a pure black. It occurs crystallized, in the form of the regular octahedron, which is its fundamental form; it usually, however, presents itself in large lamelliform masses, with distinct octahedral cleavages, in granular concretions, or compact. It is brittle, has the hardness of feldspar, and a specific gravity of 5·094. It exerts a decided action on the magnetic needle; and certain specimens, especially of a compact variety, attract and repel, alternately, the poles of a needle, according as we present the same point of a fragment of the ore to one or the other of the extremities of a needle. This variety, which is found in several countries, is called *native loadstone*. Its magnetic virtue strengthens by exposure to the air. The magnetic iron consists of 28·14 protoxide of iron, and 71·86 of peroxide of iron. It is infusible before the blowpipe, but assumes a brown colour, and loses its attractory power, after having been exposed to a great heat. It is soluble in nitric acid, and may be obtained crystallized by fusing it, as often happens in the roasting of it, in furnaces, to effect its reduction. It occurs in primitive rocks, chiefly in gneiss, mica-slate, hornblende-slate, and chlorite slate, and rarely in limestone, when it forms veins, beds, or even entire mountains. It also composes the chief ingredient of certain sands, which have been washed and deposited by the same currents which separated it from its original beds. The different varieties of this ore are exceedingly rich in metal, often yielding eighty per cent of iron, and are every where explored, when found in sufficient quantities, and connected with abundance of fuel and facility of transportation.

Specular Iron Ore, and *Red Iron Ore*. This species, scarcely less interesting than the last in economical importance, presents many difficulties to the mineralogist, in consequence of the complicated forms of its crystals, and the diversified appearance of its compound varieties. It is crystallized in a great number of forms, whose fundamental figure is a slightly acute rhomboid of 86° 10′ and 93° 50′, which may be derived from its crystals by cleavage. The general tendency of its secondary forms is to hexagonal prisms and irregular octahedra. Lustre, metallic; colour, dark steel-gray, iron-black; streak, cherry-red, or reddish-brown; surface of the crystals frequently tarnished; opaque, except in very thin laminæ, which are faintly translucent, and show a deep blood red colour; brittle; hardness, the same with the preceding species; specific gravity, 5·251. Its action upon the magnet is feeble; it never attracts iron filings, or offers magnetic polarity. Besides occurring in distinct crystals, and in lamelliform and compact masses, with a metallic lustre, it also presents itself in reniform, botryoidal, and stalactitic shapes, and earthy-looking masses, where, from the smallness of the individuals, no signs of the metallic appearance are discernible. These varieties have received distinct names, and have often been treated of, in mineralogical systems, as belonging to a distinct species, which, on account of their colour, has been designated *red iron ore*. But this distinction is now given up, as an uninterrupted transition has been noticed between all the varieties of the red iron ore and the crystalline specular iron. The following are some of the varieties of the present species, according as they have acquired distinct appellations in mineralogical books, and among mankind in general: that in distinct crystals is called *specular iron;* that in thin, lamellar concretions, with a metallic lustre, is called *micaceous iron;* the rest, with a metallic lustre, is denominated *common specular iron*. Those varieties which have lost their metallic appearance, are included within, 1. the red iron ore, divided into *fibrous* red iron ore, or *red hematite; compact* and *ochrey* red iron ore, which are massive, and consist of impalpable granular individuals, more or less firmly connected; and *scaly* red iron ore, or *red iron froth*, consisting of very small, scaly, lamellar particles, which, in most cases are but slightly coherent: 2. clay iron ore, divided into *reddle*, which possesses an earthy, coarse, slaty fracture, and is used as a drawing material; *jaspery* clay iron ore, which has a large, flat, conchoidal fracture, and considerable hardness when compared with the other varieties of red iron ore; and *columnar* and *lenticular* clay iron ore, which are distinguished, the first by the columnar form, the latter by the flattish, granular form of its particles. The micaceous iron, analyzed by Bucholtz, and the red hematite, analyzed by D'Aubuisson, have been found to consist of

Peroxide of iron,	100·00	90·00	94·00
Oxide of manganese,	0·00	a trace	a trace
Silica,	0·00	2·00	2·00

Lime,	0·00	a trace	1·00
Water,	0·00	2·00	3·00

The proportion of metal to that of oxygen, in the species, is as 69·34 : 30·66. The clay iron ores, being more or less mixed with earthy substances, vary in their contents, and several of their properties are dependant upon the nature of these admixtures. The specular iron is infusible before the blowpipe, but melts with borax, and forms a green or yellow glass, like pure oxide of iron. It is likewise soluble in heated muriatic acid. The specular iron (in the crystalline, lamelliform, and compact varieties, with a metallic lustre) forms very powerful beds, and even entire mountains, which are traversed by a multitude of fissures, and cavities lined with small, but exceedingly brilliant crystals of this substance. It yields, in the ordinary operations of reduction, sixty per cent. of metal. Its most celebrated locality is the island of Elba, which has afforded iron for sixteen centuries. Its mines are still believed to be inexhaustible. They annually yield 32,000,000 of French quintals of ore, which are transported for reduction into Tuscany, the Roman states, Liguria, and the kingdom of Naples. It is also found at Framont in the Vosges (where its exploration occupies 200 miners), in Saxony, Bohemia, Sweden, Siberia, and in the United States of America. Wherever it exists it is explored with profit. It deserves to be mentioned, also, that specular iron in exceedingly brilliant crystals and scales, occurs very frequently among the ejected matter of volcanoes, as in the lavas of Vesuvius and Auvergre, where it is, undoubtedly, a product of sublimation. The red hematite is found in beds and veins, in primitive and secondary countries. It occurs abundantly in Saxony, the Hartz, Silesia, and in England. It affords excellent iron, and often in the large proportion of sixty per cent. Most of the plate iron and iron wire of England are made of it. In Scotland, it is used, along with the ore of that country, at the Carron and Glasgow works. The ochrey red iron ore usually accompanies the other varieties of this species, and is treated conjointly with them. In places where it is found in considerable quantities, it is sometimes collected, washed, and employed as a polishing substance. The compact red iron ore is found in France and some other European countries, where it is reduced, and affords a good soft iron, yielding fifty per cent. of metal. But its most important uso is as a polisher. It forms, when perfectly compact, the burnisher of the button maker, by means of which he imparts to gilded buttons the highest polish of which they are capable. The best specimens for button-polishers command a very high price, and usually come from little pebbles and rolled masses of this ore, found in secondary countries. The following table exhibits a mineralogical analysis of nine specimens of iron ore found in the district of Clydesdale.

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
Water . . .	- -	0·99	- -	- -	- -	- -	- -	- -	- -
Carbon. acid	32·53	33·63	31·86	30·76	26·35	33·10	32·24	35·17	34·27
Protoxide of iron.	35·22	45·84	42·15	38·80	36·47	47·33	43·73	53·03	42·35
Protox. of manganese	0·00	0·20	0·00	0.07	0·17	0·13	0·00	0·00	- -
Lime . . .	8·62	1·90	4.93	5·30	1·97	2·00	2·10	3·33	3·78
Magnesia .	5·19	5·90	4·80	6·70	2·70	2·20	2·77	1·77	4·95
Silica . . .	9·56	7·83	9·73	10·87	19·90	6·63	9·70	1·40	
Alumina . .	5·34	2·53	3·77	6·20	8·03	4·30	5·13	0·63	
Peroxide of iron.	1·16	0·00	0·80	0·33	0·40	0·33	0·47	0·23	
Calcarious or bituminous matter	2·13	1·86	2·33	1·87	2·10	1·70	1·50	3·03	12·70
Sulphur . .	0·62	0·00	0·00	0·16	0·00	0·22	0·02	0·00	
Moisture and loss	- -	- -	- -	- -	1·91	2·26	2·34	1·41	1·95
	100·37	100·68	100·37	101·06	100·00	100·00	100·00	100·00	100·00

This Table, with the explanatory remarks that follow, are taken from Brewster's Edinburgh Journal for 1828.

(*a*) From Crossbasket, about seven miles south-east from Glasgow. Colour light-greyish, or greenish-black. Fracture from fine-grained even to coarse-grained, uneven, very easily frangible, soft, easily scratched by the knife. Specific gravity taken in distilled water at the temperature of 60°, 3·1793.

This is the highest and also the least valuable of the Crossbasket strata of ironstone, which are at present raised for the use of the blast furnace. The thickness of the stratum is from three to three and a half inches.

(*b*) From Crossbasket. Colour light greyish-black. Fracture fine-grained, earthy, slightly uneven. Rather tough. Not particulary soft. Specific gravity 3·3801.

This ore is found at a distance of four feet under the preceding one. It constitutes a stratum of about nine inches in thickness, and is esteemed the purest and most valuable of the Crossbasket ores.

(*c*) From Crossbasket. Colour light greyish black. Fracture fine-grained, earthy, slightly uneven. Rather tough, but more easily frangible, and softer than the last mentioned ore. Specific gravity 3·2699. The average thickness of the stratum is from six to eight inches.

(*d*) From Crossbasket. Colour brownish-black. Fracture earthy, fine-grained, uneven. Easily frangible and soft. Specific gravity 3·1175.

This stratum of ironstone is situated next under that from which the preceding specimen was taken, and forms the lowest which is at present wrought at Crossbasket. It varies in thickness from ten to fourteen inches. Both it and the preceding ore are reckoned of good average quality. This ore furnishes a curious instance of the capricious and seemingly unaccountable alterations that are liable to take place in every chemical manufacture, whose fundamental principles are little understood, and in none, perhaps, does this happen more frequently than in the smelting of iron. Although it forms the thickest of all the Crossbasket strata, and therefore holds out powerful inducements, in an economical point of view, to the iron smelter, it was at one period regarded at the Clyde iron-works as an ironstone totally unfit for the manufacture of good iron; and having once received an unfavourable character, it was allowed to remain unworked for a long course of years. It is only of late that its employment has been again resumed; but, so far from being held in low estimation, it is now considered to be little inferior in quality to any of the Crossbasket ores, and is used very extensively in the blast furnace.

Immediately above this stratum there is situated a bed of schist, containing a regular stratification of very large modules of ironstone. Being extracted by the miner simultaneously with the subjacent ore, they are used to a considerable extent in the blast furnace, and are esteemed an ironstone of uncommonly fine quality. The black bituminous substance which occurs occasionally in nodular ironstone, exists very generally distributed throughout the stratification of balls.

(*e*) A specimen found in the neighbourhood of Clyde iron-works, which are situated about four miles south-east from Glasgow. Its mineralogical details are the following,—Colour pale, between brocoli-brown and clove-brown. Fracture rather fine-grained, uneven. Not particularly hard, easily scratched by the knife. Specific gravity 3·1482. The thickness of the stratum is about two inches and a half. It is considered at the works to be an ore of a very inferior quality, and is seldom smelted.

Immediately above this ore there is situated a bed of schist, which contains an immense number of petrifactions of different kinds of bivalve shells: they consist of *a very pure ironstone*, resembling in appearance the subjacent land.

(*f*) Their forms are remarkably perfect, and they contain no visible remains of the original shell.

(*f*) An ore lying under the last-mentioned stratum, and in close contact with it. Colour between yellowish-grey and hair-brown. Fracture fine-grained, earthy, even. Rather hard; scratched with some difficulty by the knife. Specific gravity 3·2109. The stratum to which it belongs is situated above the splint coal, with the intervention of only four inches of schist, and both minerals are therefore worked out together with great advantage to the smelter. It is the most valuable ore in all the fields around Glasgow, except that called the *black ironstone*, which is at present smelted at the Clyde iron-works. The thickness of the stratum is between one and a half and two inches.

(*g*) This specimen was procured from Easterhouse, near the line of the Monkland canal, and about six miles east from Glasgow. Colour clove-brown. Fracture fine-grained, rather uneven. Somewhat tough and hard, but easily scratched by the knife. Specific gravity 3·3109.

This ore exists in precisely the same relative situation, with regard to all the other accompanying minerals, as the two ores from the Clyde iron-works, which have just been described; and wherever it makes its appearance, it seems to have been produced by the coalescence of these two strata. This compound stratum has always a uniform texture and composition throughout. Its average thickness is two and a half to three inches. It is used pretty extensively in the blast furnace, and is esteemed an ore of good average quality.

(*h*) From the neighbourhood of Airdrie, about ten miles east from Glasgow. Colour clove-brown, the intensity of the shade varying considerably in streaks which are parallel to the direction of the stratum. When reduced to powder the colour is brown. Fracture fine-grained, earthy, rather uneven. Tough, and difficultly pounded; communicating a feeling of elasticity under the pestle. Rather hard; scratched by the knife. Adheres slightly to the tongue, a property which did not appear to be possessed in a sensible degree by any of the ores already described. Specific gravity 3·0553. Numerous bivalve shells, of a pale wood-brown colour, occur scattered through the mass of this ore, and form a strong contrast with its darker shade. This is one of the most valuable iron ores in Scotland, where it is familiarly known under the name of *black ironstone*, or *Mushet's black band*. The latter appellation has been given from the circumstance that it was first smelted by Mr Mushet, to whom we have already referred as the metallurgist most distinguished for his practical skill.

It lies about fourteen fathoms below the fifth Glasgow coal-bed, or splint coal, and constitutes a layer about fourteen inches in thickness. It is remarkable that it has hitherto been found nowhere except in the neighbourhood of Airdrie; although several attempts have been made in other localities to reach it by boring. At the Clyde iron-works, it is justly regarded as the richest and most valuable ore which they at present possess.

(*i*) From a stratum situated in the vicinity of Crossbasket. Colour blueish-grey. Fracture, in the great, even; in the small, very fine-grained, earthy; rather hard.

Hydrous Oxide of Iron, and *Brown Iron Ore*. The present is a species nearly parallel to the fore-going, in the quantity of iron it affords to society. It is very rarely observed in distinct crystals, more usually occurring in botryoidal and stalactical masses, consisting of closely aggregated fibres, in which respect it resembles the most common varieties of the specular iron. The crystals are very small, externally black and brilliant, and in the shape of right rectangular prisms. The general character of the species is as follows; lustre, adamantine; colour, various shades of brown, of which yellowish-brown, hair-brown, clove-brown, and blackish-brown are the most common; streak, yellowish-brown; brittle; no action on the magnet; scratched by feldspar; specific gravity, 3·922. Besides occurring in crystals, and in globular stalactitic and fruticose shapes, it is found in masses whose composition is impalpable; sometimes also, the particles are so slightly coherent, that the mass appears earthy and dull. It differs, chemically, from the specular iron, in containing a quantity of water, not merely interspersed through its substance by simple absorption, but intimately combined with it by chemical affinity. According to D'Aubuisson, it consists of (in two analyses)

Peroxide of iron,	82·00	84·00
Water,	14·00	11·00
Oxide of manganese,	2·00	2·00
Silica,	1·00	2·00

the proportion of peroxide of iron and water being as 85·30 to 14·70. Before the blowpipe, it becomes black and magnetic. It melts, with borax, into a green or yellow glass, and is soluble in heated nitro-muriatic acid. The division introduced among the varieties of the present species, is somewhat similar to that which has been given to red iron ore. *Crystallized hydrous oxide of iron* embraces the small black crystals, which sometimes occur in fibrous and radiating bundles. *Crystallized brown iron ore* is that variety which presents itself in the form of the cube, rhomboid, or some modification of these forms, and does not properly belong to this species, being decomposed varieties of iron pyrites and spathic iron, to which they are more correctly referred. The *fibrous brown iron ore*, or *brown hematite*, contains the fibrous varieties, in stalactitic, reniform, and other imitative shapes. *Compact brown iron ore* comprehends those imitative shapes and massive varieties, in which the composition or fibrous structure is no longer observable; while *ochrey brown iron ore*, or *bog iron ore*, is applied to those which have an earthy texture, and are friable. As impure varieties of the species, we must consider some of the clay iron ores, such as the *granular*, the *common*, the *pisiform*, and the *reniform* clay iron ore. The granular variety is composed of compact, roundish, or globular masses; the reniform one, of alternating coats, of different colour and consistency, disposed in a reniform surface. In the pisiform variety, we meet with a similar composition, only in small globules, parallel to the surface of which the lamellæ are disposed. The compact pisiform clay iron ore, however, does not belong to the present species, but it is decomposed iron pyrites, as is demonstrated, not only by the crystalline forms which it affects, but likewise from the nucleus of the undecomposed pyrites, which the largest specimens of it often embrace. The crystallized hydrous oxide of iron is found, in limited quantities, in England, France, and Siberia; it either occurs in quartzose geodes, in the form of mamillary masses, or is enclosed in quartz crystals. The fibrous brown iron ore is the most abundant and widely dispersed of all the varieties of this species. The iron which this variety affords is superior in malleability to that yielded by the red ore of iron, and is much esteemed, also, on account of its toughness and hardness. The pig iron obtained from melting its purer varieties with charcoal, in particular, may be easily converted into steel. The compact variety of this species is usually found in the same localities with the fibrous hematite, and is equally employed with that variety for obtaining iron. The ochrey brown iron ore, or bog iron ore, is the most recent in its formation of all the ores of iron, its deposition being continually going on, even now, in shallow lakes and in morasses. It is wrought in all countries, more or less extensively; but the iron it yields is chiefly used for castings. The pisiform clay iron stone occurs imbedded in secondary limestone, in large deposits, in France and Switzerland, where it supplies considerable iron works; but the iron, like that from the other earthy varieties of the present species, is generally too brittle to be wrought into bar-iron.

Carbonate of Iron, or *Spathic Iron Ore*, occurs crystalline and massive. Its crystals are acute rhomboids, sometimes perfect, or only having the terminal angles replaced, six-sided prisms, and lenticular crystals. They are very easily cleavable, yielding obtuse rhomboids of 107 and 73°. Lustre, vitreous, inclining to pearly; colour, various, shades of yellowish-gray, passing into ash and greenish-gray, also into several kinds of yellow, white and red; streak, white; translucent in different degrees; brittle; hardness, nearly identical with that of fluor; specific gravity, 3·829. It occurs massive, in broad, foliated and granular masses; also in fibrous botryoidal shapes, whence it has received the name of *spherosiderite*. Two varieties of this species, 1. the spherosiderite, and 2. a cleavable variety from Newdorf in the Hartz, have yielded to Klaproth,

Protoxide of iron,	63·75	47·50
Carbonic acid,	34·00	36·00
Oxide of manganese,	0·75	3·30
Lime,	0·00	1·25
Magnesia,	0·52	0·00

Before the blowpipe, it becomes black, and acts upon the magnetic needle, but does not melt. It colours glass of borax green. It is soluble with difficulty in nitric acid, particularly if not reduced to powder. On being exposed to the air, it is gradually decomposed: first the colour of the surface becomes brown or black; afterwards, also, the streak is changed into red or brown; hardness and specific gravity are diminished; and even the chemical constitution is altered, the whole being converted into hydrate of iron. It frequently occurs, along with carbonate of lime, in veins, and beds, in primitive rocks; also in metalliferous veins, accompanied by galena, gray copper ore, and iron and copper pyrites.

Treatment of the Ores.—When the iron stone lies in a stratum or vein between two strata of clay, not more than thirty feet below the surface of the earth, it is obtained by sinking a pit, at first, of a diameter of eight feet, and deepened until the ore is reached where the pit is undermined, until the diameter at the bottom becomes twice that at the top. When all the ore is taken out of this pit, another is dug similar to the first, and near it; so that when the second pit is excavated, the bottom of the two will meet. In digging the second pit the earth is thrown into the first, and thus one pit is made and another filled, until the whole vein is exhausted. When the iron stone lies deeper it is extracted in the same way as coal, and as they frequently occur in the same district, one engine serves to drain and draw for both ore and coal.

The first step after the ore has been taken from the vein, is to calcine the stones; a process technically called *roasting*. This consists in the application of a moderate heat, whereby the more volatile components of the ore, such as sulphur, arsenic, &c. are expelled. This is effected by spreading upon the ground a stratum of coals to a depth of about eight inches, ten feet long, and eight broad; over which is laid a layer of iron stone, to a depth of about six feet, interspersed with small cinders and coke dust, and covered with small coals. The coals being set fire to, combustion will go on for nearly a month, when the cementation is completed. It is not uncommon to perform the roasting process in a kiln, the coal and iron stone being put in at the top, and the roasted ore taken out at the bottom. Care is requisite in conducting the process of roasting, for if the heat be too intense, or too long applied, then will the metal partially melt and the pieces cake together, and if on the other hand the heat be too little, all the extraneous matter, such as the water, sulphur, &c., will not be expelled, when the iron stones must be thrown aside, as unfit for the future processes in the manufacture. The iron stone of this country usually contains a sufficiency of carbonaceous matter to carry on the roasting after the fuel has been ignited; but the ores of the continent contain less carbon, and therefore require proportionally more fuel for their cementation. On the continent and in America, iron ore is most commonly roasted with wood and charcoal. When the roasting is performed with charcoal alone, a layer of the ore is laid on the ground, then a layer of charcoal, and so on alternately, the iron stone layers being each about nine inches, and the charcoal about six, until the height of the bed be seven feet. It is better, however, to lay a stratum of wood below the ironstone. When the roasting is completed, the ore becomes friable, rough to the touch, not at all vitreous, but full of fissures. The ore by the power of cementation, sustains a loss of weight of from twenty to fifty per cent.; according to the quality of the ore. The iron stones thus prepared are called by the workmen *mine*.

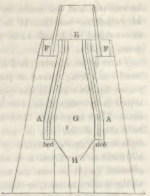
The next operation is the conversion of the roasted ore into metal, by the application of strong heat in a furnace; which process is called *smelting*. As will be readily understood after what we have said on the ores of iron, they commonly consist of an oxide of the metal combined with some earthy matter, in very various proportions. If these ores were fused alone, the chemical student will at once perceive, that they would be formed into glasses, the properties of which will vary with the composition of the ore, but retain no metallic character. The method of proceeding, therefore, must be to intermix the iron stones with such substances as during the process of fusion, will combine with the oxygen and earthy matter of the ore, and leave the metal free. From the great affinity of carbon for oxygen, forming carbonic acid gas, charcoal, or some other carbonaceous substance, is selected as the proper substance for separating the metallic base from the oxygen; and the nature of the other substances to be employed in separating the earthy matter of the ore, will be determined by the species to which that earthy matter belongs. The earths mixed with the iron, may be either calcarious, silicious, or aluminous: these exist in different proportions, in different ores, and it should be the first object of the iron manufacturer, to select such earthy matter as a flux, that when combined with the earthy matter of the iron stone, a glass will be formed, and the metallic base of the ore left free. Sometimes the combination of several kinds of ore, will produce a congeries of earths that of themselves will form an excellent flux —but this, in the ordinary course of manufacture, never occurs, so that some flux, such as lime, is always employed.

The strong affinity of carbon for oxygen, as before remarked, points it out as the best substance for separating the oxygen from the iron. In Russia and Sweden, and even in some parts of England, charcoal is employed, and it undoubtedly is best for making that kind of iron that is to be formed into steel. For many years past, almost the only ore in Britain that has been smelted with charcoal, has been the red ore of Lancashire, which being extremely rich, the product of smelting can be calculated upon with certainty. The abundance of coal in this country, in those districts where iron stone is found, determines our iron makers to employ coke from its cheapness; coal when properly coked, yields a very considerable proportion of carbonaceous matter, and bears a strong resemblance to charcoal. When coke was first introduced instead of charred wood, it was made, by merely piling the coals in a heap, which being ignited, were allowed to burn until sufficiently coked, when they were covered with ashes and sand to prevent any further combustion. In many places in Wales, this plan is still pursued. From thirty to forty tons of coals, are piled in a heap, as loose and open as possible. Small coals being spread on the surface to give a level appearance. It is then ignited in various places, and allowed to burn till the whole surface is in combustion; when it is covered with the ashes of a former fire, and left to go out. The coke is made harder and more pure, when the cooling of the heap is quickened by throwing on cold water. A slight knowledge of chemistry is sufficient to show, that much of the coal must be converted into ashes before combustion can be carried a sufficient length to coke the heap, and the more economical process of coking in a close oven, or furnace, is now becoming more general. The ovens are of a hemispherical form, about ten feet wide at the base, and two feet at the aperture, the wall being of brick, eighteen inches in thickness. There is a door-way in the side, for the purpose of taking out the coke, and the opening at the top is for charging the oven with fresh coal. Small refuse coal is used. The oven being filled up to the springing of the arch, and the heat of the oven from the former coking being adequate to set the coal on fire, the door-way is filled up with loose bricks, and the air, rushing through the crevices, supports the combustion until the whole charge is lighted up, when the door-way is plastered up, excepting the top row of bricks, and in twelve hours after covered entirely. The chimney remains open until the flame be extinguished, when it is closed, and the whole allowed to remain for twelve hours more, after which the coke is withdrawn from the doorway. The coke thus formed is of a grey colour, metallic lustre, and very hard; but when it is required to be of a nature more resembling charcoal, the coking is prepared in a place similar to a baker's oven, the door of which is kept constantly open, and the coals frequently stirred. Coke made in this way is black in colour, porous, and very light—more inflammable than the first description, but not capable of affording such intense heat, nor so durable in the smelting furnace.

The construction of the smelting furnace, will be understood, from the subjoined section.

The interior of the furnace, is a cavity, formed by the frusta of two cones joined at the base, and terminated in cylinders both at top and bottom, as will be seen at G, in the figure. The wall *d d* of this cavity, consists of the best fire brick, well cemented together, the thickness of the wall being generally fourteen inches. At a distance of about six inches behind this wall, a wall or casing of brick is built all round the former, and of a thickness of fourteen inches. The space between these two walls is filled up with river sand, crammed in compactly. Sand being but an indifferent conductor of heat prevents the casing *b b* from being much affected by the fire of the furnace. The whole is enclosed by the outer wall, A A, of ashlar stone, or brick. This wall is built very strong and thick; the interior is of course made circular to envelope the casing *b b*, but the exterior face of the wall, is made to terminate in four faces, tapering to the top, so that the outward appearance of the furnace, is a truncated quadrangular pyramid. The inside of the furnace, G, is made to terminate in a cylindrical chimney, and at the bottom, in a deep quadrangular pit H. Such is the construction of the furnaces erected in this country till of late, the whole building being made for substantiality as thick as possible. But the strong heat of the furnace, frequently so expanded the material, as to burst the mason work, and the modern furnaces are all constructed of comparatively thin walls above AA, nor is there any space left in them for the introduction of sand between the two interior walls of brick work. At the top of the chimney there are formed two or more doors by which the workmen introduce the ore, coke and flux, and above this there is a semicircular wall E erected for the purpose of preventing the flame from blowing upon the workmen while they are feeding the furnace. The materials are drawn up on a mound of earth at the back of the furnace, either by machinery or by animal strength, and being set fire to at the bottom, are allowed to burn, the combustion being afterwards accelerated by a blast from a blowing machine. (See *Blowing Machine*.) The ends of the pipes from the blowing machine enter nearly at the bottom of the furnace, as may be seen by inspection of figure 4. These blast pipes, the nozles of which are technically called tweers, are two in number, and enter the furnace opposite to each other, and a little above that point where the melted metal rests. The ore, coke, and flux, in the body of the furnace, are acted upon by the heat, just as they would be in a close vessel, the oxygen of the ore combining with the carbon of the coke, and forming carbonic acid, or rather carbonic oxide. On the ore parting with its oxygen, the carbon combines with the metal, and the mass being

Fig. 1.



reduced, falls down to a lower part of the furnace, and in this way, makes room for more to come down to the hotter part, and in its turn be smelted, and the liquid metal to fall down to the bottom of the part H, called the hearth. It may be observed, that of late it is not usual to construct the hearth as deep in proportion as it is shown in the foregoing section.

There is an opening in the wall at the bottom of the hearth, at the mouth of which a stone is placed, called the *dam* stone, beyond which an opening is made in the side of the outer wall, in order to run off the liquid metal when it rises so high as to cause the scoria to flow over the dam. The opening in the outer wall is closed by a little of sand mixed with clay, during the process of smelting; but when there has been a sufficient quantity of metal formed, the lute is removed, and the iron allowed to run off into a channel, made in a kind of sand. From this channel, called the *sow*, numerous side branches are led, called *pigs*, and as the melted metal flows along the sow, it is checked frequently by the workmen introducing a piece of wood which causes it to flow into the side channels, and thus the masses of iron called pig iron are formed.

The height of the smelting furnace is sometimes not less than sixty feet, but the usual height of the furnaces in this country, is about forty-five or fifty feet. The proportions of the parts may be guessed at, on inspecting figures 1. and 2. in this article. It may be stated in addition to the description already given, that there are numerous small openings through the sides of the walls, to permit the escape of the vapours and gases formed during the process, and to ensure durability, the whole of the mason work is bound with bars of iron. Dr Ure states, that a furnace of ordinary dimensions, will make about three and a half tons of cast iron, these furnaces being tapped once in twelve hours. For the production of this quantity of metal, there is required seven tons of coke, eight tons of roasted iron stone, and three and three-eighths tons limestone as a flux. According to a later writer on the iron manufacture, one of the large furnaces in Wales receives on an average, fifty charges in twelve hours. Each charge requires six cwt. of roasted ore, in all amounting to fifteen tons produced from eighteen tons of raw mine. The same quantity of coke is required, i. e. fifteen tons produced from about twenty-two and a half cwt. of coals. The limestone required, is six tons, so that the whole weight of the charges for twelve hours, is thirty-six tons, from which only six tons of cast iron are produced. From this, we may estimate the loss of material in roasting, coking, and smelting for two runs which occupies twenty-four hours.

Coals,	57 tons.		
Mine,	36		
Limestone,	12		
Whole weight,	105		
Supplied to the furnace,	72	loss,	33 tons.
Iron produced,	12	loss,	60
		Total loss, 93 tons.	

In England and everywhere else until very recently, it was supposed, that the colder the air was injected into the furnace the better; and the two currents on entering the furnace chilled the materials much, and produced a sort of pipe or channel in the melted metal, which opposed its entrance. These pipes often extended so as nearly to meet in the middle of the furnace. The keeper watched the state of these pipes, and regulated the blast, so that they should neither be too long nor too short. These pipes, tended to prevent the blast pipe, as well as the cast iron lining of the wall, through which they were led, from melting.

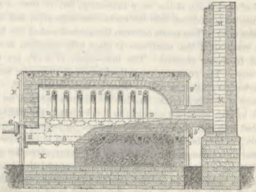
Mr J. B. Neilson, civil Engineer and manager of the Gas Works of Glasgow, had, in the course of the year 1824, directed his attention to blast furnaces, in consequence of some inquiries having been made, if he could devise any means of purifying the air propelled by the blowing engine before it reached the furnace; in any way similar to that in which coal gas is purified. The inquirer suspected that it was the presence of the sulphurous vapour, that injured the air of the blast, seeing that furnaces commonly wrought worst in the summer months. But experience led Mr Neilson to attribute the evil to another cause. From some simple experiments, he concluded, that by heating the air before it went into the furnace, he could effectually remove the evil under consideration. It is known that air will not support combustion until heated to a temperature of 1000° Fahrenheit, and therefore until it acquires that temperature, by coming into contact with the heated mass of the fire, it must act prejudicially: from which it is manifest, that the nearer it can be brought to that point before entering the fire, the better; yet all things considered, there may be a certain temperature at which the effect of the blast will be a maximum. The temperature originally employed by the patentee was, we believe, about 300°, and this was the heat of the blast at Clyde iron works in 1830, when coke was employed. The advantage obtained by the employment of the hot blast at this temperature will at once appear from the fact, that during the first six months of the year 1829, when all the furnaces at Clyde iron works, were wrought with the cold blast, 8 tons 1¼ cwt. of coal, converted into coke, were required for the smelting of one ton of cast iron, but during the first six months of 1830, when the blast was heated to about 300°, the same quantity of iron required only 5 tons 3¼ cwt. of coals converted into coke, which after deducting 8 cwt. of coal employed in heating the air gives a saving of 2 tons 10 cwt. The success of the hot blast, at a temperature of 300° induced the iron manufacturers, to try it at a still higher temperature, and the results proved proportionally beneficial. In the course of the year 1831, the temperature of the blast was doubled, so that it was not less than 600°, and the success was such, that they were induced to employ coal instead of coke in the smelting furnace, which induced a saving to a very considerable amount. In 1829, 8 tons 1¼ cwt. of coal were required for coke to smelt one ton of iron, whereas in 1833, only 2 tons 13¼ cwt. of coals, not converted into coke, were required for the same purpose. The increase of combustion with the blast at 600°, precludes the necessity of coking before smelting, for the intense heat of the blast is sufficient to compensate for the great quantity of latent heat that must arise with the vapours expelled from the coals during combustion.

The patentee does not confine himself to any particular mode of heating the pipes, nor the temperature of the air. In some cases the pipes have been heated by the smelting furnace itself, and in others, by a separate furnace, which latter mode would appear to be the most economical.

We will here lay before the reader, a description of furnaces heated in both ways, which with some modifications, we have drawn up, from a very valuable French work entitled Portefeuille Industrial, now (Jan. 1836), in the course of publication at Paris.

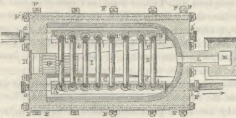
The annexed cut represents the first form of the air-heating apparatus, invented by Mr Neilson, where a separate fire is used.

Fig. 2.



The heating apparatus is contained within a kiln or furnace, F F', constructed of brick. Within this kiln two straight tubes, A B, A′ B′, are laid horizontal and parallel to each other. In the upper surface of each of these large pipes, circular openings, C C′ are made for the reception of the ends of small bent tubes. These tubes which are seen at S S′ are bent so as to form arcs of circles, the length of each arc being more than the semi-circumference. They stretch across the kiln, one extremity terminating in each of the long pipes, A B, A′ B′. There are

Fig. 3.



four small tubes, *a b*, *a′ b′*, fixed into the extremities of these long pipes, A B, A′ B′, as may be seen more particularly in the ground plan, fig. 3. It is necessary to attend to the manner in which these pipes are fitted into each other, as the joinings must be made perfectly air-tight and strong. This is effected in the following manner:—The extremities of the great pipes, A B, A′ B′, are formed into frustums of cones, the smaller parts of which are at the extremities, curbs being placed within at the bases. The little pipes are made to terminate in conical swellings, the base of each being at the very extremity, but of such a magnitude that it may be introduced into the end of the large pipe, and be pressed against the curb. The space between the conical end of the large pipe, and the swelling of the small one is filled with mastich, in which way the joint is firmly secured. The bent-pipes, D S D′, are fixed in a similar way. The construction of the furnace is altogether analogous to the reverberatory kind, as will be seen by inspecting fig. 2. The walls are formed of common brick, but fire bricks are employed for the vault. In order to give sufficient strength to the building, the walls are bound by ten cast iron pillars, F F, bound together by beams, enclosed in the brickwork, as may be seen at fig. 2, and each end is likewise furnished with four similar supports. The fuel is thrown upon the grating G, through the door H, the air which supports the combustion entering from K, the ashpit below. The smoke from the fire proceeds up by the inclined back I, and rising strikes the bent pipes, which stretch across the vault. It will easily be seen that in this way the last of the bent pipes receive more heat from the smoke than the first, but this is compensated for by the form and position of the vault and the bottom, which cause much more of the heat to be radiated to the first tubes, both from the fire, and from the vault. The flame and smoke having acted on the bent pipes, pass through the opening L, and from thence into the chimney. In order to save the joinings of the bended tubes, D S D′, with the large tubes, A B, A′ B′, a wall of brick proceeds aloug the whole length of the furnace, on each side of the fire, and between that and each large pipe, built in such a way as to protect the joinings. The manner of operating is simply this:—The air from the blowing engine is propelled with the requisite force into the pipe A′ B′, through the extremity, and passing through all the eight bent pipes D S D′, passes through the large pipe A B, through its extremity *b*, and by means of the connecting pipe into the furnace, where the smelting is effected. The pipes D S D′, being kept at a red heat, it must follow that the air must enter the smelting furnace, at a temperature very much higher than when it was propelled from the blowing engine.

The inventor has given the dimensions of an apparatus, such as we have described, calculated to supply a furnace with 800 cubic feet of air per minute. The dimensions of the horizontal pipes A B, A′ B′—

	Feet.
Length	12·008
Exterior diameter	1·1808
Interior do.	0·99

Dimensions of the four pipes *a b*, *a′ b′*—

Length	3·94
Exterior diameter	0·79
Interior do.	0·656

Dimensions of the eight bent pipes D S D′—

Exterior diameter	0·558
Interior do.	0·386
Length of the axis	9·91

Weight of the various pipes—

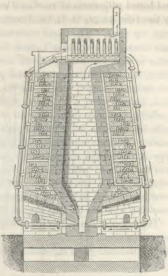
	Lbs.
The two pipes A B, A′ B′,	3329·55
The eight bent pipes,	2848·86

The eighteen supports—

Grate, bolts, and door,	5358·15

We will now describe the structure of the apparatus for heating the blast by means of the smelting furnace itself. The furnace is represented in section, in the accompanying wood engraving. This acts on the same principle as that just described, the chief difference being in the manner in which the heat is obtained. The reverberatory furnace,

Fig. 4.



with its system of horizontal and bended pipes, is placed on the top of the chimney of the smelting furnace, and the heated air and smoke from the large furnace enters the small furnace just where the grating was placed in the former construction. It may be remarked that the three first bended pipes are directly above the flues of the smelting furnace and therefore receive the first action of the flame and smoke, which are reflected again by the vault, before entering the chimney, which is here made to rise directly from the end of the vault, instead of communicating by a horizontal pipe, as in the former construction. The distance of the large horizontal pipes is somewhat greater than the diameter of the flue, i. e. the chimney of the smelting furnace, in consequence of which the furnace is fed through the opening N. The communication between the heating apparatus and the blowing engine is similar to that formerly described, but the heated air passes out of the system of pipes at the top of the smelting furnaces, and is propelled into the tweers, which are seen entering at the bottom, through two pipes, which are led down the exterior wall of the furnace, as may be seen on inspection of the figure. The furnace we have just described, is better calculated for smelting by charcoal than by coke, as the heat raised by the former is much greater than by the latter.

In order to complete the description of the apparatus with hot air invented by Mr Neilson, it remains for us to describe the system of heating, which is employed in Wilkinson's foundery, in the cupolas intended to melt the metal. This application of Mr Neilson's invention is due to Mr Taylor. Various other applications of the hot air blast have been recently made by Schauffelen, of Wurtemburg, who causes the air to pass through a sort of syphon in the chimney, before it reaches the grate.

This system of heating is represented in fig. 5 and 6. A A is the frame-work itself, which is constructed of common bricks, the interior being lined with fire bricks, in order to form the melting pot A′, and the exterior of it is covered with sheet iron plates, A″, rivetted altogether, and bound with iron circles a″. The blast enters the cupola alternately by the different pipes a′; the lowest of them is used to commence the

Fig. 5.

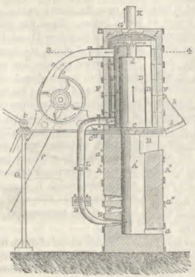
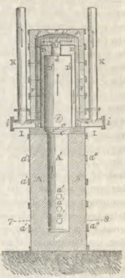


Fig. 6.



process, and as the height of the melting metal rises in the pot, they change them in order, so as always to blow at a suitable height to the bath of metal: the openings of the pipes which are not in use, are luted with care, especially when they have to support the pressure of the liquid contained in the melting pot. The tap hole is at *a*, it is always hermetically shut with a stopper, which may be lifted out in a moment from the tap hole.

The only modification that they have attempted to make, to improve the frame-work is in leading to the top, a slope by which the charges of coal and of pigs are thrown in; the opening is usually shut by the door *b*, which is lifted and attached by the little chain *b*′, during the very short time which is necessary to throw in the charge.

There are three cast iron plates, placed one above another *c*′, *c*, *c*″ of the same diameter as the frame-work, and pierced in the centre with circular holes a little greater than the diameter of the melting pot A′. The first *c*″ has a little jutting out *c*‴ (fig. 6), serving as a point of support to the fanner by which the furnace is supplied with the blast.

The fanner is put in motion by means of a belt led over a drum on its axis, and connected with the steam engine, or water wheel. The second plate *c*, has a hole at the centre, a little greater than that of the first, that it may be protected against the action of the heat. The third has a central hole, still a little greater for the same reason, but its exterior diameter is much less, so that it may leave upon the second plate *c*′ an open circular ring of from twelve to fifteen inches. Upon this third plate *c*, there are fixed two concentric cylinders of plate iron D and D′, which are open below, but shut above, and the tops of which are firmly joined by a sort of open joint *d*, *d*′. The exterior cylinder has two openings *e* and *e*′; one, that by which the cold air is introduced, the other, that by which the air goes out after being heated between the two coverings D and D′; at the distance of twelve or fifteen inches from the exterior envelop D, a third envelop F, of brickwork, is built, which is bound together with circles of iron, as the frame-work itself. The bottom of this last, rests upon the circular space, that the plate *c* left open upon the plate iron *c*′, and at its top it is shut, by a convex iron plate *f f*, upon which is erected a vault of some non-conducting substance. The iron plate is pierced in the middle with a hole, which is shut by means of a lid *f*′, above which is put a stone stopple G; this order of things serves to inspect and to clean the interior of the apparatus, as it is only necessary to lift the stopple G and the lid *f*′.

Above this opening at the top, which remains always shut during the operation of melting, the envelop F is carried down the side to its lower part; there are two openings H H, into which are fixed the strong iron pipes I I, which serve as a base and support to the two chimneys K K; the pipes I I, are shut at their extremities by stopples *i i*, which require only to be lifted out when they wish to sweep the chimney.

The smoke rises and spreads itself in the interior of the first envelop D′, and after heating the sides, goes out from this space by the little conduit *d d*′, then passes under the vault *f f*, in order to descend between the exterior envelop F and the cylinder D, so that it may arrive at the two openings of the tubes I I, and at the chimneys K K.

The cold air enters by the opening *e*′, between the envelops D and D′, and it comes immediately into contact with the hot tops of these cylindrical envelops: it comes also into contact with the sides of the conduits *d d*′, which are also at a very high temperature; thus heated against these surfaces, it descends in the spaces comprised between the envelops D and D′, the one struck by the flame descending, the other by the flame ascending, and it arrives at the lower opening *e*, by which it escapes to the blast pipes. A the blast pipe ought successively to be raised, so as to be put into the different openings *a a a*; as the liquid metal accumulates in the melting pot, we must have the means of making these changes with facility. For that purpose there is placed in the opening *e*, a fixed pipe L′ L, which, after being bent, descends vertically to L: in its straight portion, which is bored very truly, there is fitted a smaller pipe M M′, capable of sliding in its interior like a piston in the body of a pump. The lower extremity M, of the pipe M M′, has a curb *m*, upon which is fixed the opening N of the bent N N′ of which the other extremity N′ is adjusted in the opening; the two curbs *m* and *n* are joined and held fast by the two cramps P P. In order to shift the pipe, they loosen the screws of the cramps P P, and lift them off, then force up the pipe M M′ into the pipe L′ L, and remove the pipe N N′ into an opening higher. The pipes are then fixed to the cramps and curbs *m* and *n* in this new position.

We have thus endeavoured to describe the construction of several forms of the hot blast furnace, and shall conclude this part of our subject, by a short extract from a very valuable paper, on the hot blast, by Dr Clark, of Aberdeen, which was read before the Philosophical Society of Edinburgh in March of the year 1835.

"As nearly as may be, a furnace, as wrought at Clyde Iron works in 1833, had two tons of solid materials an hour put in at the top, and this supply of two tons an hour was continued for twenty hours a day, one half hour every morning, and another every evening, being consumed in letting off the iron made. But the gaseous material—the hot air—what might be the weight of it? This can easily be ascertained thus: I find, by comparing the quantities of air consumed at Clyde Iron works, and at Calder Iron works, that one furnace requires of hot air from 2500 to 3000 cubical feet in a minute. I shall here assume 2867 cubical feet to be the quantity; a number that I adopt for the sake of simplicity, inasmuch as, calculated at an avoirdupois ounce and a quarter, which is the weight of a cubical foot of air at 50° Fahrenheit, these feet correspond precisely with two cwt. of air in a minute, or *six tons an hour*. Two tons of solid material an hour, put in at the top of the furnace, can scarce hurtfully affect the temperature of the furnace, at least in the hottest part of it, which must be far down, and where the iron, besides being reduced to the state of metal, is melted, and the slag too produced. When the fuel put in at the top is coal, I have no doubt that, before it comes to this far-down part of the furnace—the place of its useful activity—the coal has been entirely coked; so that, in regard to the fuel, the new process differs from the old much more in appearance than in essence and reality. But if two tons of solid material an hour, put in at the top, are not likely to affect the temperature of the hottest part of the furnace, can we say the same of six tons of air an hour, forced in at the bottom near the hottest part? The air supplied is intended, no doubt, and answers to support the combustion; but this beneficial effect is, in the case of the cold blast, incidentally counteracted by the cooling power of six tons of air an hour, or two cwt. a minute, which, when forced in at the ordinary temperature of the air, cannot be conceived otherwise than as a prodigious refrigeratory passing through the hottest part of the furnace, and repressing its temperature. The expedient of previously heating the blast obviously removes this refrigeratory, leaving the air to act in promoting combustion, without robbing the combustion of any portion of the heat it produces."*

Dr Clark concludes his paper by the following statements regarding the Clyde Iron-works:—

The Blowing-engine has a steam cylinder of forty inches diameter, and a blowing cylinder of eight feet deep and eighty inches diameter, and goes eighteen strokes a minute. The whole power of the engine was exerted in blowing the three furnaces, as well as in blowing four, and in other cases there were two tweers of three inches diameter to each furnace. The pressure of the blast was two and a half lbs. to the square inch. The fourth furnace was put into operation after the water tweers were introduced, and the open spaces round the blowpipes were closed up by luting. The engine then went less than eighteen strokes a minute in consequence of the too great resistance of the materials contained in the three furnaces to the blast in its passage upwards.

Materials constituting a Charge.

		cwt.	qrs.	lbs.
1829,	Coke,	5	0	0
	Roasted Ironstone,	3	1	14
	Limestone,	0	3	16
1830,	Coke,	5	0	0
	Roasted Ironstone,	5	0	9
	Limestone,	1	1	16
1833,	Coal,	6	0	0
	Roasted Ironstone,	5	0	0
	Limestone,	1	0	0

* The introduction of the hot blast has caused a great increase in the manufacture of iron, in Scotland. In June, 1836, there were

Erected in		Furnaces.	Tons.
1767	Carron Company,	5	8,000
1786	Clyde	4	12,000
1786	Wilsontown	1	3,000
1790	Muirkirk	3	6,000
1790	Cleland	1	2,580
1790	Devon	3	7,000
1805	Calder	5	15,000
1805	Shotts	1	3,000
1825	Monkland	3	8,000
1828	Gartsherrie	5	15,000
1834	Dundyvan	4	12,000
	Total	35	92,000

There are eight additional ones in progress; i. e. 2 at Gartsherrie, 1 at Calder, 1 at Monkland, 2 at Govan, and 2 at Sommerlie.

Table showing the Weight of Cast-Iron produced, and the Average Weight of Coals made use of, in producing a Ton of Cast-Iron, at Clyde Iron-Works, during the Years 1829, 1830, *and* 1833, *the Blowing Engine being the same.*

COKE AND COLD AIR.			COKE AND HEATED AIR.			COKE AND HEATED AIR		
1829.	Weekly product of cast-iron by three furnaces.	Average of coals used to 1 ton of cast iron.	1830.	Weekly product of cast-iron by three furnaces.	Average of coals used to 1 ton of cast-iron.	1833.	Weekly product of cast-iron by three furnaces.	Average of coals used to 1 ton of cast-iron.
	Ton. cw. qr.	Ton. cw. qr.		Ton. cw. qr.	Ton. cw. qr.		Ton. cw. qr.	Ton. cw. qr
Jan. 7.	137 18 2	8 12 1	Jan. 6.	176 10 2	5 2 2	Jan. 9.	357 8 0	2 12 3
14.	148 2 0	6 9 2	13.	181 12 3	5 0 2	16.	267 18 0	2 4 0
21.	148 8 2	6 11 3	20.	172 5 2	5 0 2	23.	270 7 2	2 3 1
28.	138 9 2	7 0 2	27.	178 7 0	4 19 0	50.	250 9 0	2 4 0
Feb. 4.	125 13 0	7 12 1	Feb. 3.	164 8 0	5 4 0	Feb. 6.	265 3 2	2 1 0
11.	136 19 0	7 13 1	10.	172 12 0	5 4 0	13.	202 10 0	2 4 3
18.	130 16 2	7 11 3	17.	163 9 0	5 9 0	20.	257 1 0	2 4 3
25.	105 12 2	7 10 0	24.	170 1 0	5 3 0	27.	264 0 0	2 5 1
Mar. 4.	101 8 1	7 17 2	Mar. 3.	154 19 0	5 10 3	Mar. 6.	234 13 0	2 5 2
11.	111 2 0	8 2 2	10.	154 16 0	5 9 2	13.	238 7 2	2 7 1
18.	114 10 0	7 6 2	17.	151 8 2	5 9 3	20.	205 13 0	2 10 2
25.	110 14 0	8 8 1	24.	163 17 0	5 5 1	27.	217 14 0	2 2 3
Ap. 1.	111 4 0	8 7 2	31.	163 8 2	5 11 0	Ap. 3.	220 7 0	2 14 2
8.	107 7 0	8 3 0	Ap. 7.	147 10 0	5 7 0	10.	280 9 2	2 0 3
15.	91 12 2	8 15 0	14.	154 9 2	5 2 0	17.	304 7 0	1 17 3
22.	85 13 0	9 13 0	21.	163 4 0	4 19 0	24.	248 12 2	2 3 0
29.	91 14 2	9 6 2	28.	148 12 2	5 4 0	May 1.	245 7 2	2 6 0
May 6.	92 7 2	8 8 2	May 5.	162 10 2	5 2 2	8.	200 17 0	2 8 0
13.	94 6 0	9 2 1	12.	149 13 0	5 3 2	15.	246 4 2	2 5 3
July 8.	88 4 2	8 16 3	19.	162 4 0	5 5 0	22.	219 1 2	2 6 0
15.	91 13 0	8 5 0	26.	165 7 2	4 18 3	29.	231 2 0	2 8 0
22.	97 2 0	8 2 1	June 2.	160 4 0	5 2 2	June 5.	235 16 0	2 6 2
29.	104 15 2	7 10 2	9.	157 17 0	5 1 0	12.	232 10 6	2 7 1
Aug. 5.	106 17 2	7 7 2	16.	164 0 0	4 17 3	19.	271 1 2	2 1 0
12.	93 1 0	8 6 0	23.	149 3 0	4 18 0	26.	262 3 3	2 3 1
19.	113 7 0	8 18 2	30.	162 16 2	4 16 3	½ w. 30.	122 16 0	2 5 1
	2878 18 0	209 19 0		4215 6 0	134 6 2		6370 3 0	58 18 3
Average	110 14 2	8 1 1		162 2 2	5 3 1		245 0 0	2 5 1

An impression has gone abroad among founders and machine makers, that the iron produced in the hot blast furnace, is inferior in quality to that produced in the cold blast furnace; but correct experiments have, we believe, not yet been performed on the subject. It ought not to be forgotten, that the iron produced by the same furnace, is different at different times, and there is very frequently a difference of quality in the iron of one smelting.

The quality of metal issuing from the smelting furnace, will vary with the quantity of carbon it contains. The quantity of carbon will depend, in a great measure, upon the quantity of charcoal, coke, or coal that has been employed in smelting the ore; and the appearance of the metal, as it flows from the tap hole, will indicate the state of the metal. On the surface of the liquid metal, there floats a substance, called by the workmen *kish*, which has the shining appearance of plumbago, and the presence of this substance, indicates that the metal is saturated with carbon; and if great in quantity, the iron maker immediately takes the hint to diminish, proportionally, the quantity of the ore. The appearance of the cinder, is likewise a good guide, for when it assumes a greenish-yellow colour, it is a proof, that from the want of carbonaceous matter, some of the oxide of iron has not been decomposed. When the oxide of iron is in great excess, the cinder appears of a blackish-green colour. The nature of the iron produced will vary, as before observed, with the manner in which it has been smelted. Some conduct the process in such a way, as to produce iron for the foundery, and others, so as to produce iron for the forge, this latter containing less carbon than the former. The carbon is more abundant in the iron, in proportion as it is soft and tough; and there is this remarkable circumstance in pig and bar iron, or iron for the foundery, and iron for the forge; that the nearer they approach each other in appearance and mechanical properties, the greater is the difference of their chemical composition, at least, so far as carbon is concerned.

The first step in the process of converting cast or pig iron, into bars of malleable iron, is *refining*. The pigs from the smelting furnace, are placed along with coke, in a smaller furnace supplied with the blasts from the blowing-engine. The coke and pigs are placed in a trough, whose sides are formed of cast-iron plates, but the bottom is of masonry; this trough is surrounded by a sort of canal, in which cold water is kept constantly running. There is a tap hole at one side of the trough, which opens into a rectangular mould at the side of the furnace, which mould is commonly about twenty feet long, and two broad, into which the metal is allowed to run after it has been refined. This mould is likewise surrounded with cold water, as also the blast pipes. The material is set on fire, and the blast kept up until the pig-iron is brought to a state of fusion. The metal is kept in a state of fusion for at least two hours, after which it is run off into the mould, deprived of a great quantity of its carbon, or as the name of the process implies *refined*. The furnace is constructed of such dimension as to yield about a ton of refined metal at each tapping; and it may be stated that the loss of weight by the process, is usually about ten per cent. The sheet of metal which fills the mould to the depth of about two inches, is next withdrawn, and broken into pieces by means of large hammers, for the purpose of undergoing another process called *puddling*.

The puddling furnace is of the reverberatory kind, and formed of bricks.—(See ***Furnace***.) The furnace being heated, the metal begins to melt and flow down to the hearth, the temperature is then lowered, and the workman introduces his long iron rod, and stirs the melted mass, during which it swells and emits carbon, combined with oxygen, which burns with a bluish flame. The metals become thicker as the process advances until it assumes a sandy appearance, at which period the temperature of the furnace is raised, and the particles cohere, when the charge is said to work heavy. The workman now forms it while hot into five or six balls, each of from 70 to 80 pounds weight. The balls are removed and subjected to several blows of a heavy hammer, and formed into what are called *blooms*. The blooms are passed through successive pairs of rollers until they acquire the proper shape of long bars. The loss of weight by this process is generally about 10 per cent.

Five or six of these bars, cut to one length, are now piled together, and placed in a furnace similar to the puddling furnace, and brought to a welding heat, and then taken out and passed through successive pairs of rollers, until the bar is brought to the proper dimensions when the process is finished. The loss of weight is by this last process about 10 per cent.

It may be useful to bring under the reader's eye the actual weight of material employed in the mauufacturo of one ton of iron.

Raw mine ......3 tons = 2·4 tons of roasted ore.
Coal for furnace 3¾ tous = 2·5 of coke.
Do. for kiln, &c. } 1 ton.
Engines ...... }
Flux 1

8¾ tons of material for 1 ton pig iron.

Coals for kiln, steam engine, and blast furnsce .... } 6·53 tons.
Raw mine ....4·12
Limestone ....1·37
— 12·02
Add to this { Coals used in refinery .. 61
{ Do. in the puddling, &c. 1·90
— 2·51

Total, 14·53 tons used in the production of one ton of finished bar.

The pig iron produced in the operation of smelting is of very various qualities, according to the purpose for which it is wanted, and the circumstances under which it is manufactured. It may be divided, first, into foundery iron and forge iron; the former being used in the state of pigs, for casting; the latter being only applicable to the manufacture of bar iron. The reason of this is, that, from its nature, it is too thick when melted to adapt itself to the shape of the mould, and, when cold, is too weak and brittle to be serviceable as cast iron, even if the other objection did not exist.

There are three qualities of foundery iron: first, second, and third.

No. 1. foundery iron differs in its Chemical composition from the other sorts, by containing more carbon. It is, indeed, combined with as much carbou as it is capable of holding; and to effect this combination in its full extent, the coke containing the fibrous appearance of charcoal, or the purest carbon, is selected. The tendency of this combination is to render the iron soft, and to make it very fluid when melted, so that it will run into the finest and most delicate mouldings. It is used for small and ornamental castings, and any thing that requires a minute and perfect adaptation to the shape of the mould. It is distinguished in its appearance by great smoothness on the face or surface of the pig; and in the fracture it exhibits a large, dark, bright, open grain, intermixed with dead spots of a lighter colour and closer texture. When broken, the pig does not ring, but sounds rather like lead, falling dull and dead upon the block over which it is broken. It is also so soft as to yield readily to the chisel. In running from the furnace, the surface of the melted metal is smooth and dull, breaking occasionally into streaks and cracks of a darker and brighter red. When it is highly carbonized, the pigs and the cinder are frequently covered with small bright black laminæ of a substance called kish. It is a pure carburet of iron, or black lead, and evinces an excess of carbon in the pig.

No. 2. foundery iron is less carbonized than No. 1; not so soft, closer grained, and more regular in the fracture, not so fluid when melted, nor so smooth on the face of the pig; it is, however, harder and stronger, and is preferred for all the less delicate parts of machinery, where strength and durability are required.

These two sorts are all that are recognized in some places as foundery iron. Their being combined with so large a dose of carbon and oxygen renders them unfit for manufacture into bars; but iron of the next quality, or No. 3, having less foreign admixture in its composition, is destined indifferently for the forge or the foundery. It is used extensively for castings where great strength is required, or in situations where it is to be exposed to constant wear and tear; such as tram plates, heavy shafts, and wheels, cylinders for steam engines, and many descriptions of heavy work. It is selected for these purposes from being still harder than No. 2, and possessing so great a degree of toughness as well as hardness as to make very strong and durable castings. In appearance it differs from No. 2, in the same way as that does from No. 1, being more closely grained and more regular, and darker when broken. From its appearance, it is often called dark grey iron; by which term it is, indeed, as well known as by that of No. 3.

The next quality, *bright* iron, is never called foundery iron, although used extensively for large castings. It possesses great strength and hardness, but not fluidity enough to adapt itself to intricate or minute mouldings. It derives its name from its appearance, which is of a lighter colour and brighter lustre than that which has hitherto been described.

Mottled iron is used exclusively for the purposes of the forge, as it is too thick and brittle for the foundery. It is smooth in the fracture, hardly exhibiting any grain, and appears to be compounded of two qualities imperfectly combined, being spotted or mottled with grey and white.

White iron is supposed to contain a very small portion of carbon, less than any other sort of pig iron. It is totally unfit for casting, and is sometimes so thick as hardly to run into the pig moulds, although they are purposely made very large; and so brittle, that the largest and most unwieldy pigs may be readily broken by a blow with a sledge hammer. It is too hard to yield in any degree to the chisel. The colour of the fracture is a silvery white, shining and smooth in its texture, with a foliated or crystallized structure.

Thus we have six distinct gradations of pig iron, produced under different circumstances in the blast furnace: No. 1 and No. 2 foundery, No. 3 foundery iron, No. 4 is also occasionally used as foundery, but No. 5 and No. 6 are exclusively employed for forming malleable iron.

Table of the weight, in lbs. of a foot in length of Cast Iron.

Side of the square or diameter.	Square.	Hexagon.	Octagon.	Circle.	Side of the square or diameter.	Square.	Hexagon	Octagon.	Circle.
inches					inches				
½	·781	·675	·650	·612	6½	132·031	114·271	109·948	103·696
¾	1·756	1·528	1·471	1·387	6¾	142·381	123·231	118·534	111·825
1	3·125	2·703	2·603	2·454	7	153·125	132·528	127·478	120·372
1¼	4·881	4·225	4·065	3·854	7¼	161·256	142·162	136·743	128·986
1½	7·031	6·085	5·856	5·521	7½	175·781	152·037	146·337	138·056
1¾	9·568	8·281	7·971	7·515	7¾	187·693	162·449	156·259	147·415
2	12·520	10·815	10·412	9·815	8	200·000	173·099	166·503	157·078
2¼	15·818	13·990	13·168	12·425	8¼	212·693	184·087	177·071	167·049
2½	19·531	16·900	16·256	15·337	8½	225·781	195·412	187·365	177·328
2¾	23·631	20·450	19·671	18·559	8¾	239·256	207·078	199·127	187·912
3	28·125	24·340	23·412	22·087	9	253·125	219·078	210·721	199·203
3¼	33·009	28·565	27·475	25·921	9¼	266·781	231·418	222·600	210·800
3½	38·281	33·131	31·818	30·065	9½	282·031	244·100	234·793	221·506
3¾	43·943	38·031	36·581	31·512	9¾	296·968	257·105	247·315	233·318
4	50·000	43·271	41·621	39·268	10	312·500	270·471	260·163	245·437
4¼	56·443	48·353	46·990	44·331	10¼	328·318	284·159	273·341	257·659
4½	63·281	54·768	52·681	49·700	10½	344·531	298·193	286·828	270·593
4¾	70·506	61·021	58·696	55·375	10¾	351·131	312·559	300·646	283·633
5	78·125	67·515	65·040	61·359	11	378·125	327·268	314·796	296·978
5¼	86·131	74·546	71·701	67·709	11¼	393·216	342·315	329·268	310·631
5½	94·531	81·815	78·696	74·243	11½	410·281	357·693	344·062	324·587
5¾	103·318	89·421	86·015	81·126	11¾	429·023	373·325	359·187	338·856
6	112·500	97·368	93·656	88·354	12	450·000	389·475	374·631	353·428
6¼	122·058	105·640	101·621	95·871					

Table of the weight, in lbs. of a foot in length of Wrought Iron.

Side of the square or diameter.	Square.	Hexagon	Octagon.	Circle.	Side of the square or diameter.	Square.	Hexagon.	Octagon.	Circle.
inches					inches				
½	·825	·712	·686	·646	6½	139·425	120·691	116·074	109·503
¾	1·854	1·448	1·554	1·465	6¾	150·354	130·132	125·172	118·087
1	3·300	2·854	2·748	2·590	7	161·700	139·949	134·616	126·997
1¼	5·154	4·461	4·293	4·049	7¼	173·454	150·323	144·401	136·230
1½	7·425	6·425	6·184	5·831	7½	185·625	160·657	154·532	145·787
1¾	10·104	8·745	8·416	7·936	7¾	198·204	171·547	165·009	155·667
2	13·200	11·421	10·995	10·365	8	211·200	182·793	175·827	165·874
2¼	16·704	14·457	13·896	13·120	8¼	224·604	194·396	186·987	176·404
2½	20·625	17·846	17·166	16·196	8½	238·425	206·355	198·571	187·258
2¾	24·954	21·595	20·773	19·598	8¾	252·654	218·674	200·342	198·435
3	29·700	25·703	24·723	23·324	9	267·300	231·346	222·532	209·936
3¼	34·854	30·165	29·013	27·373	9¼	282·354	244·378	235·065	221·760
3½	40·425	34·986	33·653	31·749	9½	297.825	257·769	247·942	233·910
3¾	46·404	40·161	38·529	36·445	9¾	313·704	271·514	261·165	246·384
4	52·800	45·695	43·952	41·467	10	330·000	285·618	274·731	259·182
4¼	59·604	51·588	49·622	46·813	10¼	346·704	300·072	288·637	272·299
4½	66·825	57·835	55·631	52·483	10½	363·825	314·892	304·890	285·747
4¾	74·454	64·439	61·983	58·476	10¾	381·354	330·062	311·483	299·514
5	82·500	71·402	68·682	64·795	11	399·300	345·595	332·425	313·608
5¼	90·954	78·721	75·718	71·435	11¼	417·654	361·485	347·707	328·026
5½	99·825	86·397	83·103	78·101	11½	436·425	378·724	393·330	342·764
5¾	109·104	94·429	90·832	85·491	11¾	455·604	394·221	369·402	357·832
6	118·800	102·821	98·891	93·304	12	475·200	411·285	395·610	373·220
6¼	128·904	111·566	107·312	101·240					

According to the statements of that justly eminent engineer, Mr Tredgold, the specific gravity of cast iron is 7·207; weight of a cubic foot 450 lbs.; a bar one foot long and one inch square weighs 3·2 lbs. nearly; it expands $\frac{1}{162,000}$ of its length by one degree of heat; greatest change of length in the shade in this climate $\frac{1}{1723}$; greatest change of length exposed to the sun's rays $\frac{1}{1270}$; melts at 3479°; and shrinks in cooling from $\frac{1}{98}$ to $\frac{1}{85}$ of its length: is crushed by a force of 93,000 lbs. upon a square inch: will bear without permanent alteration, 15,300 lbs. upou a square inch, and an extensiou of $\frac{1}{1204}$ of its length; weight of modulus of elasticity for a base of an inch square 18,400,000 lbs.; height of modulus of elasticity 5,750,000 feet; modulus of resilience 12·7; specific resilience 1·76.

Malleable iron. Specific gravity 7·6; weight of a cubic foot 475 lbs.; weight of a bar one foot long and one inch square 3·3 lbs.; ditto when hammered 3·4 lbs.; expands in length, by 1° of heat $\frac{1}{143,000}$; good English iron will bear on a square inch without permanent alteration

17,800 lbs. and an extension in length of $\frac{1}{1400}$; cohesive force diminished $\frac{1}{3000}$ by an elevation 1° of temperature; weight of modulus of elasticity for a base of an inch square 24,920,000 lbs.; height of modulus of elasticity 7,550,000 feet; modulus of resilience 12·7; specific resilience 1·7. Compared with cast iron as unity, its strength is 1·12 times; its extensibility 0·86 times; and its stiffness 1·3 times.

The following hints for distinguishing cast-iron by the fracture will be useful to the practical man.

When cast-iron is fractured it exhibits a grey colour, sometimes approaching to dull white, and in other cases the colour is dark grey with spots nearly black. The lustre is sometimes metallic, resembling freshly cut particles of lead lying on the surface, and in other cases there seem to be crystals in the iron disposed in rays.

When the colour is an uniform dark grey, the iron is tough, provided there be also high metallic lustre; but if there be no metallic lustre, the iron, though soft, will be more easily crumbled than in the former case. The weakest sort of soft cast-iron is where the fracture is of a dark colour, mottled, and without lustre.

The iron may be accounted hard, tenacious and stiff, when the colour of the fracture is lightish grey with a high metallic lustre.

When the colour is light grey without metallic lustre the iron is hard and brittle.

When the colour is dull white the iron is still more hard and brittle than in the last case.

When the fracture is greyish white, interspersed with small radiating crystals, the iron is of the extreme degree of hardness and brittleness.

When cast-iron is dissolved in muriate of lime or muriate of magnesia the specific gravity is reduced to 2·155, most of the iron is removed and the remainder consists of plumbago with the impurities of cast-iron. A similar change takes place when weavers' paste is applied to iron cylinders. Sea water when applied for a considerable time has the same effect. It takes three times as long to saturate acid with white cast iron as with grey.

The best way to try the quality of a piece of cast-iron is to strike its edge with a hammer. Should the blow make a slight impression the iron must be in some degree malleable, and provided the texture be uniform, the specimen may be regarded as good for machinery. If on the contrary the hammer makes no impression, and fragments fly off, the iron is brittle, and consequently bad. The soft grey cast-iron yields easily to the file after the outer crust has been removed, and is, in a cold state, slightly malleable.

We have taken the liberty of introducing two valuable tables from a very excellent work lately published on the strength of timber, by Mr Turnbull. They are very accurate, and will be found exceedingly useful in practice.

These Tables are intended to facilitate the process of estimating the strength, magnitude, and deflexion of cast-iron beams, when employed as bearers or supports in buildings and other mechanical constructions.

Table A exhibits the greatest weight that a beam of cast iron will bear in the middle of its length, when it is just able to restore itself if the load be removed; if loaded beyond that point, its elastic force is destroyed, and it takes a permanent set. The numbers at the top of the columns denote the depth of the beam in inches, and those in the left-hand marginal column denote the length of bearing, or distance between the supports in feet; the other columns contain the weight in tons that the beam will bear with safety, the breadth being one inch; consequently the numbers found in the table must always be multiplied by the given breadth, to obtain the entire load.

Table B contains the deflexion in inches produced in the middle of the beam by the load in Table A, the arguments being the same. The black lines that run across the pages, mark the point where the depth has arrived at that proportion of the length, when the beam becomes too rigid for bearing purposes, if exposed to any degree of impulsive force.

A few examples will render the use of the tables manifest. Thus:— A cast-iron beam, 2 inches broad, 18 inches deep, and 42 feet long, is placed horizontally on two supports exactly 40 feet asunder; how much will it bear suspended from the middle of its length, the elastic force remaining perfect?

In Table A, under 18 inches at top, and opposite 40 feet in the left hand column, stands 3·07 tons: this is the load that a beam one inch broad of the given dimensions will bear with safety: but the proposed beam is two inches broad, and the strength increases directly as the breadth; therefore, $3{\cdot}07 \times 2 = 6{\cdot}14$ tons, the entire load.

A cast iron beam, 18 inches broad and 40 feet between the supports, is found to bear 6·14 tons at the middle of its length, while the elastic force remains perfect; what is the breadth?

In Table A, under 18 inches at top and opposite 40 feet in the left hand column, stands 3·07 tons for the load that a beam one inch broad will bear; therefore

$$\frac{6{\cdot}14}{3{\cdot}07} = 2 \text{ inches, the required breadth.}$$

And exactly after the same manner is Table B to be applied for the deflexions.

Table A.—*The strength of Cast-iron beams.—Breadth one inch.*

Len. in feet.	Depth in inches.——$w = \frac{850\ bd^2}{2240\ l}$.											
	1	2	3	4	5	6	7	8	9	10	11	12
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
1	0·38	1·51	3·41	6 07	9·48	13·66	18·59	24·28	30·74	37·95	45·91	54·64
2	0·19	0·76	1·70	3·03	4·74	6·83	9·29	12·14	15·37	18·97	22·96	27·32
3	0·13	0·50	1·13	2·02	3·16	4·55	6·19	8·09	10·25	12·65	15·31	18·22
4	0·09	0·38	0·85	1·51	2·37	3·41	4·64	6·07	7·68	9·49	11·48	13·66
5	0·07	0·30	0·68	1·21	1·89	2·73	3·71	4·85	6·14	7·59	9·18	10·93
6	0·06	0·25	0·57	1·01	1·58	2·27	3·10	4·04	5·12	6·32	7·65	9·11
7	0·05	0·22	0·49	0·86	1·35	1·95	2·65	3·47	4·39	5·42	6·56	7·81
8	0·04	0·18	0·42	0·76	1·18	1·70	2·32	3·03	3·84	4·74	5·74	6·83
9	0·04	0·17	0·38	0·67	1·05	1·51	2·06	2·69	3·41	4·21	5·10	6·07
10	0·03	0·15	0·34	0·61	0·95	1·36	1·85	2·42	3·07	3·79	4·59	5·46
11	0·03	0·14	0·31	0·55	0·86	1·24	1·69	2·20	2·79	3·45	4·17	4·97
12	0·03	0·13	0·28	0·50	0·79	1·13	1·55	2·02	2·56	3·16	3·82	4·55
13	0·03	0·12	0·26	0·46	0·73	1·05	1·43	1·86	2·36	2·92	3·53	4·20
14	0·03	0·11	0·24	0·43	0·68	0·97	1·32	1·73	2·19	2·71	3·28	3·90
15	0·02	0·10	0·23	0·40	0·63	0·91	1·24	1·62	2·05	2·53	3·06	3·64
16	0·02	0·09	0·21	0·38	0·59	0·85	1·16	1·51	1·92	2·37	2·87	3·41
17	0·02	0·09	0·20	0·36	0·55	0·80	1·09	1·42	1·81	2·23	2·70	3·21
18	0·02	0·08	0·19	0·33	0·53	0·75	1·03	1·35	1·71	2·11	2·55	3·04
19	0·02	0·08	0·18	0·32	0·50	0·72	0·98	1·27	1·62	1·99	2·42	2·88
20	0·02	0·07	0·17	0·30	0·47	0·68	0·93	1·21	1·54	1·89	2·29	2·73
21	0·02	0·07	0·16	0·29	0·45	0·65	0·88	1·15	1·46	1·80	2·18	2·60
22	0·02	0·07	0·15	0·27	0·43	0·62	0·84	1·10	1·39	1·72	2·08	2·48
23	0·01	0·06	0·15	0·26	0·41	0·59	0·81	1·05	1·33	1·65	1·99	2·37
24		0·06	0·14	0·25	0·39	0·57	0·77	1·01	1·28	1·58	1·91	2·27
25		0·06	0·14	0·24	0·38	0·54	0·74	0·97	1·23	1·52	1·83	2·18
26		0·06	0·13	0·23	0·36	0·52	0·71	0·93	1·18	1·46	1·76	2·10
27		0·05	0·12	0·22	0·35	0·50	0·69	0·90	1·14	1·40	1·70	2·02
28		0·05	0·12	0·21	0.34	0·49	0·66	0·86	1·09	1·35	1·64	1·95
29		0·05	0·11	0·21	0·33	0·47	0·64	0·84	1·06	1·31	1·58	1·88
30		0·05	0·11	0·20	0·31	0·45	0·62	0·81	1·02	1·26	1·53	1·82
31		0·05	0·11	0·19	0·30	0·44	0·60	0·78	0·99	1·22	1·48	1·76
32		0·05	0·10	0·19	0·29	0·43	0·58	0·76	0·96	1·18	1·43	1·71
33			0·10	0·18	0·29	0·41	0·56	0·73	0·93	1·15	1·39	1·66
34			0·10	0·18	0·28	0·40	0·55	0·71	0·90	1·11	1·35	1·61
35			0·10	0·17	0·27	0·39	0·53	0·69	0·88	1·08	1·31	1·56
36			0·09	0·17	0·26	0·38	0·51	0·67	0·85	1·05	1·27	1·52
37			0·09	0·16	0·25	0·37	0·50	0·65	0·83	1·02	1·24	1·48
38			0·09	0·16	0·25	0·36	0·49	0·64	0·81	0·99	1·21	1·44
39			0·08	0·15	0·24	0·35	0·48	0·62	0·79	0·97	1·17	1·40
40			0·08	0·15	0·24	0·34	0·46	0·60	0·77	0·95	1·15	1·36
41				0·15	0·23	0·33	0·45	0·59	0·75	0·92	1·12	1·33
42				0·14	0·22	0·32	0·44	0·58	0·73	0·90	1·09	1·30
43				0·14	0·22	0·32	0·43	0·56	0·71	0·88	1·07	1·27
44				0·14	0·21	0·31	0·42	0·55	0·69	0·86	1·04	1·24
45				0·13	0·21	0·30	0·41	0·54	0·68	0·84	1·02	1·21
46				0·13	0·20	0·29	0·40	0·53	0·66	0·82	0·99	1·19
47					0·20	0·29	0·39	0·51	0·65	0·81	0·98	1·16
48					0·19	0·28	0·39	0·50	0·64	0·79	0·96	1·14
49					0·19	0·28	0·38	0·49	0·63	0·77	0·94	1·11
50					0·19	0·27	0·37	0·48	0·61	0·76	0·92	1·09

TABLE A, *continued.*

Len. in feet.	Depth in inches.——— $w = \frac{850\, bd^2}{2240\, l}$.											
	13	14	15	16	17	18	19	20	21	22	23	24
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
1	64·13	74·38	85·38	97·14	109·67	122·94	136·98	151·78	167·34	183·66	200·74	218·58
2	32·07	37·19	42·69	48·57	54·83	61·47	68·49	75·89	83·67	91·83	100·37	109·29
3	21·37	24·79	28·46	32·38	36·55	40·98	45·66	50·60	55·78	61·22	66·91	72·86
4	16·03	18·59	21·34	24·29	27·42	30·73	34·25	37·95	41·83	45·91	50·18	54·64
5	12·83	14·87	17·07	19·48	21·93	24·59	27·40	30·36	33·47	36·73	40·15	43·71
6	10·68	12·39	14·23	16·19	18·28	20·49	22·83	25·30	27·89	30·61	33·46	36·43
7	9·16	10·62	12·20	13·88	15·66	17·56	19·57	21·68	23·91	26·24	28·68	31·22
8	8·02	9·29	10·67	12·14	13·71	15·37	17·12	18·97	20·92	22·96	25·09	27·32
9	7·12	8·26	9·48	10·79	12·18	13·66	15·22	16·86	18·59	20·41	22·30	24·28
10	6·41	7·44	8·54	9·71	10·96	12·30	13·70	15·18	16·73	18·36	20·07	21·85
11	5·83	6·76	7·76	8·83	9·97	11·10	12·45	13·80	15·21	16·70	18·25	19·87
12	5·34	6·19	7·11	8·09	9·14	10·25	11·42	12·65	13·95	15·31	16·73	18·21
13	4·93	5·72	6·57	7·47	8·43	9·46	10·54	11·67	12·87	14·12	15·44	16·81
14	4·58	5·31	6·10	6·94	7·83	8·78	9·78	10·84	11·95	13·12	14·34	15·61
15	4·27	4·96	5·69	6·47	7·31	8·19	9·13	10·12	11·16	12·24	13·38	14·57
16	4·01	4·65	5·33	6·07	6·85	7·68	8·56	9·48	10·46	11·48	12·55	13·66
17	3·77	4·37	5·02	5·71	6·45	7·23	8·05	8·93	9·84	10·80	11·81	12·86
18	3·56	4·13	4·74	5·39	6·09	6·83	7·61	8·43	9·29	10·20	11·15	12·14
19	3·37	3·91	4·49	5·11	5·77	6·47	7·21	7·99	8·81	9·66	10·56	11·50
20	3·20	3·72	4·26	4·85	5·48	6·14	6·85	7·59	8·36	9·18	10·04	10·93
21	3·05	3·54	4·06	4·62	5·22	5·85	6·52	7·22	7·96	8·74	9·56	10·41
22	2·91	3·38	3·88	4·41	4·98	5·58	6·22	6·90	7·60	8·35	9·12	9·93
23	2·78	3·23	3·71	4·22	4·76	5·34	5·95	6·60	7·27	7·98	8·72	9·50
24	2·67	3·09	3·55	4·04	4·57	5·12	5·71	6·32	6·97	7·65	8·36	9·10
25	2·56	2·97	3·41	3·88	4·38	4·92	5·48	6·07	6·69	7·34	8·03	8·74
26	2·46	2·86	3·28	3·73	4·21	4·73	5·27	5·85	6·43	7·06	7·72	8·40
27	2·37	2·75	3·16	3·59	4·06	4·55	5·07	5·62	6·19	6·80	7·43	8·09
28	2·29	2·65	3·05	3·47	3·91	4·39	4·89	5·42	5·97	6·56	7·17	7·80
29	2·21	2·56	2·94	3·35	3·78	4·24	4·72	5·23	5·77	6·33	6·92	7·54
30	2·13	2·48	2·84	3·23	3·65	4·09	4·56	5·06	5·57	6·12	6·69	7·28
31	2·07	2·39	2·75	3·13	3·53	3·96	4·42	4·89	5·39	5·92	6·47	7·05
32	2·00	2·32	2·66	3·03	3·42	3·84	4·28	4·74	5·23	5·74	6·27	6·83
33	1·94	2·25	2·58	2·94	3·32	3·72	4·15	4·60	5·07	5·56	6·68	6·62
34	1·88	2·18	2·51	2·85	3·22	3·61	4·03	4·46	4·92	5·40	5·90	6·43
35	1·83	2·12	2·44	2·77	3·13	3·51	3·91	4·33	4·78	5·24	5·73	6·24
36	1·78	2·06	2·37	2·69	3·04	3·41	3·80	4·21	4·65	5·10	5·57	6·07
37	1·73	2·01	2·31	2·62	2·96	3·32	8·70	4·01	4·52	4·96	5·42	5·90
38	1·68	1·95	2·24	2·55	2·88	3·23	3·60	3·99	4·40	4·83	5·28	5·75
39	1·64	1·91	2·19	2·49	2·81	3·15	3·51	3·89	4·29	4·71	5·14	5·60
40	1·60	1·86	2·13	2·42	2·74	3·07	3·42	3·79	4·18	4·59	5·01	5·46
41	1·56	1·81	2·08	2 37	2·67	2·99	3·34	3·70	4·08	4·48	4·89	5·33
42	1·52	1·77	2·03	2·31	2·61	2·92	3·26	3·61	3·98	4·37	4·78	5·20
43	1·49	1·73	1·98	2·26	2·55	2·86	3·18	3·53	3·89	4·27	4·66	5·08
44	1·45	1·69	1·94	2·21	2·49	2·79	3·11	3·45	3·80	4·17	4·56	4·96
45	1·42	1·65	1·89	2·15	2·43	2·73	3·04	3·37	3·71	4·08	4·46	4·85
46	1·39	1·61	1·85	2·11	2·38	2·67	2·97	3·30	3·63	3·99	4·36	4·75
47	1·36	1·58	1·81	2·06	2·33	2·61	2·91	3·23	3·56	3·91	4·27	4·65
48	1·33	1·55	1·78	2·02	2·28	2·56	2·85	3·16	3·48	3·82	4·18	4·55
49	1·31	1·51	1·74	1·98	2·24	2·51	2·79	3·09	3·41	3·74	4·09	4·46
50	1·28	1·48	1·71	1·94	2·19	2·46	2·74	3·03	3·34	3·67	4·01	4·37

TABLE A, *continued.*

Len. in feet.	Depth in inches.——$w = \frac{850\ bd^2}{2240\ l}$.											
	25	26	27	28	29	30	31	32	33	34	35	36
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
1	237·18	256·53	276·63	297·51	319·12	341·52	364·68	388·56	413·25	438·65	464·85	491·80
2	118·59	128·26	138·31	148·75	159·56	170·76	182·34	194·28	206·62	219·32	232·43	245·90
3	79·06	85·51	92·21	99·17	106·37	113·84	121·56	129·52	137·75	146·22	154·95	163·93
4	59·29	64·13	69·16	74·38	79·78	85·38	91·17	97·14	103·31	109·66	116·21	122·95
5	47·43	51·30	55·33	59·50	63·82	68·30	72·93	77·71	82·65	87·73	92·97	98·36
6	39·53	42·75	46·11	49·58	53·19	56·92	60·78	64·76	68·87	73·11	77·47	81·96
7	33·88	36·65	39·52	42·50	45·59	48·78	52·09	55·51	59·03	62·67	66·41	70·25
8	29·65	32·06	34·58	37·19	39·89	42·69	45·58	48·57	51·65	54·83	58·11	61·47
9	26·35	28·50	30·74	33·05	35·46	37·95	40·57	43·17	45·92	48·74	51·65	54·64
10	23·72	25·65	27·66	29·75	31·91	34·15	36·47	38·86	41·32	43·87	46·48	49·18
11	21·56	23·32	25·15	27·05	29·01	31·05	33·15	35·32	37·57	39·88	42·26	44·71
12	19·76	21·37	23·05	24·79	26·59	28·46	30·39	32·38	34·44	36·56	38·74	40·98
13	18·24	19·73	21·28	22·88	24·55	26·27	28·05	29·89	31·79	33·74	35·76	37·83
14	16·94	18·32	19·76	21·25	22·79	24·39	26·05	27·76	29·52	31·33	33·20	35·13
15	15·81	17·10	18·44	19·83	21·28	22·77	24·31	25·91	27·55	29·24	30·99	32·79
16	14·82	16·03	17·29	18·59	19·95	21·34	22·79	24·29	25·83	27·42	29·05	30·74
17	13·95	15·09	16·27	17·50	18·77	20·09	21·45	22·86	24·31	25·80	27·34	28·93
18	13·17	14·25	15·37	16·53	17·73	18·97	20·26	21·59	22·95	24·37	25·82	27·32
19	12·48	13·50	14·56	15·66	16·80	17·97	19·19	20·45	21·75	23·09	24·46	25·88
20	11·86	12·83	13·83	14·87	15·96	17·08	18·23	19·43	20·66	21·93	23·24	24·59
21	11·29	12·22	13·17	14·17	15·20	16·26	17·36	18·50	19·68	20·89	22·14	23·42
22	10·78	11·66	12·57	13·52	14·51	15·52	16·58	17·66	18·78	19·94	21·13	22·35
23	10·31	11·15	12·03	12·93	13·88	14·85	15·86	16·89	17·97	19·07	20·21	21·38
24	9·88	10·69	11·53	12·40	13·30	14·23	15·19	16·19	17·22	18·28	19·37	20·49
25	9·48	10·26	11·06	11·90	12·77	13·66	14·58	15·54	16·53	17·55	18·59	19·67
26	9·12	9·86	10·64	11·44	12·27	13·14	14·03	14·94	15·90	16·87	17·88	18·92
27	8·78	9·50	10·25	11·02	11·82	12·65	13·51	14·39	15·31	16·25	17·22	18·21
28	8·47	9·16	9·88	10·62	11·40	12·20	13·02	13·88	14·76	15·67	16·60	17·56
29	8·17	8·84	9·54	10·26	11·00	11·78	12·57	13·40	14·25	15·13	16·03	16·96
30	7·90	8·55	9·22	9·91	10·64	11·38	12·16	12·95	13·77	14·62	15·50	16·39
31	7·65	8·27	8·92	9·59	10·29	11·02	11·76	12·53	13·33	14·15	14·99	15·86
32	7·41	8·01	8·64	9·29	9·97	10·67	11·40	12·14	12·92	13·71	14·53	15·37
33	7·18	7·77	8·38	9·01	9·67	10·35	11·05	11·77	12·52	13·29	14·09	14·90
34	6·97	7·54	8·13	8·75	9·38	10·04	10·73	11·43	12 15	12·90	13·67	14·46
35	6·77	7·33	7·90	8·50	9·12	9·75	10·42	11·10	11·81	12·53	13·28	14·05
36	6·58	7·12	7·68	8·26	8·86	9·48	10·13	10·79	11·48	12·18	12·91	13·66
37	6·41	6·93	7·47	8·04	8·62	9·23	9·85	10·50	11·17	11·86	12·56	13·29
38	6·24	6·75	7·28	7·83	8·39	8·98	9·59	10·23	10·87	11·54	12·23	12·94
39	6·08	6·57	7·09	7·63	8·18	8·75	9·35	9·96	10·59	11·25	11·92	12·61
40	5·93	6·41	6·91	7·43	7·97	8·53	9·11	9·71	10·33	10·96	11·62	12·29
41	5·78	6·25	6·74	7·25	7·78	8·33	8·89	9·47	10·08	10·70	11·34	11·99
42	5·64	6·10	6·58	7·08	7·59	8·13	8·68	9·25	9·84	10·45	11·07	11·71
43	5·51	5·96	6·43	6·92	7·42	7·94	8·48	9·03	9·61	10·20	10·81	11·44
44	5·39	5·83	6·28	6·76	7·25	7·76	8·29	8·83	9·39	9·97	10·56	11·18
45	5·27	5·70	6·14	6·61	7·09	7·59	8·10	8·63	9·18	9·74	10·33	10·93
46	5·15	5·57	6·01	6·46	6·93	7·42	7·92	8·44	8·98	9·53	10·11	10·69
47	5·04	5·45	5·88	6·33	6·79	7·26	7·75	8·26	8·79	9·33	9·89	10·46
48	4·94	5·34	5·76	6·19	6·64	7·11	7·59	8·09	8·61	9·13	9·68	10·25
49	4·84	5·23	5·64	6·07	6·51	6·97	7·44	7·93	8·43	8·95	9·48	10·04
50	4·74	5·13	5·53	5·95	6·38	6·83	7·29	7·77	8·26	8·77	9·29	9·83

Table B.—*Deflexion of Cast Iron Beams.*

Len. in feet.	Depth in inches.—— $\delta = \frac{\cdot 02\, l^2}{d}$											
	1	2	3	4	5	6	7	8	9	10	11	12
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1	0·02	0·01										
2	0·08	0·04	0·03	0·02	0·01	0·01						
3	0·18	0·09	0·06	0·04	0·03	0·03	0·02	0·02	0·02	0·02	0·02	0·01
4	0·32	0·16	0·11	0·08	0·06	0·05	0·04	0·04	0·04	0·03	0·03	0·03
5	0·50	0·25	0·17	0·12	0·10	0·08	0·07	0·06	0·06	0·05	0·04	0·04
6	0·72	0·36	0·24	0·18	0·14	0·12	0·10	0·09	0·08	0·07	0·06	0·06
7	0·98	0·49	0·33	0·24	0·19	0·16	0·14	0·12	0·11	0·09	0·09	0·08
8	1·28	0·64	0·43	0·32	0·25	0·21	0·18	0·16	0·14	0·13	0·11	0·10
9	1·62	0·81	0·54	0·40	0·32	0·27	0·23	0·20	0·18	0·16	0·14	0·13
10	2·00	1·00	0·67	0·50	0·40	0·33	0·28	0·25	0·22	0·20	0·18	0·16
11	2·42	1·21	0·81	0·60	0·48	0·40	0·34	0·30	0·27	0·24	0·22	0·20
12	2·88	1·44	0·96	0·72	0·57	0·48	0·41	0·36	0·32	0·29	0·26	0·24
13	3·38	1·69	1·13	0·84	0·67	0·56	0·48	0·42	0·38	0·34	0·31	0·28
14	3·92	1·96	1·31	0·98	0·78	0·65	0·56	0·49	0·44	0·39	0·35	0·33
15	4·50	2·25	1·50	1·12	0·90	0·75	0·64	0·56	0·50	0·45	0·41	0·37
16	5·12	2·56	1·71	1·28	1·02	0·85	0·73	0·64	0·57	0·51	0·46	0·43
17	5·78	2·89	1·93	1·44	1·15	0·96	0·82	0·72	0·64	0·58	0·52	0·48
18	6·48	3·24	2·16	1·62	1·29	1·08	0·92	0·81	0·72	0·65	0·59	0·54
19	7·22	3·61	2·41	1·80	1·44	1·20	1·03	0·90	0·80	0·72	0·65	0·60
20	8·00	4·00	2·67	2·00	1·60	1·33	1·14	1·00	0·89	0·80	0·73	0·66
21	8·82	4·41	2·94	2·20	1·76	1·47	1·26	1·10	0·98	0·88	0·80	0·74
22	9·68	4·84	2·23	2·42	1·93	1·61	1·38	1·21	1·08	0·97	0·88	0·80
23	10·58	5·29	3·53	2·64	2·11	1·76	1·51	1·32	1·18	1·06	0·96	0·88
24		5·76	3·84	2·88	2·30	1·92	1·64	1·44	1·28	1·15	1·04	0·96
25		6·25	4·17	3·13	2·50	2·08	1·78	1·57	1·39	1·25	1·13	1·04
26		6·76	4·51	3·38	2·70	2·25	1·93	1·69	1·50	1·35	1·23	1·13
27		7·29	4·86	3·64	2·90	2·43	2·08	1·82	1·62	1·45	1·32	1·21
28		7·84	5·23	3·92	3·12	2·61	2·24	1·96	1·74	1·57	1·42	1·30
29		8·41	5·61	4·20	3·36	2·80	2·40	2·10	1·87	1·68	1·53	1·40
30		9·00	6·00	4·50	3·60	3·00	2·57	2·25	2·00	1·80	1·63	1·50
31		9·61	6·41	4·80	3·84	3·20	2·74	2·40	2·13	1·92	1·75	1·60
32		10·24	6·83	5·12	4·10	3·41	2·92	2·56	2·27	2·05	1·86	1·70
33			7·26	5·44	4·36	3·63	3·11	2·72	2·42	2·18	1·98	1·81
34			7·71	5·78	4·62	3·85	3·30	2·89	2·57	2·31	2·10	1·92
35			8·17	6·13	4·90	4·08	3·50	3·07	2·72	2·45	2·22	2·04
36			8·64	6·48	5·18	4·32	3·70	3·24	2·88	2·59	2·35	2·16
37			9·13	6·85	5·48	4·56	3·91	3·43	3·04	2·74	2·49	2·28
38			9·63	7·22	5·78	4·81	4·12	3·61	3·21	2·89	2·62	2·40
39			10·14	7·60	6·08	5·07	4·34	3·80	3·38	3·04	2·76	2·53
40			10·67	8·00	6·40	5·33	4·57	4·00	3·55	3·20	2·91	2·66
41				8·40	6·72	5·60	4·80	4·20	3·73	3·36	3·05	2·80
42				8·82	7·06	5·88	5·04	4·41	3·92	3·53	3·21	2·94
43				9·25	7·38	6·16	5·28	4·63	4·11	3·69	3·36	3·08
44				9·93	7·74	6·45	5·53	4·97	4·30	3·87	3·52	3·22
45				10·13	8·10	6·75	5·78	5·06	4·50	4·05	3·68	3·37
46				10·58	8·46	7·05	6·04	5·29	4·70	4·23	3·84	3·52
47					8·84	7·36	6·31	5·52	4·91	4·42	4·01	3·68
48					9·22	7·68	6·58	5·76	5·12	4·61	4·19	3·84
49					9·60	8·00	6·86	6·00	5·33	4·80	4·36	4·00
50					10·00	8·33	7·14	6·25	5·55	5·00	4·54	4·16

TABLE B, *continued.*

Len. in feet.	Depth in inches.—— $\delta = \frac{\cdot 02\, l^2}{d}$.											
	13	14	15	16	17	18	19	20	21	22	23	24
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1												
2												
3	0·01	0·01										
4	0·02	0·02	0·02	0·02	0·02	0·02	0·01	0·01	0·01			
5	0·04	0·03	0·03	0·03	0·03	0·03	0·02	0·02	0·02	0·02	0·02	0·02
6	0·05	0·05	0·05	0·04	0·04	0·04	0·04	0·03	0·03	0·03	0·03	0·03
7	0·07	0·07	0·06	0·06	0·06	0·05	0·05	0·04	0·04	0·04	0·04	0·04
8	0·10	0·09	0·08	0·08	0·07	0·07	0·07	0·05	0 06	0·05	0·05	0·05
9	0·12	0·11	0·11	0·10	0·09	0·09	0·08	0·08	0·07	0·07	0·07	0·06
10	0·15	0·14	0·13	0·12	0·12	0·11	0·10	0·10	0·09	0·09	0·08	0·08
11	0·18	0·17	0·16	0·15	0·14	0·13	0·13	0·12	0·11	0·11	0·10	0·10
12	0·22	0·20	0·19	0·18	0·17	0·16	0·15	0·14	0·13	0·13	0·12	0·12
13	0·26	0·24	0·22	0·21	0·20	0·19	0·18	0·17	0·16	0·15	0·14	0·14
14	0·30	0·28	0·26	0·24	0·23	0·22	0·21	0·19	0·18	0·17	0·17	0·16
15	0·35	0·32	0·30	0·28	0·26	0·25	0·24	0·22	0·21	0·20	0·19	0·18
16	0·39	0·36	0·34	0·32	0·30	0·28	0·27	0·25	0·24	0·23	0·22	0·21
17	0·44	0·41	0·38	0·36	0·34	0·32	0·30	0·29	0·27	0·26	0·25	0·24
18	0·49	0·46	0·43	0·40	0·38	0·36	0·34	0·33	0·31	0·29	0·28	0·27
19	0·55	0·51	0·48	0·45	0·42	0·40	0·38	0·36	0·34	0·32	0·31	0·30
20	0·61	0·57	0·53	0·50	0·47	0·44	0·42	0·40	0·38	0·36	0·35	0·33
21	0·68	0·63	0·59	0·55	0·52	0·49	0·46	0·44	0·42	0·40	0·38	0·37
22	0·74	0·69	0·64	0·60	0·57	0·54	0·51	0·48	0·46	0·44	0·42	0·40
23	0·81	0·75	0·70	0·66	0·62	0·59	0·56	0·53	0·50	0·48	0·46	0·44
24	0·88	0·82	0·76	0·72	0·67	0·64	0·60	0·57	0·54	0·52	0·50	0·48
25	0·96	0·89	0·83	0·78	0·73	0·69	0·66	0·63	0·59	0·56	0·54	0·52
26	1·04	0·96	0·90	0·84	0·79	0·75	0·71	0·67	0·64	0·61	0·59	0·56
27	1·12	1·04	0·96	0·91	0·85	0·81	0·77	0·72	0·69	0·66	0·63	0·60
28	1·20	1·12	1·05	0·98	0·92	0·87	0·82	0·78	0·74	0·71	0·68	0·66
29	1·29	1·20	1·12	1·05	0·98	0·93	0·88	0·84	0·80	0·76	0·73	0·70
30	1·38	1·28	1·20	1·12	1·06	1·00	0·94	0·90	0·86	0·81	0·78	0·75
31	1·48	1·37	1·28	1·20	1·13	1·06	1·01	0·96	0·91	0·87	0·83	0·80
32	1·57	1·46	1·36	1·28	1·20	1·13	1·08	1·02	0·97	0·93	0·89	0·85
33	1·67	1·55	1·45	1·36	1·28	1·21	1·15	1·09	1·03	0·99	0·94	0·90
34	1·78	1·65	1·54	1·44	1·35	1·28	1·22	1·15	1·10	1·05	1·00	0·96
35	1·88	1·75	1·63	1·53	1·43	1·36	1·29	1·22	1·16	1·11	1·06	1·02
36	1·99	1·85	1·73	1·62	1·52	1·44	1·36	1·29	1·23	1·17	1·12	1·08
37	2·10	1·95	1·83	1·72	1·60	1·52	1·44	1·37	1·30	1·24	1·19	1·14
38	2·22	2·06	1·93	1·80	1·69	1·60	1·52	1·44	1·37	1·31	1·25	1·20
39	2·34	2·17	2·02	1·90	1·78	1·69	1·60	1·52	1·45	1·38	1·32	1·26
40	2·46	2·28	2·13	2·00	1·88	1·77	1·68	1·60	1·52	1·45	1·39	1·33
41	2·58	2·40	2·24	2·10	1·97	1·86	1·77	1·68	1·60	1·52	1·46	1·40
42	2·71	2·52	2·35	2·20	2·07	1·96	1·86	1·76	1·68	1·60	1·53	1·47
43	2·84	2·64	2·46	2·32	2·17	2·05	1·96	1·84	1·76	1·68	1·61	1·54
44	2·98	2·76	2·58	2·48	2·27	2·15	2·04	1·93	1·84	1·76	1·68	1·61
45	3·11	2·89	2·70	2·53	2·37	2·25	2·13	2·02	1·92	1·84	1·76	1·68
46	3·25	3·02	2·82	2·64	2·48	2·35	2·23	2·11	2·01	1·92	1·84	1·76
47	3·39	3·15	2·95	2·76	2·59	2·45	2·32	2·21	2·10	2·00	1·92	1·84
48	3·54	3·29	3·07	2·88	2·69	2·56	2·42	2·30	2·19	2·09	2·00	1·92
49	3·69	3·43	3·20	3·00	2·81	2·66	2·53	2·40	2·29	2·18	2·09	2·00
50	3·84	3·57	3·33	3·12	2·92	2·77	9·63	2·50	2·38	2·27	2·17	2·08

TABLE B, *continued.*

Len. in feet.	Depth in inches.—— $\delta = \frac{\cdot 02\, l^2}{d}$.											
	25	26	27	28	29	30	31	32	33	34	35	36
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1												
2												
3												
4												
5	0·02	0·02	0·02									
6	0·03	0·03	0·03	0·02	0·02	0·02	0·02	0·02	0·02	0·02	0·02	0·02
7	0·04	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·02
8	0·05	0·05	0·04	0·04	0·04	0·04	0·04	0·04	0·03	0·03	0·03	0·03
9	0·06	0·06	0·06	0·05	0·05	0·05	0·05	0·05	0·04	0·04	0·04	0·04
10	0·08	0·07	0·07	0·07	0·07	0·06	0·06	0·06	0·06	0·06	0·05	0·05
11	0·09	0·10	0·09	0·08	0·08	0·08	0·07	0·07	0·07	0·07	0·06	0·06
12	0·11	0·11	0·10	0·10	0·10	0·09	0·09	0·09	0·08	0·08	0·08	0·08
13	0·13	0·13	0·12	0·12	0·11	0·11	0·11	0·10	0·10	0·10	0·09	0·09
14	0·16	0·15	0·15	0·14	0·13	0·13	0·12	0·12	0·11	0·11	0·11	0·11
15	0·18	0·17	0·16	0·16	0·15	0·15	0·14	0·14	0·13	0·13	0·13	0·12
16	0·20	0·19	0·19	0·18	0·17	0·17	0·16	0·16	0·15	0·15	0·14	0·14
17	0·23	0·22	0·21	0·20	0·20	0·19	0·18	0·18	0·17	0·17	0·16	0·16
18	0·26	0·24	0·24	0·23	0·22	0·21	0·21	0·20	0·19	0·19	0·18	0·18
19	0·29	0·27	0·26	0·25	0·25	0·24	0·23	0·22	0·21	0·21	0·20	0·20
20	0·32	0·30	0·29	0·28	0·27	0·26	0·26	0·25	0·24	0·23	0·23	0·22
21	0·35	0·34	0·32	0·31	0·30	0·29	0·28	0·27	0·26	0·26	0·25	0·24
22	0·38	0·37	0·36	0·34	0·33	0·32	0·31	0·30	0·29	0·28	0·27	0·27
23	0·42	0·41	0·39	0·37	0·36	0·35	0·34	0·33	0·32	0·31	0·30	0·29
24	0·46	0·44	0·42	0·41	0·39	0·38	0·37	0·36	0·34	0·33	0·32	0·32
25	0·50	0·48	0·46	0·44	0·43	0·41	0·40	0·39	0·37	0·36	0·35	0·34
26	0·54	0·52	0·50	0·48	0·46	0·45	0·43	0·42	0·41	0·39	0·38	0·37
27	0·58	0·56	0·54	0·52	0·50	0·48	0·47	0·45	0·44	0·42	0·41	0·40
28	0·63	0·60	0·58	0·56	0·54	0·52	0·50	0·49	0·47	0·46	0·45	0·43
29	0·67	0·64	0·62	0·60	0·58	0·56	0·54	0·52	0·51	0·49	0·48	0·46
30	0·72	0·69	0·66	0·64	0·62	0·60	0·58	0·56	0·54	0·53	0·51	0·50
31	0·77	0·74	0·71	0·68	0·66	0·64	0·62	0·60	0·58	0·56	0·55	0·53
32	0·82	0·78	0·75	0·73	0·71	0·68	0·66	0·64	0·62	0·60	0·58	0·56
33	0·87	0·83	0·80	0·77	0·75	0·72	0·70	0·68	0·66	0·64	0·62	0·60
34	0·92	0·89	0·85	0·82	0·79	0·77	0·74	0·72	0·70	0·67	0·66	0·64
35	0·98	0·94	0·91	0·87	0·84	0·81	0·79	0·76	0·74	0·71	0·70	0·68
36	1·04	0·99	0·96	0·92	0·89	0·86	0·83	0·81	0·78	0·76	0·74	0·72
37	1·09	1·05	1·01	0·97	0·94	0·91	0·88	0·86	0·83	0·80	0·78	0·76
38	1·16	1·11	1·07	1·03	0·99	0·96	0·93	0·90	0·87	0·84	0·82	0·80
39	1·22	1·17	1·12	1·08	1·05	1·01	0·98	0·95	0·92	0·89	0·87	0·84
40	1·28	1·23	1·18	1·14	1·10	1·06	1·03	1·00	0·97	0·94	0·91	0·88
41	1·34	1·29	1·24	1·20	1·16	1·12	1·08	1·05	1·02	0·98	0·96	0·93
42	1·41	1·35	1·31	1·26	1·22	1·17	1·13	1·10	1·07	1·03	1·01	0·98
43	1·47	1·42	1·37	1·32	1·27	1·23	1·19	1·16	1·12	1·08	1·05	1·02
44	1·55	1·49	1·43	1·38	1·33	1·29	1·25	1·21	1·17	1·13	1·10	1·07
45	1·62	1·55	1·46	1·44	1·40	1·35	1·30	1·26	1·22	1·18	1·16	1·12
46	1·69	1·62	1·56	1·51	1·46	1·41	1·36	1·32	1·28	1·24	1·21	1·17
47	1·77	1·69	1·63	1·57	1·52	1·47	1·42	1·38	1·34	1·29	1·26	1·22
48	1·84	1·77	1·71	1·64	1·59	1·53	1·48	1·44	1·39	1·34	1·31	1·28
49	1·92	1·84	1·77	1·71	1·65	1·60	1·55	1·50	1·45	1·40	1·37	1·33
50	2·00	1·92	1·85	1·78	1·72	1·66	1·61	1·56	1·51	1·46	1·43	1·38

IRREGULAR, that which deviates from the usual form or rule; thus, in geometry, a polygon which has not all its sides and angles equal, is called an irregular polygon.

ISAGONE, a figure having equal angles.

ISOCHRONAL, or ISOCHRONOUS, is applied to such vibrations of a pendulum as are performed in equal times. Of this kind are all the cycloidal vibrations or swings of the same pendulum, whether the arcs it describes be longer or shorter; for when it describes a shorter arc, it moves so much the slower; and when a long one, proportionally faster.

ISOMETRICAL PERSPECTIVE; a new method of drawing plans of machines, &c. whereby the elevation and ground plan are represented in one view. See *Perspective*.

ISOPERIMETRICAL FIGURES, are those which have equal perimeters.

ISOSCELES TRIANGLE, is a triangle of two equal legs or sides. The angles at the base of an isosceles triangle are equal, and if the sides be produced, the angles under the base are also equal. If the line be drawn perpendicular to the base, it will bisect the base and the vertical angle; or if it be drawn to bisect the base, it will be perpendicular to it.

J

JACKET, STEAM. The cylinders of steam engines of the larger size are encircled with another cylinder of greater diameter, steam being introduced between them in order that the inner cylinder may be kept warm. This envelope, or outer cylinder, is called a *Jacket*. This arrangement is not accompanied with any great economisation of fuel, and besides the engine room is kept uncomfortably warm. A better arrangement is to make the space between the cylinder and the jacket air tight, and admit no steam at all. In a high pressure engine, working with steam at a temperature of 300° Fah., the loss of power by the cooling of a cylinder without a jacket does not amount to more than one sixty-fifth part of the original pressure of the steam.

JACK, in mechanics, a sort of crane for raising heavy weights. It consists first of a small pinion wrought with a common winch. This pinion works in the teeth of a large wheel, on whose axis there is fixed a small pinion with teeth, working in a rack. The turning of the handle raises the rack, and of course any weight attached to it. If the length of the handle of the winch be 7 inches, and the pinion which it drives contain 4 leaves, working in the teeth of the large wheel having 20 teeth, then will 5 turns of the handle be requisite for one of the wheel. But the length of the arm of the winch being 7 inches, the circumference through which the handle moves will be about 44 inches, and for one turn of the wheel the handle must pass through $5 \times 44 = 220$. The wheel carries a pinion of say 3 leaves, of a pitch of $\frac{1}{3}$ of an inch, working the rack that carries the weight; one turn of the pinion will therefore raise the rack one inch, and as the power moves through 220 in the same time, 220 will be the power of the jack.

JET, CONDENSING. The water used for condensing the steam in Watt's engine is introduced into the condenser through a rose, or vessel at the end of the injection pipe, which is perforated into a great number of small holes, so that the water enters the condenser in a shower, and thus exposes the greatest possible extent of surface to the steam, in order to ensure rapidity of condensation.—See *Condenser*.

JET D'EAU, a French word signifying a fountain that throws up water to some height in the air.

JOINT; the place where two pieces of timber, metal, &c., are joined together. Timber bars may be extended to any length in a right line, by joining one to the end of another as often as may be necessary to make the required length. The corresponding ends which join are cut in such a manner that every point of the part cut away in the one will coincide with a corresponding point in the other. The parts cut away at the two ends of two pieces which join are commonly plane surfaces, and the joint such, that when the two timbers are joined and kept together, two forces applied in a direction of the length of the two pieces thus united, may not be able to pull them asunder without breaking at the joint. Timbers thus joined are said to be *scarfed*.

Timbers may also be joined either at oblique or at right angles. The timber bars which form the enclosure of every frame used in building may be rectangular, excepting those which are employed in the different faces of a roof in order to support the covering. The interior timbers of every frame comprised between the sides of the enclosure may be rectangular. Whenever two pieces of timber are joined to form an angle, we shall always suppose that they are rectangular bars, of which two faces are parallel to a plane, and consequently the other two faces perpendicular to that plane, unless the contrary is expressed: and thus, when one piece of timber is perpendicular to another, if the end of the one piece fit close upon the side of the other, that end must be in a plane perpendicular to any one of the four arrises of that piece. Every timber in a building which terminates with a close joint upon the face of another, will have its end in the figure of a rectangle, of which two sides will be perpendicular to the plane of the angle formed by these two timbers, except in the faces of hip or in hip and valley roofs, where the ends of the jack rafters and the ends of the purlins meet the hips. When the ends of a piece of timber join one of the faccs of another pioce of timber, and form such a joint that all the faces of the piece of which the ends fit upon the other intersect, and form a close joint, these two timbers may be firmly secured to each other by means of nails or bolts, provided that the angle which they form is very oblique. This form of joint is called a *shoulder joint*, and the end of the piece which fits upon the face of the other is called the *shoulder;* but if the directions of the pieces form a right angle, or approach nearly to a right angle, such a method of fixing them cannot be secure, especially where one of them acts as a lever upon the other. If the ends of each of the pieces are cut so that they may meet each other in a plane perpendicular to the plane of the angle which the two pieces make with each other, and which will either bisect that angle or pass through the intersections of the outer and inner faces of these timbers. This form of joint is called a *mitre joint*, and the two pieces are said to be *mitred*. Here the lengths of the mitring surfaces in both pieces are equal. The pieces which are mitred together may be rendered much more secure by means of nails or bolts, than when they are simply shoulder jointed, particularly when one of the pieces is required to act as a lever upon the other. One piece of timber may be joined to another by inserting a part of the one into an excavation of the other, or reciprocally by excavating both, and inserting a portion of the solid of the one into the hollow of the other. The surfaces which are thus concealed by being brought into contact are called a *close joint*. A close joint may be made in an infinite variety of ways; by making the hollow of the one in such a manner, that when the two pieces are jointed all the points of the surface which were excavated in either piece may come in contact with some point or other of the surface of the other solid. This is an universal method of joining timbers, but the modes by which it may be done are of infinite variety. Generally, whatever may be the office of a piece of timber which is to be fixed to another, the excavation which is cut in the one piece in order to receive a part of the solid of the other, ought to be such that the surfaces may be in planes either perpendicular or parallel to the face of the timber from which the excavation may be made. The particular manner of forming the joint will depend upon the two following cases; viz. 1. when one of the pieces is fixed and the other in a state of tension; and 2. when one is fixed and the other in a state of compression. As every timber bar has a considerable weight, it cannot be kept stationary without being supported at least under one point; but the most secure supports will be under its extremities. For whatever be the kind of pressure to which a bar of timber may be subjected, it has also to support its own weight; and thus the formation of the joint of two timber bars to be fixed to each other at a given angle will depend upon the joint consideration of the species of strain and the weight of the timber. In forming the joint of two timbers making a given angle with each other, we shall always suppose that one of the pieces is fixed or immovable, and the species of strain to which the other may be subjected given, and that the fixed piece has to support the other. The case of tension requires the joint to be made in such a manner, that it would be impossible to pull the piece of which the strain is given out of the fixed piece without leaving a part of the end of the one or the other or of both timbers. The operation of forming such a joint has been called *cocking*.

When two pieces of timber are of the same thickness, and are required to be joined to each other in the form of a cross, the two parts may be so cut, that when put together they may be comprised between two parallel planes at a distance from each other equal to the thickness of one of the pieces only. This method is called *notching*, and when each of the pieces is reduced to half its thickness, by taking away a rectangular solid equal to half their thickness, the method of notching is called *halving*.

When two timber bars are intended to be joined together in order to form a cross, where one of the pieces is to be let down upon the other, two notches are generally cut from the upper face of the lower bar, by taking away two rectangular solids, and leaving a solid part between the two notches, and one notch is cut from the lower face of the upper bar to fit the piece which remains whole between the two notches in the lower timber bar, so that when the two timbers come to be joined, two ends of the two notches of the lower piece, and one of the perpendicular faces of the upper piece, may be in the same plane, and the remaining ends of these two notches in the lower bar in the same plane as the remaining opposite perpendicular face of the upper bar, and that the depths of the notches in both pieces may be equal to the distance intended to be let down.

Metallic joints in steam engines are usually fixed by screw bolts passing through flanches, between which some durable elastic material such as leather or hemp is introduced, or some cement. Steam tight joints may be formed by fitting the pieces to be joined very accurately into a conical ring, and then screwing them tightly together; or a very tight joint may be made between two flat surfaces, by introducing a ring of small copper wire which flattens and accomodates itself to the surfaces when they are screwed together.

If cement is to be used a good one for iron may be made as follows:—Mix together

Sal ammoniac, ...	2 ounces.
Flowers of Sulphur, . . .	1 —
Thin cast-iron filings or turnings,	16 —

Grind them in a mortar and keep the powder dry 'till required for immediate use. When it is required take a portion of the powder and mix with it twenty times its weight of clean iron filings, grind in a mortar and wet with water until the mass assumes the consistence of paste. Put this between the surfaces to be joined, screw them tightly together and the joint will soon become as strong as if it had been entirely solid. Watt was in the habit of using a little sand from the grindstone trough which he thought improved the cement.

When joists require to be opened occasionally a very good cement may be formed by mixing white lead with a little red lead, and these with oil to a proper consistence. This is laid on each side of a piece of plaited hemp, leather, or thick canvass, and placed between the parts before they are screwed together.

A cheap and durable cement, useful for many purposes, and very applicable to be laid over the rivets and edges of the sheets of a copper boiler, for preventing the leakage of cocks, &c., may be made by mixing quick lime with white of egg, or the serum of blood, of the consistence of paste. This cement must be applied as soon as it is made.

JOINT, UNIVERSAL, is a very simple and effectual method of transferring rotation from one axis to another.

The single universal joint is represented in fig. 1. A and B are the shafts, between which the rotation is transmitted; C D, E F is a cross of metal, the ends of which turn freely in bushes placed in the extremities of two diameters in which the shafts terminate.

From considering this arrangement, it is evident that, when the shaft A is turned round, the shaft B will receive a similar motion. If, however, the angle under the shafts A and B be less than 140°, this will fail to act.

Fig. 1.

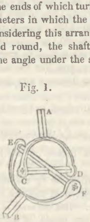
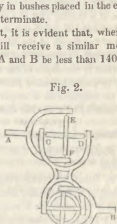


Fig. 2.



In this case, the double universal joint must be resorted to. This is represented in fig. 2. There are here two crosses, the extremities of which move on pivots, like the former. This will serve when the angle contained by the shafts is less than 140°.

These joints may also be constructed with four pins, fastened at right angles upon the circumference of a hoop, or solid ball. They are of considerable use in cotton mills, where the tumbling shafts extend to a great distance from the impelling power; for, by applying an universal joint, the shaft may be cut into convenient lengths, and be thus enabled to overcome a greater resistance.

Joist, a beam that supports a floor, being itself supported by the walls at each end. The strength of joisting ought to be in proportion to the squares of their lengths, or, if supported beneath, their strength ought to be in proportion to the squares of the distances of the supports. For we may suppose that all apartments are meant to contain a quantity of furniture in proportion to their size, or otherwise to accommodate occasionally a number of persons in that proportion; wherefore they support a weight or strain in proportion to the length of the joist, and the strain with equal weights is also as that length; that is, the joint strain is in proportion to the square of the length. For instauce, if a set of joisting has twice the length of another set between the supports, the strength of the first in any section should be four times the strength of the other in a similar section. This is an important truth beyond all controversy, and yet it does not seem to be generally known or attended to by builders. Suppose it to be known what size of the section of a joist is sufficient for a given length in a certain case, let it be required to find the section of a similar joist of a different given length in a similar case. Multiply the cube of the depth of the joist whose section is known, by the square of the length of the joist whose section is required, and divide the product by the square of the length of the known joist; the cube root of the quotient is the depth of the section required.

Thus if in a certain case a joist whose depth is 1 foot, and thickness 3 inches, be sufficient for a length of 30 feet; what must the section of a similar joist be in a similar case whose length is 15 feet? By the rule the depth $= \sqrt[3]{\frac{1^3 \times 15^2}{30^2}} = \sqrt[3]{\frac{225}{900}} = \sqrt[3]{\cdot 25} = \cdot 6298$ feet, and 1 foot : 3 inches : : ·6298 feet : 1·8894 inches = thickness of the similar beam.

It will be found, by multiplying the thickness by the square of the depth in each of these beams, that the section of the one is four times the strength of the other, as it ought to be. But the areas of the sections are as 3 to 1·19, and as the less is half the length of the greater, the quantity of material in the one is therefore above five times as much as in the other; and yet, although it may seem a paradox, the one has been shown to be as strong as the other. The above rule may be extended to dissimilar beams. Suppose we know, as above, the three dimensions of a beam that is of a sufficient strength in a certain case. Let it be required to find any one dimension of any beam that will be equally strong with the given beam in a similar case.

To find the length, the depth and thickness being given. Multiply the square of the depth of the unknown beam by its thickness; multiply this product again by the square of the length of the known beam; divide the product by the product of the square of the depth and the thickness of the known beam, and the square root of the quotient is the length required. Thus, suppose a joist 30 feet long, 12 inches deep, and 3 inches thick, has sufficient strength in a given case, it is required to know the length of another joist of equal strength, whose depth and thickness are 8 and 6 inches respectively in a similar case.

By the rule, $\sqrt{\frac{8^2 \times 6 \times 30^2}{12^2 \times 3}} = \sqrt{\frac{64 \times 6 \times 900}{144 \times 3}} = \sqrt{800} = 28.28$ feet, Ans. To find the depth, the length and thickness being given. Multiply the square of the depth of the known beam by its thickness, and this product again by the square of the length of the beam whose depth is required; divide the product by the product of the square of the length of the known beam, and the thickness of the other; and the square root of the quotient is the depth required. Suppose a joist 30 feet long, 12 inches deep, and 8 thick, be of sufficient strength in a given case; it is required to know the depth of another joist, whose length is 28·28 feet, and thickness 6 inches, of the same strength in a similar case.

By the rule, $\sqrt{\frac{12^2 \times 3 \times 28{\cdot}28^2}{30^2 \times 6}} = \sqrt{\frac{144 \times 3 \times 800}{900 \times 6}} = \sqrt{64} =$ 8 inches, Ans. To find the thickness, the length and depth being given. Multiply the square of the depth of the known beam by its thickness, and this again by the square of the length of the beam whose thickness is required; divide the product by the product of the square of the length of the known beam, and the square of the depth of the other, and the quotient is the thickness required.

Suppose a joist 30 feet long, 12 inches deep, and 3 inches thick, has strength sufficient for a certain purpose; it is required to know the thickness of another joist of equal strength, whose length is 28·28 feet, and whose depth is 8 inches for a similar purpose.

By the rule, $\frac{12^2 \times 3 \times 28{\cdot}28^2}{8^2 \times 30^2} = \frac{144 \times 3 \times 800}{64 \times 900} = 6$ inches, Ans.

It is evident also, from the foregoing propositions, that a joist is four times stronger when supported in the middle. That the main part of the strength of a joist consists in its depth; for it may be shown, that a joist may have twice the strength of another, and yet have less timber in it of equal quality and length; for instance, suppose a joint to be 6 inches square, its lateral strength in any section is the square of 6 multiplied by

6, equal to 216. Let another joist be 11 deep, and 3 inches thick, its lateral strength is the square of 11 multiplied by 3, equal to 363; this last is above one-third stronger than the first; but, suppose this last joist laid on its broad side, the depth will be 3 inches, and its strength is the square of 3 multiplied by 11, equal to 99, nearly four times weaker than in the other position, while the quantity of timber evidently remains the same. The quantity of timber in the first joist is $6 \times 6 = 36$, and the quantity in the last is $11 \times 3 = 33$. Deep and thin joists are therefore the strongest when they have no side pressure; they are also the lightest and the most efficient, for they do not strain the building so much by their own weight, and very slight levers are sufficient to prevent them from warping. Joists are twice as strong with their ends firmly built into the wall, as when the ends are merely laid loosely upon it,—a circumstance that ought certainly to be attended to when the walls are strong; but if not, they in that case have a tendency to shake the walls.

In estimating the strength of joists the stress of the flooring is of course the first thing to be considered. On an average the weight of a superficial foot of unloaded flooring, where there is a ruling counter-floor and iron girders, is about 40 lbs., and when loaded with people about 120 lbs. to the square foot, this therefore ought to be taken as the minimum stress. Cast iron joists are employed for fire proof floors, a species of floors which ought to be used in all spinning and weaving factories. The iron joists are laid parallel to each other across the narrowest direction of the apartment, the spaces between them being occupied by arches of brick work. The joists are usually of this form, viewed endwise.

For such cast iron joints Mr Tredgold gives the subjoined formula, in which W = the weight in lbs., l = the length in feet, d = the depth and b = the breadth in inches, q the difference of the breadth of the broadest and narrowest parts, and p a fraction such that when multiplied by the whole depth will give the depth of the middle part of the figures. Then for cast iron joists we have

$$\frac{W \times l}{1700 \times (1 - q \times p^2)} = b \times d^2.$$

Table of Cast Iron Joists for Fire-proof Floors, when the extraneous load is not greater than 120 lbs. on a superficial foot.

Length of joists in feet.	Half brick arches, breadth of beams 2 inches.			Nine inch arches, breadth of beams 3 inches.		
	3 feet span.	4 feet span.	5 feet span.	6 feet span.	7 feet span.	8 feet span.
Feet.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.
8	4½	5¼	5¾	5¼	5¾	6
10	5½	6½	7	6½	7¼	7½
12	6¼	7¾	8½	7¾	8½	9
14	7¾	9	10	9¼	10	10½
16	9	10¼	11½	10½	11½	12
18	10	11¾	12¾	11¾	13	13½
20	11¼	13	14	13	14¼	15
22	12½	14¼	15½	14¼	15¾	16½
24	13¾	15½	17	15½	17	18

JOURNAL, is that part of a shaft that revolves on a support somewhere between these points where the power and resistance are applied. See *Shaft.*

K

KEY STONE, the highest stone in an arch.

KEY SCREW. See *Screw key.*

KING POST. See *Roof.*

KNEE JOINT. See *Taggle.*

L

LACQUER. See *Varnish.*

LAMINÆ, are extremely thin plates, of which solid bodies are supposed to be made up. These are indeed rather ideal than real; but such a confirmation is frequently supposed for the sake of simplifying the solution in a great variety of physical problems.

LARCH, this kind of timber is very useful to the mechanic. Worms do not destroy it, and the weather has very little influence upon it. It is well adapted for framing of machines, for masts of ships, &c. The weight of a cubic foot is 35 lbs.

LEAD, a well known metal much used in the arts. Lead unites with most of the metals, has little elasticity, and is the softest of them all. Gold and silver are dissolved by it in a slight red heat, but when the heat is much increased, the lead separates, and rises to the surface of the gold, combined with all heterogeneous matters; hence lead is made use of in tho art of refining the precious metals. If lead be heated so as to boil and smoke, it soon dissolves pieces of copper thrown into it; the mixture, when cold, being brittle. The union of these two metals is remarkably slight, for upon exposing the mass to a heat no greater than that in which lead melts, the lead almost entirely runs off by itself.

Sheet lead is made by suffering the melted metal to run out of a box through a long horizontal slit, upon a table covered with sand, and the box is drawn over it, leaving the melted lead behind to congeal in the desired form. The requisite uniformity and thinness are given to these sheets, by rolling them between two cylinders of iron.

An alloy of lead and antimony is used for printers' types; four parts of lead to one of antimony form a good composition. If the antimony be pure, one part of it, to seven or eight of lead, form an alloy too brittle to be extended under the hammer, and as hard as the generality of types. Antimony renders the lead more fusible, more fluid when melted, and as it expands in passing to a solid state, it is calculated to produce a sharper impression of the mould, than could be easily obtained by lead alone. The antimony in combining with lead, as it is little more than half its weight, rises to the surface, and requires to be well stirred before it will incorporate.

The surface of melted lead, as every one knows, becomes quickly covered with a skin or pellicle, often assuming different lively hues at first, and subsequently increasing in quantity and darkness of colour. This effect, termed by chemists oxidation, as it is occasioned by the action of the oxygen of the atmosphere, the activity of which is greater in proportion to the heat of the lead, wastes the metal so fast, that it becomes an object of importance to those who melt much lead, to check its formation, or to convert it, when formed, by the cheapest process, into the metallic state again. A thick coating of ashes of any kind, will check the formation of the oxide, and may be easily pushed back, when a quantity of lead must be taken out of the crucible or melting pan. Charcoal, which is also a good covering for lead in the pan, will convert dross into metal, when assisted by a sufficient heat; fat, oily, and bituminous substances in general, have a similar effect. Common resin answers exceedingly well; thrown in powder upon melted lead, and stirred about, it immediately converts the oxide into metal, causes the surface to shine like mercury, and if any thing remains, it is only a black dirt, containing little or no lead. But in taking off this dirt, small globules of pure lead, skimmed off at the same time, get mixed with it; by throwing it into water, stirring it thoroughly, and pouring off all that does not immediately sink, these grains may be separated. If part of what has appeared to be dirt, is found to be so heavy as instantly to sink to the bottom of water, it may be suspected to be true dross or oxide, and may be revived by mixing it with charcoal, and exposing it to a considerable heat. It is always, however, more prudent and economical, to use means of preventing the formation of oxide, than to bestow much time upon its revival. Lead becomes less fluid every time it is melted, and by much or frequent exposure to a high temperature, a state in which it is said to be rotten, is superinduced. To use new lead, and not to melt it oftener, or expose it to a greater heat than is indispensable, are necessary precautions to preserve this metal in its best state. Plumbers, when they cast it into sheets, strew common salt upon the table, to facilitate its spreading, when they are not using new lead, and are for that, or any other reason, apprehensive that it will not run well.

Leibnitzian Philosophy, is a system formed and published by its author in the last century, partly in emendation of the Cartesian, and partly in opposition to the Newtonian Philosophy. In this philosophy the author retained the Cartesian subtile matter, with the vortices and universal plenum; and he represented the universe as a machine that should proceed for ever, by the laws of mechanism, in the most perfect state, by an absolute inviolable necessity. After Newton's philosophy was published in 1687, Leibnitz printed an Essay on the Celestial Motions in the Act. Erud. 1689, where he admits the circulation of the ether with Des Cartes, and of gravity with Newton; though he has not reconciled these principles, nor shown how gravity arose from the impulse of this ether, nor how to account for the planetary revolutions in their respective orbits. His system is also defective, as it does not reconcile the circulation of the ether with the free motions of the comets in all directions, or with the obliquity of the planes of the planetary orbits, nor does he resolve other objections to which the hypothesis of the vortices and plenum is liable. Soon after the period just mentioned, the dispute commenced concerning the invention of the method of fluxions, which led Mr Leibnitz to take a very decided part in opposition to the philosophy of Newton. From the goodness and wisdom of the Deity, and his principle of a sufficient reason, he concluded, that the universe was a perfect work, or the best that could possibly have been made; and that other things, which are evil or incommodious, were permitted as necessary consequences of what was best: that the material system, considered as a perfect machine, can never fall into disorder or require to be set right; and to suppose that God interposes in it, is to lessen the skill of the author, and the perfection of his work. He expressly charges an impious tendency on the philosophy of Newton, because he asserts that the fabric of the universe and course of nature could not continue for ever in its present state, but in process of time would require to be re-established or renewed by the hand of its first framer. The perfection of the universe, in consequence of which it is capable of continuing for ever, by mechanical laws, in its present state, led Mr Leibnitz to distinguish between the quantity of motion and the force of bodies; and, whilst he owus, in opposition to Des Cartes, that the former varies, to maintain that the quantity of force is for ever the same in the universe; and to measure the forces of bodies by the squares of their velocities.

Leibnitz proposes two principles as the foundation of all our knowledge; the first, that it is impossible for a thing to be, and not to be at the same time, which, he says, is the foundation of speculative truth; and, secondly, that nothing is without a sufficient reason why it should be so, rather than otherwise; and by this principle, he says, we make a transition from abstracted truths to natural philosophy. Hence he concludes that the mind is naturally determined in its volitions and elections, by the greatest apparent good, and that it is impossible to make choice between things perfectly like, which he calls indiscernibles; from whence he infers, that two things perfectly like could not have been produced even by the Deity himself: and one reason why he rejects a vacuum, is because the parts of it must be supposed perfectly like to each other. For the same reason, too, he rejects atoms, and all similar parts of matter; to each of which, though divisible *ad infinitum*, he ascribes a *monad* (Act. Lipsic. 1698, p. 435) or active kind of principle, endued with perception. The essence of substance he places in action or activity, or, as he expresses it, in something that is between acting and the faculty of acting. He affirms that absolute rest is impossible, and holds that motion, or a sort of *nisus*, is essential to all material substances. Each monad he describes as representative of the whole universe from its point of sight; and yet he tells us in one of his letters, that matter is not a substance, but a *substantiatum* or *phénoméne bien fondé*.

Lemma, in mathematics, a previous proposition, laid down in order to clear the way for some following demonstration, and prefixed either to theorems in order to render their demonstration less perplexed and intricate, or to problems to make their resolution more easy and short.

Level, an instrument employed in ascertaining a horizontal line, of which there are various sorts; as the *Air Level*, which shows the line of level by means of a bubble of air inclosed with some fluid in a glass tube of an indeterminate length and thickness, and having its two ends hermetically sealed. When the bubble fixes itself at a certain mark, made exactly in the middle of the tube, the case or ruler in which it is fixed is then level. When it is not level the bubble will rise to one end. This glass tube may be set in another of brass, having an aperture in the middle, where the bubble of air may be observed. The liquor, with which the tube is filled, is oil of tartar, that not being so liable to freeze as common water, or so subject to rarefaction and condensation as spirit of wine. *Plumb Level*, shows the horizontal line by means of a line perpendicular to that described by a plummet or pendulum. This instrument consists of two legs or branches, joined together at right angles, whereof that which carries the thread and plummet is about a foot and a half long; the thread is hung towards the top of the branch. The middle of the branch where the thread passes is hollow, so that it may hang free every where: but towards the bottom, where there is a little blade of silver, whereon is drawn a line perpendicular to the telescope, the said cavity is covered by two pieces of brass, making, as it were, a kind of case, lest the wind should agitate the thread; for which reason the silver blade is covered with a glass, to the end that it may be seen when the thread and the plummet play upon the perpendicular. The telescope is fastened to the other branch of the instrument, and is about two feet long; having a hair placed horizontally across the focus of the object-glass, which determines the point of the level. The telescope must be fitted at right angles to the perpendicular. It has a ball and socket, by which it is fastened to the foot. *Water Level*, that which shows the horizontal line by means of a surface of water or any other fluid; founded on this principle, that water always places itself level or horizontal. The most simple kind is made of a long wooden trough or canal; which being equally filled with water, its surface shows the line of level. The water level is also made with two cups fitted to the two ends of a straight pipe, about an inch diameter, and three or four feet long, by means of which the water communicates from the one cup to the other; and this pipe being moveable on its stand, by means of a ball and socket, when the two cups show equally full of water, their two surfaces mark the line of level. This instrument, instead of cups, may also be made with two short cylinders of glass, three or four inches long, fastened to each extremity of the pipe with wax or mastic. The pipe is filled with common or coloured water, which shows itself through the cylinders, by means of which the line of level is determined; the height of the water, with respect to the centre of the earth, being always the same in both cylinders. This level, though very simple, is yet very commodious for levelling small distances.

Where works of moderate extent are carried on, and where the perfect level of each stratum of materials is not an object of importance, the common bricklayer's level, made thus, ⊥, having a plumb suspended from the top, and received in an opening at the junction of the perpendicular with the horizontal piece, will answer well enough. The principle on which this acts is, that as all weights have a tendency to gravitate towards the centre of the earth, so as the plumb-line is a true perpendicular, any line cutting that at right angles must be a horizontal line at the point of intersection.

Levelling, the finding a line parallel to the horizon at one or more stations, to determine the height or depth of one place with respect to another, for laying out grounds even, regulating descents, draining morasses, conducting water, &c.

Two or more places are on a true level when they are equally distant from the centre of the earth. Also one place is higher than another, or out of level with it, when it is farther from the centre of the earth; and a line equally distant from that centre in all its points, is called the line of true level. Hence, because the earth is round, a line must be a curve, and make a part of the earth's circumference, or at least be parallel to it, or concentrical with it.

The line of sight given by the operations of levels, is a tangent, or a right line perpendicular to the semi-diameter of the earth at the point of contact, rising always higher above the true line of level, the farther the distance is, is called the apparent line of level. The difference, it is evident, is always equal to the excess of the secant of the arch of distance above the radius of the earth.

The common methods of levelling are sufficient for laying pavements of walks, or for conveying water to small distances, &c.; but in more extensive operations, as in levelling the bottoms of canals, which are to convey water to the distance of many miles, and such like, the difference between the true and the apparent level must be taken into the account.

Now the difference between the true and apparent level, at any distance, may be found by a well-known property of the circle, to be equal to the square of the distance between the places, divided by the diameter of the earth; and consequently it is always proportional to the square of the distance.

Now the diameter of the earth being nearly 7958 miles, if we first take the distance = 1 mile, then the excess becomes 7·962 inches, or almost eight inches, the height of the apparent above the true level at the distance of one mile. Hence, proportioning the excesses in altitude according to the squares of the distances, the following table is obtained, showing the height of the apparent above the true level for every 100 yards of distance on the one hand, and for every mile on the other.

An easy rule to find the extent of the visible horizon is; the distance to which an object may be seen touching the horizon is proportional in leagues to the square root of the observer's height in fathoms, that is, if the heights be 1, 4, 9, 16, &c. fathoms the distances will be 1, 2, 3, 4, &c. leagues, or 3, 6, 9, 12, &c. miles; or multiply the height in feet by the constant number 1·5, and extract the square root of the product for the distance in miles. Thus if the height of the observer be 3262 feet, then $\sqrt{(3262 \times 1\cdot5)} = 69\cdot95$ miles = the distance to which an object can be seen on the horizon.

Distance.	Dif. of Level.	Distance.	Dif. of Level.	
Yards.	Inches.	Miles.	Ft.	In.
100	0·026	$\frac{1}{4}$	0	0$\frac{1}{2}$
200	0·103	$\frac{1}{2}$	0	2
300	0·231	$\frac{3}{4}$	0	4$\frac{1}{2}$
400	0·411	1	0	8
500	0·643	2	2	8
600	0·925	3	6	0
700	1·200	4	10	7
800	1·645	5	16	7
900	2·081	6	23	11
1000	2·570	7	32	6
1100	3·110	8	42	6
1200	3·701	9	53	9
1300	4·344	10	66	4
1400	5·038	11	80	3
1500	5·784	12	95	7
1600	6·580	13	112	2
1700	7·425	14	130	1

By means of this table of reductions, we can now level to almost any distance at one operation, which the ancients could not do but by a great multitude; for, being unacquainted with the correction answering to any distance, they only levelled from one twenty yards to another, when they had occasion to continue the work to some considerable extent.

This table will answer several useful purposes. Thus, first, to find the height of the apparent level above the true, at any distance. If the given distance is in the table, the correction of level is found on the same line with it. Secondly, To find the extent of the visible horizon, or how far can be seen from any given height, on an horizontal plane, as at sea, &c. Suppose the eye of an observer, on the top of a ship's mast at sea, is at the height of 130 feet above the water, he will then see about 14 miles all around. Or from the top of a cliff by the sea-side, the height of which is 66 feet, a person may see to the distance of near 10 miles on the surface of the sea. Also, when the top of a hill or the light in a light-house, or such like, whose height is 130 feet, first comes into the view of an eye on board a ship, the table shows that the distance of the ship from it is 14 miles, if the eye is at the surface of the water; but if the height of the eye in the ship is 80 feet, then the distance will be increased by near 11 miles, making, in all, about 25 miles in distance. Thirdly, Suppose a spring to be on one side of a hill, and the house on an opposite hill, with a valley between them, and that the spring seen from the house appears by a levelling instrument to be on a level with the foundation of the house, which suppose is at a mile distance from it, then is the spring eight inches above the true level of the house; and this difference would be barely sufficient for the water to be brought in pipes from the spring to the house, the pipes being laid all the way in the ground. Fourthly, If the height or distance exceed the limits of the table, then, first, if the distance be given, divide it by 2, or by 3, or by

4, &c. till the quotient come within the distances in the table; then take out the height answering to the quotient, and multiply it by the square of the divisor, that is, by 4, or 9, or 16, &c. for the height required.

Lever. A lever is an inflexible rod, moveable about a centre of motion, or fulcrum, and having forces applied to two or more points in it. There are three kinds or orders of levers. A lever of the first order has the fulcrum C between the weight W and the power P. A lever of the second order has the weight between the power and the fulcrum. A lever of the third order has the power between the weight and the fulcrum.

When the power and weight keep the lever in equilibrio, they are to each other reciprocally as the distances of their lines of direction from the fulcrum. That is, P : W : : C D : C E (fig. 1); where C D and C E are perpendicular to W O and A O, the directions of the two weights, or the power A and weight W; or what is the same thing, each force is reciprocally proportional to the distance of its direction from the fulcrum. When the two forces act perpendicularly on the lever, as two weights, then, in case of an equilibrium, D coincides with W, and E with P; therefore the above proportion becomes

$$P : W : : C W : C A;$$

and since the product of the extremes is equal to the product of the means, $P \times C E = W \times C D$; or if the forces act perpendicularly on the lever, we have this theorem, $P \times C A = W \times C W$. Also should any force P act at A in the direction A E, its effect on the lever to turn it about the centre of motion C, is as the length of the lever AC, and the sine of the angle of direction C A E.

Fig. 1.

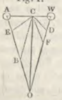
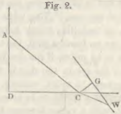


Fig. 2.



In the bended lever A C W, we have $P \times A C \times \text{sine } C A D = W \times C W \times \text{sine } C W G$. (Fig. 2.)

Also in a straight lever of the first order, $P \times A C = W \times C W$, and the pressure on the fulcrum is $P + W$. (Fig. 3.) In a straight lever of the second order $P \times A C = W \times C W$; but the pressure on the fulcrum is, in this case, $W - P$. (Fig. 4.) In a straight lever of the third order, $P \times A C = W \times C W$, and the pressure on the fulcrum is P + W. (Fig. 5.) If a straight lever be kept in equilibrio, by several weights, P, Q, R, S, T, acting perpendicularly, (Fig. 6,) then,

$$P \times AC + Q \times BC + R \times DC = S \times EC + T \times FC.$$

Therefore, (Fig. 7),

$$P + W : P :: AW : CW.$$

$$\text{and } P + W : W :: AW : AC.$$

$$\therefore\ CW = \frac{P \times AW}{P + W} \text{ and } AC = \frac{W \times AW}{P + W}$$

which theorems are useful in finding the fulcrum, when the power and weight are both given, together with the whole length of the lever.

Fig. 3.

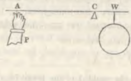


Fig. 4.

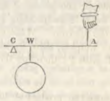


Fig. 5.

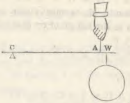


Fig. 6.

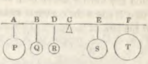


Fig. 7.

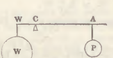
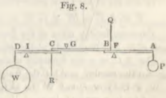


Fig. 8.



In the compound lever, or where several levers act perpendicularly upon one another, as A B, B C, C D (Fig. 8), the fulcrums of which are F, G, I; then $P : W :: BF \times CG \times DI : AF \times BG \times IC$, and the pressure on the fulcrum $F = P + Q = \frac{P \times A\,B}{B\,F}$: the pressure on the fulcrum $G = Q + R = \frac{P \times A\,F}{B\,F} + \frac{W \times I\,D}{C\,I}$ and upon $I = R + W = W + \frac{W \times I\,D}{C\,I} = \frac{W \times C\,D}{C\,I}$.

The following rule holds, whether the lever be of the first, second, or third order.

Multiply the power by its distance from the fulcrum, and this product will be equal to the weight multiplied by its distance from the fulcrum, the weight of the lever not being considered: when if the weight upon each end of the lever is given, then the sum of the weights, is to either of the weights, as the sum of the distances, or whole length of the lever, is to the distance of the other from the fulcrum.

The Balance is a lever of the first kind with equal arms. See *Balance*. The steelyard is also a lever of the first order. See *Steelyard*.

If we take the weight of the lever into account, we must consider its whole weight to act at its centre of gravity; and if the lever be in the form of a cylinder, prism, or an uniform bar of any kind, its centre of gravity will be in its middle point.

We will show afterwards how to take the weight of the lever into consideration, when the centre of gravity is not in the middle point of the lever.

In a lever of the first order, we may consider the weight of each arm of the lever as a new power acting at its centre of gravity, therefore, (see Fig. 3)

$P \times A\,C$ + weight of $A\,C \times \frac{1}{2} A\,C = W \times C\,W$ + weight of $C\,W \times \frac{1}{2} C\,W$.

In a lever of the second kind, we have,

$P \times A\,C = W \times C\,W$ + weight of $A\,C \times \frac{1}{2} A\,C$. (Fig. 4.)

In a lever of the third order (Fig. 5),

$P \times A\,C = W \times C\,W$ + weight of $C\,W \times \frac{1}{2} C\,W$.

Formulæ for the lever of the first order, when the power acts at one end of it, and the weight at the other.

Put $A\,C = a$ the diameter of the power from the fulcrum, and $C\,W = b$, the fulcrum, and let the weight of one inch in length of the lever $= c$, P the power, and W the weight.

$$P = \frac{W\,b + \frac{1}{2}\,b^2c - \frac{1}{2}\,a^2c}{a} \quad (1)$$

$$W = \frac{P\,a + \frac{1}{2}\,a^2c - \frac{1}{2}\,b^2c}{b}. \quad (2)$$

$$a = \frac{1}{c}\sqrt{(P^2 + 2\,W\,b\,c + b^2\,c^2)} - \frac{P}{c}. \qquad (3)$$

$$b = \frac{1}{c}\sqrt{(W^2 + 2\,P\,a\,c + a^2\,c^2)} - \frac{W}{c}. \qquad (4)$$

$$c = \frac{2\,P\,a \backsim 2\,W\,b}{b^2 \backsim a^2}. \qquad (5)^*$$

When W = O, or when there is no weight, we have,

$$a = \sqrt{\left(b^2 + \frac{P^2}{c^2}\right)} - \frac{P}{c}. \qquad (6)$$

And when P = O, or there is no power, we have,

$$a = \sqrt{\left(b^2 + \frac{2\,W\,b}{c}\right)}. \qquad (7)$$

Where the power acts at some intermediate point between A and C, and the weight acts also at some intermediate point between W and C.

$$P = \frac{W\,r + \frac{1}{2}\,b^2 c - \frac{1}{2}\,a^2 c}{d}. \qquad (8)$$

$$W = \frac{P\,d + \frac{1}{2}\,a^2 c - \frac{1}{2}\,b^2 c}{r}. \qquad (9)$$

$$d = \frac{2\,W\,r + b^2 c - a^2 c}{2\,P}. \qquad (10)$$

$$r = \frac{2\,P\,d + a^2 c - b^2 c}{2\,W}. \qquad (11)$$

When the power acts at one end of the lever, and the weight at the other, and the power is required. Suppose a case where W = 100 lbs. $a = 60$ inches, $b = 36$, and $c = \frac{4}{96} = \frac{1}{24}$ lbs.; therefore, then by (1) we have,

$$P = \frac{100 \times 36 + \frac{1}{2} \times 36^2 \times \frac{1}{24} - \frac{1}{2} \times 60^2 \times \frac{1}{24}}{60} = 59.2 \text{ lbs.}$$

Take now a case where the power is applied at a given point D between A and C, and the weight at a given point E between W and C; then for the power P we must take formula (8.) Suppose W = 3 cwt. = 336 lbs. $a = 8$ feet, $b = 6$ feet, $c = \frac{42}{14} = 3$ lbs. weight of one foot of the lever, $d = 5$ feet, and $r = 2$ feet; substitute those values in the above, and

---

* It is more simple to divide the whole weight of the lever by the whole length, and the quotient will give the weight of one inch or one foot in length, according as you take the length in inches or in feet.

$p = \frac{336 \times 2 + \frac{1}{2} \times 6^2 \times 3 - \frac{1}{2} 8^2 \times 3}{5} = \frac{672 + 54 - 96}{5} =$ 126 lbs.

Let A W C be a lever of the second order, and C its fulcrum; the power multiplied by its distance from the fulcrum, is equal to the weight multiplied by its distance from the fulcrum, together with the whole weight of the lever multiplied by half its length; the lever being considered uniform throughout its length.

Given the whole weight of the lever 9 lbs. its length A C = 6 feet, a weight of 100 lbs. is put on at 1½ feet from the fulcrum; it is required to determine the power acting at A which will keep the lever in equilibrio. (See Fig. 4.)

Now 100 lbs. × 1½ feet = 150 = the weight multiplied by its distance. $9 \times 3 = 27$ = the weight of the lever multiplied by half its length. Hence $\frac{150 + 27}{6} = 29\frac{1}{2}$ lbs. is the weight or power acting at A which will keep the whole in equilibrio.

Or thus, 6 : 100 : : 4½ : 75, the weight upon the fulcrum from the action of the weight. 6 : 100 : : 1½ : 25, the power at A which will just support the weight. And the lever being uniform, its whole weight must be considered as acting at the middle of A F; therefore the fulcrum will bear one half of its weight, and the power must support the other. Consequently 75 + 4½ = 79½ lbs. weight upon the fulcrum. And 25 + 4½ = 29½ lbs. the power necessary to keep the whole in equilibrio, which is exactly the same as before.

Again, a beam, the weight of which is 12 lbs. and its length 18 feet, is supported at both ends; a weight of 36 lbs. is suspended at 3 feet from one end, and a weight of 24 lbs. at 8 feet from the other end; required the pressure on each prop or support.

Then, 18 : 36 : : 15 : 30 lbs. the pressure on the support C by the action of the 36 lbs. weight. 18 : 24 : : 8 : 10⅔ lbs. the pressure on the support C from the action of the 24 lbs. weight. 30 + 10⅔ = 40⅔ lbs. pressure on the support C from both weights. Also 18 : 36 : : 3 : 6 lbs. pressure on the support A from the action of the 36 lbs. weight. 18 : 24 : : 10 : 13⅓ lbs. pressure on the support A from tho 24 lbs. weight. 6 + 13⅓ = 19⅓ lbs. the whole pressure on the support A from both weights; half the weight of the lever added to each of the above sums will give the whole pressure on each support: thus, 40⅔ + 6 = 46⅔ lbs. whole pressure on the support C; and 19⅓ + 6 = 25⅓ lbs. the whole pressure on the support A.

Given the whole length of the lever A C = 10 feet (Fig. 4), its weight 15 lbs. a weight of 50 lbs. is suspended at 2 feet from the fulcrum or end C; what power, acting at 3 feet from the other end A, will keep the whole in equilibrio?

Since $10 - 3 = 7$ feet, the distance of the power from the fulcrum C; therefore $7 : 50 :: 2 : 14\frac{2}{7}$ lbs. the power necessary to balance the weight alone; and since the centre of gravity of the lever is 2 feet from the power, and 5 feet from the fulcrum, we have $7 : 15 :: 5 : 10\frac{5}{7}$ lbs. the power necessary to sustain the lever. And $14\frac{2}{7} + 10\frac{5}{7} = 25$ lbs. the power required to sustain both weight and lever. And to find the weight sustained by the fulcrum,

$7 : 50 :: 5 : 35\frac{5}{7}$ lbs. from the action of the weight.

Also $7 : 15 :: 2 : 4\frac{2}{7}$ lbs. from the action of the lever.

Hence $35\frac{5}{7} + 4\frac{2}{7} = 40$ lbs. the whole pressure on the fulcrum or end C.

Formulæ for the lever of the second order.

$$P = \frac{W\,b}{a} + \frac{a\,c}{2}. \qquad (1)$$

$$W = \frac{P\,a - \frac{1}{2}a^2 c}{b}. \qquad (2)$$

$$a = \frac{1}{c}\left(P \pm \sqrt{(P^2 - 2\,W\,b\,c)} \right). \qquad (3)$$

$$b = \frac{P\,a - \frac{1}{2}a^2 c}{W}. \qquad (4)$$

$$c = \frac{2\,P\,a - 2\,W\,b}{a^2}. \qquad (5)$$

When $W = 0$, or the power just sustains the lever, we have $P = \frac{1}{2}\,a\,c$, and $a = \frac{2\,P}{c}$. (6)

Formulæ for the lever of the third order.

$$P = \frac{W\,b + \frac{1}{2}b^2 c}{a}. \qquad (1)$$

$$W = \frac{P\,a}{b} - \frac{b\,c}{2}. \qquad (2)$$

$$c = \frac{2\,P\,a - 2\,W\,b}{b^2}. \qquad (3)$$

$$b = \frac{1}{c}\sqrt{(W^2 + 2\,P\,a\,c)} - \frac{W}{c}. \qquad (4)$$

$$a = \frac{W\,b + \frac{1}{2}b^2 c}{P}. \qquad (5)$$

When $W = O$, or the power just sustains the lever, we have $\frac{P\,a}{b} - \frac{b\,c}{2} = O$, hence $a = \frac{b^2 c}{2\,P}$ (6)

$$b = \sqrt{\frac{2\,P\,a}{c}}. \qquad (7)$$

When the weight does not act at the end: let $r =$ the distance of the weight from the fulcrum, the rest remaining the same as in the notation of the above formulæ.

Then $P\,a = W\,r + \frac{1}{2}\,b^2 c.$

$$P = \frac{W\,r + \frac{1}{2}\,b^2 c}{a}. \qquad (8)$$

$$W = \frac{P\,a - \frac{1}{2}\,b^2 c}{r}. \qquad (9)$$

$$r = \frac{P\,a - \frac{1}{2}\,b^2 c}{W}. \qquad (10)$$

The above theorems and examples are taken, with some alterations, from a very excellent work, before alluded to, Hann's and Dodd's Mechanics. Many more examples are given in that work, but the attentive reader will have no difficulty in applying the formulæ to other cases from the specimens we have laid before him.

Line, in geometry, is that which has length without thickness. Lines are either right or curved. A *Right* or *Straight Line* is that which lies all in the same direction between its extremes or ends. A *Curve Line*, is that which continually changes its direction. Curve lines are again divided into algebraical, geometrical, and mechanical, or transcendental.

Locomotive Engine. See *Railways*.

Logarithms are artificial numbers, used to facilitate or abridge arithmetical calculations, and may be considered as expressing the relation between an arithmetical and geometrical series of terms, or between ratios and the measures of ratios, and are, in short, the indices or exponents of a series of numbers in geometrical progression. The origin and nature of them may be easily explained.

In an arithmetical series the quantities increase or decrease by the same difference, but in a geometrical series they increase or diminish by a common measure. The first of the following lines exhibits an arithmetical progression, all the other lines are examples of geometrical progression:

1—0, 1, 2, 3, 4, 5, 6, 7, 8, 9.
2—1, 2, 4, 8, 16, 32, 64, 128, 256, 512.
3—1, 3, 9, 27, 81, 243, 729, 2187, 6561, 19683.
4—1, 10, 100, 1000, 10000, &c. &c.

Here, considering the upper line as the index to all the rest, every term of it is the *logarithm* of a corresponding term in each of them; and it is evident, that an infinitude of other lines, or any one of the same lines, varying the point of commencement, and containing numbers in geometrical progression, might be added, to all of which the same arithmetical series might furnish logarithms. But any other series of numbers in arithmetical progression, for example, one increasing or diminishing by the common difference of two, three, four, &c. might be used for an index to a geometrical series. Hence, then, there may be various systems of logarithms, any one of which may be contrived so as to abridge calculation. It has been found most convenient to adopt that system which takes the natural series of numbers for the indices of the terms in the geometric series, 10, 100, 1000, &c. increasing in a tenfold progression, as in the fourth line.

Now, in every multiplication by a whole number, the ratio which the product bears to the multiplicand is the same as that of the multiplier to unity; and, consequently, the ratio of the product to unity must be equal to the sum of the ratios of the multiplier to unity, and the multiplicand to unity. Obviously, then, the addition of the ratios of the multiplicand to unity, and the multiplier to unity, corresponds with the multiplication of the two quantities; and, hence, adding together the representatives of such ratios, we obtain the representatives or indices of the ratios of the products to unity; and, accordingly, if we have a table containing the natural numbers with which such representatives correspond, we shall there find the product of the multiplicand and multiplier, the ratio of which was indicated. In other words, the addition of the terms of the arithmetical series corresponds to the multiplication of the terms of the geometrical series; and thus, the arithmeticals may be considered as presenting a set of artificial numbers, which, when arranged in tables, will convert operose multiplication into simple addition; and, on the same principle, the labour of division may, by means of such table, be performed by subtraction.

But we may also consider logarithms as the indices of those powers of numbers which are equal to any given numbers. This is easily explained. All affirmative numbers may be regarded as the powers of any one given affirmative number. For example, the powers of 2 may become equal, or approach within less than any assignable difference to all other numbers whatever. Now, in those nnmbers which are expressed by integers, as 2^0, 2^1, 2^2, 2^3, &c. we have the geometrical progression 1, 2, 4, 8, 16, &c., and the intermediate numbers of this series, viz. 3, 5, 6, 7, &c. are expressed, very nearly, by powers of two with fractional exponents. Thus, $3 = 2^{1\cdot53496}$ nearly : $5 = 2^{2\cdot3219}$: $6 = 2^{2\cdot58496}$. The powers of 10 might be used, in the same manner, to express all numbers, as $10^0 = 1$, $10^{\cdot 30103} = 2$, $10^{\cdot 47712} = 3$, and thus also might fractions be expressed, as $10^{-1} = \frac{1}{10}$, $10^{-\cdot 30103} = \frac{1}{2}$, &c. where the negative powers of 10 are employed. In short, any number whatever, whether integer or fractional, might be taken in place of 2 or 10, and such exponents of it found as would give its powers equal to all numbers from 0 upwards; and there are, accordingly, no limits or conditions as to the magnitude of the number, the powers of which are to represent all numbers, save that it must be neither equal to unity nor negative, and that for very obvious reasons—for, in the first case, that is, if it be 1. all its powers would be $= 1$, and, in the second, that is, if negative, there will be numbers to which none of its powers can possibly be equal. Now, suppose $N = r^n$, r representing any number whatever, according to the system of logarithms adopted, then the logarithm of N is n, which may be either positive or negative. When N is 1, then $n = o$, whatever may be the value of r; and accordingly the logarithm of 1 is 0 in every system of logarithms. In the commonly adopted system, $r = 10$, so that the logarithm of any number is the index of that power of 10 which is equal to the said number. Accordingly, 100 or 10^2, that is the second power of 10 has 2 for its logarithms and 1000, that is 10^3, or the third power of 10, has 3 for its logarithm: or, as in this series,

	10^3,	10^2,	10^1,	10^0,	10^{-1},	10^{-2},	10^{-3},
that is, . . .	1000,	100,	10,	1,	·1,	·01,	·001,
we have respectively for the logarithms	3,	2,	1,	0,	-1,	-2	-3

Now the logarithm of any number that is intermediate between any two terms in the first series, is included between the corresponding terms of the last series, and consequently will have the same index, whether positive or negative, as the less of the terms, together with a decimal fraction, which is always positive. For instance, 50 falls between 10 and 100; its logarithm therefore falls between 2 and 1, and has 1 for its index, or characteristic, as it is sometimes called, and a decimal fraction, that is together 1·69897. Thus, then, 0, 1, 2, 3, 4, &c. are the logarithms of 1, 10, 100, 1000, 10000, &c. in a system of logarithms having 10 for its base, that is, the number the powers of which, as marked by exponents, are used to indicate the logarithms of other numbers. The index, or characteristic of a logarithm, is always either $= 0$, or an integer, positive or negative, and points out the place that is occupied by the first significant figure of the given number, either above or below that of units, being positive in the former case, and negative in the latter. When negative, the sign — is usually set over the characteristic to distinguish it from the decimal part, which, as already mentioned, is always positive. But the whole expression may be converted into a negative form by making the characteristic figure less by 1, and taking the arithmetical complement of the decimal, namely, commencing at the left hand, and subtracting each figure from 9, except the last significant figure, which is to be subtracted from 10, the remainder constituting the required logarithm in an entirely negative form. Thus, the logarithm ·05, that is, 2·69897, or — 2 + ·69897, may also be expressed by — 1·30103, which is entirely negative. On the other hand, such logarithms are sometimes conveniently expressed altogether in a positive form, by joining to the tabular decimal the complement of the index to 10, as in the above case, 8·69897.

A system of logarithms, then, may be considered as the numbers arising in and expressed by the indices or exponents of a power according to every value that may be given to that power, while the base of the system, which is the same as the base of the power, may be any constant number greater than unity. The number 10, as already remarked, is the number chosen for the base in the system of logarithms now generally adopted, which is that of Henry Briggs; whereas the radical number in the system originally proposed by the celebrated Napier, the inventor of logarithms, is 2·7182818, &c. But however systems of logarithms may differ in this respect, the logarithms of the same number are always in a constant ratio to one another. Of the methods of constructing logarithms we need not speak particularly, as we merely concern ourselves with the general principles of numbers. The following table, which gives the logarithms of numbers from 1 to 120, will afford some idea of the nature of them, and serve all the purposes we have at present in view.

No.	Logar.	No.	Logar.	No.	Logar.	No.	Logar.
1	0,0000000	31	1,4913617	61	1,7853298	91	1,9590414
2	0,3010300	32	1,5051500	62	1.7923917	92	1,9637878
3	0,4771213	33	1,5185139	63	1,7993405	93	1,9684829
4	0,6020600	34	1,5314789	64	1,8061800	94	1.9731279
5	0,6989700	35	1,5440680	65	1,8129134	95	1,9777236
6	0,7781513	36	1,5563025	66	1,8195439	96	1,9822712
7	0,8450980	37	1,5682017	67	1,8260748	97	1,9867717
8	0,9030900	38	1,5797836	68	1,8325089	98	1,9912261
9	0,9542425	39	1,5910646	69	1,8388491	99	1,9956352
10	1,0000000	40	1,6020600	70	1,8450980	100	2,0000000
11	1.0413927	41	1.6127839	71	1,8512583	101	2,0043214
12	1,0791812	42	1.6232493	72	1.8573325	102	2,0086002
13	1,1139434	43	1,6334685	73	1,8633229	103	2,0128572
14	1,1461280	44	1,6434527	74	1 8692317	104	2.0170333
15	1,1760913	45	1,6532125	75	1,8750613	105	2,0211893
16	1,2041200	46	1,6627578	76	1,8808136	106	2,0253059
17	1,2301489	47	1,6720979	77	1,8864907	107	2,0293838
18	1,2552725	48	1,6812412	78	1,8920946	108	2,0334238
19	1,2787536	49	1,6901961	79	1,8976271	109	2,0374265
20	1,3010300	50	1,6989700	80	1,9030900	110	2,0413927
21	1,3222193	51	1,7075702	81	1,9084850	111	2.0453230
22	1,3424227	52	1,7160033	82	1,9138139	112	2,0492180
23	1,3617278	53	1,7242759	83	1,9190781	113	2.0530784
24	1,3802112	54	1,7323938	84	1,9242793	114	2,0569049
25	1,3979400	55	1,7403627	85	1,9294189	115	2,0606978
26	1,4149733	56	1,7481880	86	1,9344985	116	2,0644580
27	1,4313638	57	1,7558749	87	1,9395193	117	2,0681859
28	1,4471580	58	1,7634280	88	1,9444827	118	2 0718820
29	1,4623980	59	1,7708520	89	1,9493900	119	2,0755470
30	1,4771213	60	1,7781513	90	1,9542425	120	2,0791812

The chief properties of logarithms are these: 1. The sum of the logarithms of two numbers is equal to the logarithm of their produce. 2. The difference of the logarithms of two numbers is equal to the logarithms of their quotient. 3. The logarithm of the power of any number is equal to the logarithm of the number taken as often as is denoted by that power; *e. g.* the log. $b^n = n$ log. b. On the same principle it can be shown, that the logarithm of any root of a number is equal to the logarithm of that number divided by the index of the roots.

All logarithms are derived from the equation of the hyperbola, but one system has been peculiarly denominated hyperbolic logarithms, i. e. those first laid down by lord Napier, the inventor. These latter species are very frequently used in calculations connected with the steam engine, and we therefore present a table below.

HYPERBOLIC LOGARITHMS.

No.	Logar.	No.	Logar.	No.	Logar.	No.	Logar.	No.	Logar.
1¼	·2231435	7½	2·0149030	29	3·3672958	53	3·9702919	77	4·3438054
1½	·4054651	7¾	2·0476928	30	3·4011973	54	3·9889840	78	4·3567088
1¾	·5596157	8	2·0794415	31	3·4339872	55	4·0073331	79	4·3694478
2	·6931472	8½	2·1400661	32	3·4657359	56	4·0253516	80	4·3820266
2¼	·8109302	9	2·1972245	33	3·4965075	57	4·0430512	81	4·3944491
2½	·9162907	9½	2·2512919	34	3·5263605	58	4·0604430	82	4·4067192
2¾	1·0116008	10	2·3025851	35	3·5553480	59	4·0775374	83	4·4188406
3	1·0986123	11	2·3978952	36	3·5835189	60	4·0943445	84	4·4308168
3¼	1·1786549	12	2·4849066	37	3·6109179	61	4·1108738	85	4·4426512
3½	1·2527629	13	2·5649493	38	3·6375861	62	4·1271343	86	4·4543473
3¾	1·3217558	14	2·6390573	39	3·6635616	63	4·1431347	87	4·4659081
4	1·3862943	15	2·7080502	40	3·6888794	64	4 1588830	88	4·4773368
4¼	1·4469189	16	2·7725887	41	3·7135720	65	4·1743872	89	4·4886363
4½	1·5050774	17	2·8332133	42	3·7376696	66	4·1896547	90	4·4998096
4¾	1·5581446	18	2·8903717	43	3·7612001	67	4·2046926	91	4·5108595
5	1·6094379	19	2·9444389	44	3·7841896	68	4·2195077	92	4·5217885
5¼	1·6582280	20	2·9957322	45	3·8066624	69	4·2341065	93	4·5325994
5½	1·7047481	21	3·0445224	46	3·8286414	70	4·2484952	94	4·5432947
5¾	1·7491998	22	3·0910424	47	3·8501476	71	4·2626798	95	4·5538768
6	1·7917594	23	3·2354942	48	3·8712010	72	4·2766661	96	4·5643481
6¼	1·8325814	24	3·1780538	49	3·8918203	73	4·2904594	97	4·5747109
6½	1·8718021	25	3·2188758	50	3·9120230	74	4·3040650	98	4·5849674
6¾	1·9095425	26	3·2580965	51	3·9318256	75	4·3174881	99	4·5951198
7	1·9459101	27	3·2958368	52	3·9512437	76	4·3307333	100	4·6051701
7¼	1·9810014	28	3·3322045						

Lune, Lunula, in geometry, is the space included between the arcs of two unequal circles, forming a sort of crescent or half-moon; the area of which may, in many cases, be as accurately determined as that of any rectilinear figure. On the diameter of a semicircle describe a right-angled triangle, of which the angular point will necessarily fall in the circumference. Then on each of the sides describe a semicircle; the two figures contained between them and the first semicircle will be lunes; and the area of them will be equal to the area of the right-angled triangle. For the semicircles, when the two sides are equal to that upon the diameter; and if the segments between the sides and the lunes which are common to both be taken away, the remaining lines will be equal to the remaining triangle.

M

MACHINE, any thing that is used to augment or to regulate moving forces or powers; or it is any instrument employed to regulate motion so as to save either time or force.

Machines are classed under different denominations, according to the agents by which they are put in motion, the purposes they are intended to effect, or the art in which they are employed; as Electric, Hydraulic, Pneumatic, Military, Architectural, &c.

Maximum effect of machines is the greatest effect which can be produced by them. In all machines that work with a uniform motion, there is a certain velocity, and a certain load of resistance, that yields the greatest effect, and which are therefore more advantageous than any other. A machine may be so heavily charged, that the motion resulting from the application of any given power will be but just sufficient to overcome it, and if any motion ensue it will be very trifling, and therefore the whole effect very small. And if the machine is very lightly loaded, it may give great velocity to the load; but from the smallness of its quantity the effect may still be very inconsiderable, consequently between these two loads there must be some intermediate one that will render the effect the greatest possible. This is equally true in the application of animal strength as in machines.

1. The maximum effect of a machine is produced when the weight or resistance to be overcome is just $\frac{4}{9}$ of that which the power when fully exerted is just able to balance, or of that resistance which is necessary to reduce the machine to rest; and the velocity of the part of the machine to which the power is applied should be one-third of the greatest velocity of the power.

2. The moving power and the resistance being both given; if the machine be so constructed that the velocity of the point to which the power is applied be to the velocity of the point to which the resistance is applied, as nine times the resistance to four times the power, the machine will work to the greatest possible advantage.

3. This is equally true when applied to the strength of animals; that is, a man, horse, or other animal will do the greatest quantity of work, by continued labour, when his strength is opposed to a resistance equal to $\frac{4}{9}$ of his natural strength, and his velocity equal to $\frac{1}{3}$ of his greatest velocity when not impeded.

Now, according to the best observations, the force of a man at rest is on an average about 70 lbs.; and his greatest velocity, when not impeded, is about 6 feet per second, taken at a medium. Hence the greatest effect will be produced when the resistance is equal to about $31\frac{1}{9}$ lbs. and his uniform motion 2 feet per second.

The strength of a horse at a dead pull is generally estimated at about 420 lbs. and his greatest rate of walking 10 feet per second; therefore the greatest effect is produced when the load $= 186\frac{2}{3}$ lbs. and the velocity $\frac{10}{3}$, or $3\frac{1}{3}$ feet per second.

4. A machine driven by the impulse of a stream, produces the greatest effect when the wheel moves with one-third of the velocity of the water.

The following may be taken as a general arrangement of machines.

CLASS I.

Machines for overcoming inertia.

Machines for raising weights.
Machines for transporting weights on land.
Machines for raising water.
Blowing machines.
Machinery for ascending and descending in fluids.
Machines for navigation.

CLASS II.

Machines for overcoming cohesion.

Ploughs.
Drilling machines.
Reaping machines.
Thrashing machines.
Mills.
Block machinery.
Boring machines.
Machinery used in button-making.
Card wire machine.
Chaff-cutting machines.
Machines for cleaning, or removing impurities.
Machines for cleaning cotton.
Grinding machines.
Machines for turning.
Machines which act by compression.
Drilling machine.
Pile engines.

CLASS III.

Machines for combining materials.

Machines for weaving cloths, carpets, nets, stockings.
Machine for combining materials in brewing.

CLASS IV.

Machines for measuring forces.

Anemometers.
Torsion machines.
Balances and steelyards.
Barometers.
Thermometers.
Hygrometers.
Machines for measuring the elasticity and strength of materials.
Dynamometers for measuring the force of men, animals, and other agents.
Ballistic pendulum for measuring the force of projectiles.
Machines for measuring the force of running water.

CLASS V.

Machines for measuring and dividing space.

Quadrants.
Circles.
Theodolites.
Levels.
Micrometers.
Goniometers.
Dividing machines.
Odometers.
Drawing and copying instruments.
Craniometers.

CLASS VI.

Machines for measuring time.

MACHINERY. [We take the liberty of extracting this article from the Popular Encyclopedia; a work alike remarkable for the clearness and comprehensiveness with which its subjects are treated.] The utility of machinery, in its application to manufactures, consists in the addition which it makes to human power, the economy of human time, and in the conversion of substances apparently worthless into valuable products. The forces derived from wind, from water, and from steam, are so many additions to human power, and the total inanimate force thus obtained in Great Britain (including the commercial and manufacturing) has been calculated, by Dupin, to be equivalent to that of 20,000,000 labourers. Experiments have shown that the force necessary to move a stone on the smoothed floor of its quarry is nearly two-thirds of its weight; on a wooden floor, three-fifths; if soaped, one-sixth; upon rollers on the quarry floor, one thirty-second; on wood, one fortieth. At each increase of knowledge, and on the contrivance of every new tool, human labour is abridged: the man who contrived rollers quintupled his power over brute matter. The next use of machinery is the economy of time, and this is too apparent to require illustration, and may result either from the increase of force, or from the improvement in the contrivance of tools, or from both united. Instances of the production of valuable substances from worthless materials are constantly occurring in all the arts; and though this may appear to be merely the consequence of scientific knowledge, yet it is evident that science cannot exist, nor could its lessons be made productive by application, without machinery. In the history of every science, we find the improvements of its machinery, the invention of instruments, to constitute an important part. The chemist, the astronomer, the physician, the husbandman, the painter, the sculptor, is such only by the application of machinery. Applied science in all its forms, and the fine and useful arts, are the triumphs of mind, indeed, but gained through the instrumentality of machinery. The difference between a tool and a machine is not capable of very precise distinction, nor is it necessary, in a popular examination of them, to make any distinction. A tool is usually a more simple machine, and generally used by the hand; a machine is a complex tool, a collection of tools, and frequently put in action by inanimate force. All machines are intended either to produce power, or merely to transmit power and execute power. Of the class of mechanical agents by which motion is transmitted,—the lever, the pulley, the wedge,—it has been demonstrated that no power is gained by their use, however combined. Whatever force is applied at one part, can only be exerted at some other, diminished by friction and other incidental causes; and whatever is gained in the rapidity of execution, is compensated by the necessity of exerting additional force. These two principles should be constantly borne in mind, and teach us to limit our attempts to things which are possible.

1. *Accumulating power*. When the work to be done requires more force for its execution than can be generated in the time necessary for its completion, recourse must be had to some mechanical method of preserving and condensing a part of the power exerted previously to the commencement of the process. This is most frequently accomplished by a fly-wheel, which is a wheel having a heavy rim, so that the greater part of the weight is near the circumference. It requires great power, applied for some time, to set this in rapid motion, and when moving with considerable velocity, if its force is concentrated on a point, its effects are exceedingly powerful. Another method of accumulating power consists in raising a weight and then allowing it to fall. A man

with a heavy hammer, may strike repeated blows on the head of a pile without any effect; but a heavy weight, raised by machinery to a greater height, though the blow is less frequently repeated, produces the desired effect.

2. *Regulating power*. Uniformity and steadiness in the motion of the machinery are essential both to its success and its duration. The governor, in the steam-engine, is a contrivance for this purpose. A vane or fly of little weight, but large surface, is also used. It revolves rapidly, and soon acquires a uniform rate, which it cannot much exceed; because any addition to its velocity produces a greater addition to the resistance of the air. This kind of fly is generally used in small pieces of mechanism, and, unlike the heavy fly, it serves to destroy, instead of to preserve, force.

3. *Increase of Velocity*. Operations requiring a trifling exertion of force may become fatiguing by the rapidity of motion necessary, or a degree of rapidity may be desirable beyond the power of muscular action. Whenever the work itself is light, it becomes necessary to increase the velocity in order to economize time. Thus twisting the fibres of wool by the fingers would be a most tedious operation. In the common spinning-wheel, the velocity of the foot is moderate, but, by a simple contrivance, that of the thread is most rapid. A band, passing round a large wheel, and then round a small spindle, effects this change. This contrivance is a common one in machinery.

4. *Diminution of Velocity*. This is commonly required for the purpose of overcoming great resistances with small power. Systems of pulleys afford an example of this: in the smoke jack, a greater velocity is produced than is required, and it is therefore moderated by transmission through a number of wheels.

5. *Spreading the Action of a Force exerted for a few minutes over a large time*. This is one of the most common and useful employments of machinery. The half minute which we spend daily in winding up our watches is an exertion of force which, by the aid of a few wheels, is spread over twenty-four hours. A great number of automata, moved by springs, may be classed under this division.

6. *Saving time in natural operations*. The process of tanning consists in combining the tanning principle with every particle of the skin, which, by the ordinary process of soaking it in a solution of the tanning matter, requires from six months to two years. By enclosing the solution, with the hide, in a close vessel, and exhausting the air, the pores of the hide being deprived of air, exert a capillary attraction on the tan, which may be aided by pressure, so that the thickest hides may be tanned in six weeks. The operation of bleaching affords another example.

7. *Exerting forces too large for human power*. When the force of

large bodies of men or animals is applied, it becomes difficult to concentrate it simultaneously at a given point. The power of steam, air, or water, is employed to overcome resistances which would require a great expense to surmount by animal labour. The twisting of the largest cables, the rolling, hammering, and cutting of large masses of iron, the draining of mines, require enormous exertions of physical force, continued for considerable periods. Other means are used when the force required is great, and the space through which it is to act is small. The hydraulic press can, by the exertiou of one man, produce a pressure of 1500 atmospheres.

8. *Executing operations too delicate for human touch.* The same power which twists the stoutest cable, and weaves the coarsest canvass, may be employed, to more advantage than human hands, in spinning the gossamer thread of the cotton, and entwining, with fairy fingers, the meshes of the most delicate fabric.

9. *Registering operations.* Machinery affords a sure means of remedying the inattention of human agents, by instruments, for instauce, for counting the strokes of an engine, or the number of coins struck in a press. The tell-tale, a piece of mechanism connected with a clock in an apartment to which a watchman has not access, reveals whether he has neglected, at any hour of his watch, to pull a string in token of his vigilance.

10. *Economy of materials.* The precision with which all operations are executed by machinery, and the exact similarity of the articles made, produce a degree of economy in the consumption of the raw material which is sometimes of great importance. In reducing the trunk of a tree to planks, the axe was formerly used, with the loss of at least half the material. The saw produces thin boards, with a loss of not more than an eighth of the material.

11. *The identity of the result.* Nothing is more remarkable than the perfect similarity of things manufactured by tho same tool. If the top of a box is to be made to fit over the lower part, it may be done by gradually advancing the tool of the sliding rest; after this adjustment, no additional care is requisite in making a thousand boxes. The same result appears in all the arts of printing: the impressions from the same block, or the same copperplate, have a similarity which no labour of the hand could produce.

12. *Accuracy of the work.* The accuracy with which machinery executes its work is, perhaps, one of its most important advantages. It would hardly be possible for a very skilful workman, with files and polishing substances, to form a perfect cylinder out of a piece of steel. This process, by the aid of the lathe and the sliding rest, is the every day employment of hundreds of workmen. On these two last advantages

of machinery depends the system of copying, by which pictures of the original may be multiplied, and thus almost unlimited pains may be bestowed in producing the model, which shall cost 10,000 times the price of each individual specimen of its perfections. Operations of copying take place, by printing, by casting, by moulding, by stamping, by punching, with elongation, with altered dimensions. A remarkable example of the arts of copying lies before the eye of the reader in these pages. 1. They are copies obtained by printing from stereotype plates. 2. Those plates are copies obtained (by casting) from moulds formed of plaster of Paris. 3. The moulds are copies obtained by pouring the plaster, in a liquid state, upon the movable types. 4. The types are copies (by casting) from moulds of copper, called matrices. 5. The lower part of the matrices, bearing the impressions of the letters or characters are copies (by punching) from steel punches, on which the same characters exist in relief. 6. The cavities in these steel punches, as in the middle of the letters *a*, *b*, &c., are produced from other steel punches in which those parts are in relief.

Montesquieu somewhere regrets the introduction of the use of water-mills for grinding corn, instead of the hand-mills formerly in use, as it threw a great many labourers out of employment, besides diverting the water from the purposes of irrigation. Upon this principle of throwing labourers out of employment, our hand-loom weavers were opposed to the use of power looms. It is not remarkable that labourers themselves, who, for a time, feel the inconveniences of the introduction of any improvement, should oppose its introduction; but it is singular that any man of enlarged and philosophical views should fall into such a notion. Nobody certainly would think it a misfortune to a community, that, in consequence of some improvement in agriculture, the same labour would produce a greater quantity of grain; on the contrary, every one consents to the praise bestowed, by Johnson, upon the man who makes two blades of grass grow where only one grew before. And an improvement in machinery, whereby the same labour will produce twice the quantity of cloth, is precisely the same in its general effects upon the condition of the community, as an improvement in agriculture. But in a case of improvement in machinery, the effect is more apparent and more sudden, as it will spread rapidly, and, accordingly, the inconvenience to the labourers is, in fact, greater, though it can last only for a time. However, the circumstance that its effect in discharging labourers is only temporary, though it shows that the inconvenience to the community is very limited, while its advantages are permanent, yet affords no great consolation to the labourers themselves, if the population is dense, and employment difficult to be obtained, since, while this temporary effect is passing off, they may starve. To avoid producing distress, and consequent disorder, labour-saving machinery, therefore, should be introduced gradually among a community of labourers, like those of Britain, to whom it is ordinarily difficult to find full employment, and who, if unemployed, are immediately reduced to distress. Hitherto no inconvenience has been experienced in North America in consequence of the introduction of improvements in machinery, since it is, as yet, the more general habit of all classes to save something, so that very few are reduced to immediate distress, though thrown out of employment; and there is usually less difficulty in obtaining full employment for the industrious classes than in most other countries; and, accordingly, all classes are in favour of improvements and inventions whereby labour may be saved, or its products augmented.

MAGNITUDE, is used to denote the extension of any thing, whether it be in one direction, as a line; in two directions, as a surface; or in three directions, which constitute a body or solid. Geometrical magnitudes, may be conceived to be generated by motion, as a line by the motion of a point, a surface by the motion of a line, and a solid by the motion of a surface.

MAHOGANY; one of the most valuable of the woods imported into this country. Mahogany balks are often three or four feet in diameter. Mahogany varies very much in quality; that grown on rocks is the hardest, heaviest, closest in the grain, and most beautifully veined; and Jamaica wood is preferable to that obtained on the coast of Cuba and the Spanish Main, on account of its being mostly found on rocky eminences, while the latter is cut in swampy soils near the sea-coast, and is light, porous, pale coloured, and open grained. On soils neither rocky nor swampy, the wood is of a medium excellence. Hence a good idea of the value of a parcel of mahogany may be formed, if we know correctly the nature of the soil upon which it grew. Different parts, however, of the trunk of the same tree, vary somewhat in quality; and in felling the timber, the most beautiful portion of it is commonly left behind. The negro workmen raise a scaffolding of four or five feet elevation from the ground, and hack up the trunk, which they cut into balks. The part below, extending to the root, is not only of larger diameter, but of a closer texture than the other parts, most elegantly diversified with shades or clouds, or dotted like ermine with spots. This part is only to be come at by digging below the spur, to the depth of two or three feet, and cutting it through; an operation too laborious to be often attempted.—The remark just made, with respect to the superiority of the wood of the mahogany-tree, near the earth, is applicable to timber in general, and ought not to escape the observations of those who are desirous of selecting the choicest and most ornamental portions for particular purposes. The exquisite beauty of the finer kinds of mahogany, the incomparable lustre of which it is susceptible, exempt also from the depredations of worms, hard, durable, warping and shrinking very little, it is preeminently calculated to suit the work of the cabinet-maker. Accordingly, these admirable properties, added to its abundance, and the largeness of its dimensions, have occasioned it to be manufactured into every description of furniture. From its being so little subject to shrink and warp, it is particularly excellent and much used for the patterns of iron and brass founders, especially for the patterns of wheel-work and other things which require the greatest nicety. It is the commoner sorts of mahogany which are generally wrought up in this way. The commoner kinds also are often stained black, and made to look to great advantage, for small turnery wares, such as picture frames.

Malleability, the property of a solid that is hard and ductile, and which may, therefore, be beaten, forged, and extended under the hammer without breaking; as is the case with all metals, not excepting quicksilver, but of these gold possesses this property in the highest degree. See *Metals*.

Manometer, an instrument intended to measure the rarefaction and condensation of elastic fluids in confined circumstances, whether occasioned by variation of temperature or by actual destruction, or generation of portions of elastic fluid. It is sometimes called *manoscope*.

Man, Strength of. The power of a man to produce motion varies according to the mode in which he applies his force, and the number of muscles which are brought into action. In the operation of turning a crank, a man's power changes in every part of the circle which the handle describes. It is greatest when he pulls the handle upward from the height of his knees, next greatest when he pushes it down on the opposite side, though here the power cannot exceed the weight of his body, and is therefore less than can be exerted in pulling upward. The weakest points are at the top and bottom of the circle, where the handle is pushed or drawn horizontally. If a windlass be provided with two cranks placed at right angles with each other, two men will perform much more work than they could if the cranks were disconnected, because at the moment one puts forth his strength to the least advantage, the other is exerting his with the greatest effect. The mode in which a man can exert the greatest active strength, is in pulling upward from his feet, because the strong muscles of the back as well as those of the upper and lower extremities, are then brought advantageously into action, and the bones are favourably situated by the fulcra of the levers being near to the resistance. Hence the action of rowing is one of the most advantageous modes of muscular exertion; and no method which has been devised for propelling boats by the labour of men, has hitherto superseded it. According to Mr Buchanan, the comparative effect produced by different modes of applying the force of a man, is nearly as follows. In the action of turning a crank, his force may be represented by the number 17. In working at a pump, by 29. In pulling downward, as in the action of ringing a bell, by 39. And in pulling upward from the feet, as in rowing, by 41. Violent efforts are not true specimens of a man's labour, since they can be exerted for a short time only. A moderate computation of an ordinary man's uniform strength, is that he can raise a weight of 10 pounds to the height of 10 feet once in a second, and continue this labour for 10 hours in the day; his power may be estimated at $10 \times 10 \times 60 = 6000$ lbs. raised one foot high per minute, about the fifth of what a horse can raise. This is supposing him to use his force under common mechanical advantages, and without any deduction for friction.

Mass, the quantity of matter in any body, which is always proportional to, and may be truly estimated by, its weight, whatever be its figure or magnitude.

Materials, Properties of. The following is a table of some of the properties of bodies, compiled from Tredgold's alphabetical list of materials.—See another table under article *Body*.

WOODS.	Specific gravity.	Weight of a cubic foot.	Weight of a bar 1 ft. long and 1 inch square.	Will bear without permanent alteration.	Extension in parts of its length.	Comparative strength.	Comparative extensibility.	Comparative stiffness.
		lbs.	lbs.	lbs.		Cast iron being unity.		
Ash	0·76	47·5	0·33	3540	0·00215	0·23	2·6	0 089
Beech	0·696	45·3	0·315	2360	0·00175	0·15	2·1	0·073
Elm	0·544	34·0	0·236	3240	0·00241	0·21	2·9	0·073
Fir, red or yellow	0·557	34·8	0·242	4290	0·00217	0·3	2·6	0·1154
Fir, white	0·47	29·3	0·204	3630	0·00198	0·23	2·4	0·1
Larch	0 56	35·0	0·243	2065	0·00192	0·136	2·3	0·058
Mahogany, Honduras	0·56	35·0	0·243	3800	0·00238	0·24	2·9	0·087
Oak, English	0·83	52·0	0·36	3960	0·00232	0·25	2·8	0·093
Pine, American yellow	0·40	26·75	0·186	3900	0·00241	0·25	2·9	0·057
METALS.								
Brass, Cast	8·37	523	3·63	6700	0·00075	0·435	0·9	0·49
Bronze, or gun metal	8·153	509·5	3·54	10000	0·00104	0 65	1·25	0·535
Copper	8·75	549	3·81					
Iron, cast	7·207	450	3·2	15300	0·00083	1	1	1
Iron, malleable	7·6	475	3·3	17800	0·00071	1·12	0 86	1·3
Lead cast	11·352	709·5	4·94	1500	0·00208	0·096	2·5	0·0385
Steel	7·84	490	3·4					
Tin, cast	7·291	455·7	3·165	2880	0·00663	0·182	0·75	0·25
Zinc, cast	7·028	439·25	3·05	5700	0·00024	0·365	0·5	0·76

Table of Properties of Materials, continued.

SUNDRIES.	Specific gravity.	Weight of a cubic foot. lbs.	Cohesive force of a sq. inch. lbs.	Crushed by, on a square inch. lbs.	Absorbs of its weight of water.	Extension in parts of the length.
Brick	1·841	115	275	562	0·6666	
—— work		117				
Clay	2·000	125				
Earth, common	1·76	110				
Granite, Aberdeen	2·625	164		10901		
Marble, white	2·706	169	1811	6060		000·0717
Porphyry, red	2·871	179		35568		
Slate, Welsh	2·752	172	11500			0·00073
—— Westmoreland			7870			0·00061
—— Scotch			9600			0·000608
Stone, Portland	2·113	132	857	3729	0·0625	0·000559
—— Bath	1·975	123·4	478		0·0769	
—— Craigleith	2·362	147·6	772	5490	0·0159	
—— Dundee	2·621	163·8	2661	6630	0·0196	
—— work		160				

Materials, Strength of. When materials are employed for mechanical purposes, the power or strength with which they resist external force, depends not merely upon the nature of the material, but upon its shape, its bearings, and upon the manner in which force is applied to it. It is, therefore, important to consider not only the qualities of individual substances, but likewise the laws, which are common to different materials, by which they act in resisting mechanical change, from forces applied to them. Two methods are employed in estimating the strength of materials, in different forms and situations; one by mathematical computation, and the other by actual experiment. The first supposes the structure of given bodies to be homogeneous, so that the cohesion of their particles shall be equal throughout. In the second, a single specimen is taken as the representative of a class; or at most the average of a number of specimens, is so taken. Neither method, therefore, is to be looked upon as precisely accurate in its results; yet these results furnish approximations to truth, which, in many cases, it is useful to understand.

The following divisions are generally made of the various strains to which materials are exposed.

1. They may be drawn asunder by a force acting endwise.

2. They may be compressed and destroyed by a force acting also endwise.

3. A bar of any substance may be strained laterally, one part being supported, and the strain applied immediately at the point of the support, as when a tenon breaks or a rafter fails at the wall. If the material is

cast iron or any similar substance, viz. non-fibrous, the direction of the force with respect to the body is important, but in fibrous bodies as timber, this strain may be considered under two distinct heads; accordingly as the force acts perpendicular to, or parallel with, the direction of the fibres.

4. A bar or beam may be strained transversely, as in the case of a girder or rafter.

5. It may be twisted as in the axle of mills, &c.

6. It may be strained by any two or more of these forces combined.

7. A material may also be strained by an internal pressure, as in the case of hydraulic cylinders, pieces of ordnance, water pipes, &c.

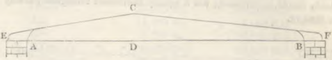
Before proceeding further with this article the reader will do well to consult the articles *Stress*, *Strain*, *Resistance*, *Extension*, *Compression*, *Cohesion Lateral*, *Strain*, *Stiffness*, *Resilience*, *Torsion*, *Cohesion*, and *Elasticity*.

We will here take a general view of the subject, and collect together such practical rules and tables as we consider most useful to the practical man.

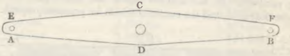
In frames of houses, and for various other purposes, beams are used of a prismatic form, having straight parallel sides. But such beams, when exposed to a lateral strain, are not of equal, or duly proportioned strength throughout; and therefore a part of them is superfluous. This consideration is not of much importance in ordinary practical cases. But in cases where economy of the material is important, as in cast iron railroads, also in machinery where it is desirable that the moving parts should be as light as possible, consistently with the requisite strength; it becomes of consequence to ascertain the best form for resisting a force with the smallest amount of material. Mathematicians have calculated the forms of different beams, which are suited to give them, at all points, a strength proportionate to the pressure they sustain, supposing the material to be of uniform texture. But the outline which answers merely to mathematical truth, is in many cases too scanty for actual employment; so that in order to obtain sufficient length for a secure connexion of the beam with its bearings, it is necessary to include the mathematical figure in a somewhat similar one, of larger dimensions. The following rules are, most of them, given in substance by Mr Tredgold.

If a beam be supported at both ends, and the load applied at some one point between the supports, and always acting in the same direction, the best plan appears to be, to make the extended side, or that opposite the load, perfectly straight; and to make the breadth equal throughout the whole. Then the mathematical form of the compressed side will be that which is formed by drawing two semi-parabolas, A C D and

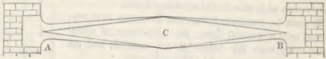
B C D, their vertices being at A and B, and C being the point where the force acts. Now since the curve terminates at A, it is necessary, in applying it to use, to add some such parts as are indicated by the lines extending to E and F at the extremities, for the sake of better support.



The same form is proper for a beam supported in the middle, as the beam of a balance. If the beam be strained, sometimes from one side and sometimes from the other, as in the beam of a steam engine, then both sides should be of the same form, and E A and F B should each be equal to half C D.

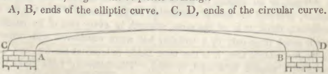


It is sometimes desirable to preserve the same depth throughout; and in this case the section through the length of the beam, made perpendicular to the direction of the straining force, should be a rhombus or trapezium, as in the annexed figure, the force acting perpendicularly at C, and the points of support being at A and B. To give this figure stability, the ends may be formed as shown in the continued outline.



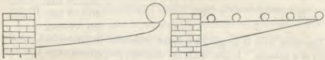
If a beam be intended to support a weight uniformly distributed throughout its length, or a load rolling over it, as in a railway, the line bounding the compressed side should be a semi-ellipse, the other side being straight. In practice the semi-ellipse may be included in a portion of a circle, to give the requisite bearings.

A, B, ends of the elliptic curve. C, D, ends of the circular curve.

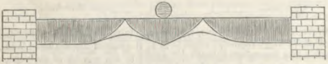


Where it is necessary that the upper side should be straight, the above form may be inverted, and the ends adapted to the bearings.

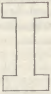
Beams which are fixed at one end only and support weights, should decrease as they recede from the wall, or point of fixture. If the weight be at the extremity, the outline, in a beam cut from a vertical plank, should be parabolic; but if equally distributed throughout, it may be straight.



If a beam be firmly fixed at both ends, and supports a weight in the middle, it should be largest at the ends and in the middle, the outlines being parabolic. In the annexed figure the shaded part shows the mathematical form, and the outline the form for practical purposes.



For resisting a cross strain, it is advantageous that the edges of a beam should be made thicker than the rest of its substance, so that a section of the beam would be nearly such as is seen in the adjoining figure.



It must be recollected that the foregoing rules prescribe only a general form, the proportions of which must vary with the nature of the material, and the degree of resistance, or load to be supported.

The absolute strength of a beam of timber, or a bar of metal, when acted upon by a weight in the direction of its length, is proportional to the area of its transverse section. The form of the bar makes no difference with respect to its strength, that is, it may be round, or square, a polygon, or an oblong, or any other shape; it may also be solid, or hollow, provided the area of the section be the same. When the bar is uniformly thick, it is of the same strength in every part of its length, when acted upon only by a weight; but when considered with respect to its own weight also, it is the most liable to break at the top, and the same with respect to a cord, or rope. The following table gives the absolute cohesion, or the weight that will rend a prism of an inch square, as well as the length of a prism, which would be pulled in two by its own weight only. This last is called the madidus of cohesion,*

Teak	12,915 lbs. . .	36,049 feet.
Oak	11,880 lbs. . . .	32,900 feet.
Sycamore	9,630 lbs. . .	35,800 feet.
Beech	12,225 lbs. . . .	38,940 feet.
Ash	14,130 lbs. . .	42,080 feet.
Elm	9,720 lbs. . . .	39,050 feet.
Memel fir	9,540 lbs. . .	40,500 feet.
Christiana fir . .	12,346 lbs. . . .	55,500 feet.
Larch	12,240 lbs. . .	42,160 feet.
Cast steel	134,256 lbs. . . .	39,455 feet.
Swedish malleable iron	72,064 lbs. . .	19,740 feet.
English do. .	55,872 lbs. . . .	16,938 feet.
Cast iron	19,096 lbs. . .	6,110 feet.
Cast copper . . .	19,072 lbs. . . .	5,003 feet.
Yellow brass . . .	17,958 lbs. . . .	5,180 feet.
Cast tin	4,736 lbs. . . .	1,496 feet.
Cast lead . . .	1,824 lbs. . . .	348 feet.

In ropes of the same thread, and manufactured in the same manner, the force to break them is proportional to the area of the section. The strength is found to be nearly proportional to the weight of the rope, under an equal length, when the quality of the threads, and the degree of twisting, is the same.

Table showing what weight a good hemp rope will bear with safety.

Diameter.	Circumference.	Pounds.	Diameter.	Circumference.	Pounds.
·315	1	200	1·510	4·75	4512·5
·397	1·25	312·5	1·590	5	5000
·477	1·50	450	1·670	5·25	5512·50
·557	1·75	612·5	1·750	5·50	6050
·636	2	800	1·830	5·75	6612·50
·715	2·25	1012·5	1·910	6	7200
·795	2·50	1250	1·990	6·25	7812·50
·874	2·75	1512·5	2·070	6·50	8450
·954	3	1800	2·150	6·75	9112·50
1·030	3·25	2112·5	2·230	7	9800
1·110	3·50	2450	2·310	7·25	10512·50
1·190	3·75	2812·5	2·390	7·50	11250
1·270	4	3200	2·470	7·75	12012·50
1·350	4·25	3612·5	2·540	8	12800
1·430	4·50	4050			

* See Cohesion for a very extensive Table of the weight that will break a square inch of various materials.

Table showing what weight a good hemp cable will bear with safety.

Circumference.	Pounds.	Circumference.	Pounds.	Circumference.	Pounds.
6	4320	10·25	12607·5	14·50	25230
6·25	4687·5	10·50	13230	14·75	26107·5
6·50	5070	10·75	13867·5	15	27000
6·75	5467·5	11	14520	15·25	27907·5
7	5880	11·25	15187·5	15·50	28830
7·25	6307·5	11·50	15870	15·75	29767·5
7·50	6750	11·75	16567·5	16	30720
7·75	7207·5	12	17280	16·25	31687·5
8	7680	12·25	18007·5	16·50	32670
8·25	8167·5	12·50	18750	16·75	33667·5
8·50	8670	12·75	19507·5	17	34680
8·75	9187·5	13	20280	17·25	35707·5
9	9720	13·25	21067·5	17·50	36750
9·25	10267·5	13·50	21870	17·75	37807·5
9·50	10830	13·75	22687·5	18	38880
9·75	11407·5	14	23520	18·25	39967·5
10	12000	14·25	24367·5		

Longitudinal Compression.—The compression which a column suffers, is, at first, nearly as the force of extension occasioned by an eqnal and opposite power; but as the weight, or compressive force increases, the power of resistance, likewise, augments, so long as the column does not bend: after it once begins to bend, it very soon breaks, wherefore a slender vertical prism is capable of supporting less pressure than the tension it can bear; but if the base of a column be considerable, with respect to its height, it will sustain a greater pressure than its cohesive power. The cohesion of a rod of cast iron of a quarter of an inch square is only 300 lbs., but a cube of that dimensions will require 1440 lbs. to crush it. The weights required to crush cubes of a quarter of an inch of certain materials are,

Iron cast vertically	11,140 lbs.
Iron cast horizontally	10,110 lbs.
Cast copper	7,318 lbs.
Cast tin	966 lbs.
Cast lead	483 lbs.

Cubes of an inch were crushed by the following weights:—

Elm	1,284 lbs.
White deal	1,928 lbs.
English oak	3,860 lbs.
Free-stone	8,688 lbs.

When the pressure is applied to the upper end, in the direction of the axis, the particles will become condensed perpendicularly, and accumulate towards the sides, and thus the incumbent weight will cause an oblique action, by which the column will be made to swell. The ellipse forms a good outline for columns, but the enlargement of the diameter at the bottom seldom amounts to a fourth part, and, in practice, it is generally varied according to different notions of beauty. See *Order*. It appears that if b be the breadth, d the depth, and l the length of the column, the force, or weight, at the top, required to bend it, will be as $\frac{b\,d^3}{l^2}$. And when the columns to be compared are similar, the resistance will be as $\frac{d^3}{l^2}$. Thus the weight which a cylindrical column can support, will be directly as the cube of the diameter and inversely as the square of the length.

The strength of a regular beam to resist a fracture by a force acting laterally upon it, is as the area of a section of the beam at the place where the force is applied, multiplied into the distance of its centre of gravity from the point or line where the breach will end. In squaro beams the lateral strengths are as the cubes of the breadths or depths; and in cylindrical beams the lateral strengths are as the cubes of their diameters. The lateral strengths of any two similar beams are as the cubes of any two corresponding dimensions of the sections. In rectangular beams, the lateral strengths are as the breadths into the squares of their depths. The lateral strength of a beam with its narrow side upwards, is to its strength with its broader face upwards, as the breadth of the broader side to the breadth of the narrower. That is, $bd^2 : db^2 : : d : b$. Thus, the area of the end of a joist which is 3 inches by 4, is 12 inches; and its strength, with its narrow side upwards, is as $4^2 \times 3 = 48$. A joist 6 inches by 2, contains the same quantity of timber, but with its narrow side upwards, its strength is as $6^2 \times 2 = 36 \times 2 = 72$. A joist 8 inches by $1\frac{1}{2}$, still contains the same quantity of timber, and with its narrow side upwards, its strength is as $8^2 \times 1\frac{1}{2} = 96$; so that a joist 8 inches by $1\frac{1}{2}$, which contains exactly the same quantity of wood as a joist that is 3 inches by 4, is, however, exactly twice as strong; for $96 = 2 \times 48$.

The lateral strengths of prismatic beams are as the areas of the sections multiplied by the distances of their centres of gravity from the line which terminates the fracture, divided by the products of their lengths and weights. A beam when fixed at both ends, is as strong as one of equal breadth and depth, and but half the length, which is fixed only at one end.

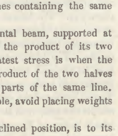
The strength of a beam of any form, of a given length, is, in most cases, the same as if the whole power were collected in the centre of gravity of each section; wherefore, if a triangular prism be supported at both ends, it will be just twice as strong when its edge is uppermost, as when the opposite side is uppermost. When the beam is supported only at one end, the breach will terminate at the under side; in this case, the beam will be twice as strong when the edge is downward as when its opposite side is downward.

A square, or rectangular beam, will be stronger when the diagonal of its end is placed vertically. For when a side is vertical, the distance of the centre of gravity from the case of fracture is equal to half the side; but when the diagonal is vertical, that distance is equal to half the diagonal, hence when the diagonal is vertical the beam will be strongest. The strength, when the diagonal of a square beam is vertical, is greater than when the side is vertical, in the ratio of $\sqrt{2}$ to 1, or as 1414 to 1000, nearly.

The lateral strengths of two cylinders, of the same matter, of equal weight and length, one of which is hollow and the other solid, are to each other as the diameters of their ends. Let a hole be bored lengthwise through a cylinder, equal to half its diameter; the strength will be diminished only $\frac{1}{8}$th, while the quantity of metal is diminished $\frac{1}{4}$th; therefore hollow axles are stronger than solid ones containing the same quantity of material.

If a weight be placed on any part of a horizontal beam, supported at both ends, the strain upon that part will be as the product of its two distances from the supported ends. The greatest stress is when the weight is placed at the middle point; for the product of the two halves is greater than the product of any other two parts of the same line. Hence in all structures we must, as far as possible, avoid placing weights on the middle of the beams.

The strength of a rectangular beam, in an inclined position, is to its strength in a horizontal position, to resist a vertical pressure, as the square of radius to the square of the cosine of elevation. The transverse vertical section of a beam is a rectangle, whether the beam be in an inclined or horizontal position, and the strengths in both cases will be as the squares of the depths. Let C D represent a vertical section of the beam, then C d would be its depth in a horizontal position; hence the strength of the beam in one position is to its strength in the other, $CD^2 : Cd^2$. But the triangles C D d, A D O, are similar; therefore $CD^2 : Cd^2 :: AD^2 : AO^2 :: (\text{radius})^2 : \cos^2 DAO$.



Hence the strength of any beam is the greatest when in a vertical position, and weakest when horizontal, the pressure on it being vertical.

When a beam just breaks with its own weight, let $L =$ its length;

also, let l be the length of a given prism, w its weight, u a weight attached to it at the distance d from the fixed end, theu

$$L = \sqrt{\left(l \times (l + \frac{2du}{w}) \right)}.$$

From the preceding deductions it is plain, that in similar beams of the same materials, the force which tends to break them in the larger beams increases in a greater proportion than the force which tends to keep them whole, or to secure them against accidents; their tendency also to break by their own weight increases as their length increases, so that although a small beam may be firm and secure, yet a large, though similar one may be so long, as to break with its own weight. Hence we find, that what often appears firm and successful in a model, is weak, or infirm, or often falls to pieces by its own weight, and will by no means answer in a large machine. The strongest rectangular beam which can be cut out of a given cylinder, is that of which the squares of the breadth, depth, and the diameter of the cylinder, are as 1, 2, 3, respectively.

The strength of axles and other parts of machines to resist the twist to which they are liable, is generally supposed to be as the cubes of their diameters; but M. Dulean, concludes, from many experiments, that the resistance which a piece of round iron opposes to the twist, is inversely as its length, and directly as the fourth power of its diameter. Mr G Rennie has also made experiments on the twisting of cast iron bars one-fourth of an inch in diameter. He found that vertical casts are stronger than horizontal ones; but that when he threw out of the account of his experiments the badly cast specimens, the difference between the two castings was but trifling. When the average of the two kinds of casts was taken jointly, and compared with a similar cast of half inch bars, the strength of the bars appeared to be nearly as the cubes of their diameters.

TABLE A.

Experiments on the direct cohesive powers of various materials.

Names of Materials.	Cohesive powers reduced to a square inch rod.	Experimenters.	Quoted from
WOODS.	lbs.		
Oak	17,300	Muschenbroek	Introd. ad Phil. Nat.
Ditto	13,950	Rondelet	L'Art. de Batir, iv.
Ditto			
Ditto dry English from	12,000 / 8,000	Barlow.	Essay on the strength of timber.
Beech	17,709	Muschenbroek	Introd. ad Phil. Nat.
Ditto	11,500	Barlow	Essay on the strength oftimber
Alder	14,186	Muschenbroek	Introd. ad Phil. Nat.
Chesnut, Spanish	13,300	Rondelet	L'Art de Batir, iv.
Ash very dry, from	17,850 / 15,784	Barlow.	Essay on the strength of timber.
Ditto	12,000	Muschenbroek	Introd. ad Phil. Nat.
Elm	13,489	do.	ditto
Acacia	20,582	do.	ditto
Mahozany	8,000	Barlow	Essay on the strength of timber.
Walnut	8,130	Muschenbroek	Introd. ad Phil. Nat.
Teak	15,000	Barlow	Essay on the strength of timber.
Poplar from / to	6,641 / 4,596	Muschenbroek	Introd. ad Phil. Nat. i.
Fir from / to	13,448 / 11,000	Barlow	Essay on the strength of timber.
Ditto	8,506	Muschenbroek	Introd. ad Phil. Nat. i.
Scotch Pine	7,818	do.	ditto
Norway Pine	7,287	Rondelet	L'Arte de Batir, iv.
Larch	10,224	do.	ditto
Cedar	4,973	Muschenbroek	Introd. ad Phil. Nat. i.
METALS.			
STEEL.			
Cast steel previouslytilted	134,256	Rennie	Phil. Trans. for 1813.
Cast steel not tilted	68,110	Brown	Barlow's Essays, etc.
Blistered steel reduced per hammer	133,152	Rennie	Phil. Trans. for 1818.
Sheer steel reduced per hammer	127,632	do.	ditto
IRON WIRE.			
Iron wire	113,077	Sickengen	Ann. de Chimie, vol. 25.
Iron wire one-tenth inch diameter	93,964	Telford	Barlow's Essay, p. 245, 2d ed.
Iron wire	85,797	Buffon	Œuvres de Gauthey, ii. p. 153.
MALLEABLE IRON IN BARS.			
German bar, mark B R highest results	93,069	Muschenbroek	Introd. ad. Phil. Nat. i. 426.
Swedish bar, highest result	88,972	do.	ditto
German bar, mark L highest result	85,900	do.	ditto
Liege bar, highest result	82,839	do.	ditto
Spanish bar	81,901	do.	ditto
Oosement bar, highest result	76,697	do.	ditto
Swedish bar reduced per hammer	72,064	Rennie	Phil. Trans. 1818.
Common round iron	66,309	Telford	Barlow's Essay, p. 230.
German bar marked L	69,520	Muschenbroek	Introd. ad Phil. Nat. i. 426.
Common Staffordshire bar	64,580	Telford	Barlow's Essay, p. 230.
Common German bar	69,133	Muschenbroek	Introd. ad. Phil. Nat. i. 426.
Swedish bar	68,728	do.	ditto
Oosement bar	68,728	do.	ditto

Table A, *continued.*

Names of Materials.	Cohesive powers reduced to a square inch rod.	Experimenters.	Quoted from
Welsh bar	62,079	Telford	Barlow's Essay, p. 230.
Bar of the best quality	66,000	Rumford	Phil. Mag. x. p. 51.
A bar of Welsh, one of Swedish, and one faggoted scrap iron, each gave a result of	60,413	Telford	Barlow's Essay, p. 229.
The Swedish iron broke at a flaw.			
Liege bar	62,369	Muschenbroek	Introd. ad Phil. Nat. i. 426.
Staffordshire bar	57,288	Telford	Barlow's Essay, p. 229.
German bar, marked B R	61,361	Muschenbroek	Introd. ad Phil. Nat. i. 426.
Bar (mean of 33 expts.)	61,041	Perronnet	Œuvres de Gauthey, ii. 154.
Russian old sable, mark CCN	64,230	Brown	Barlow's Essay, p. 233.
English bar reduced by the hammer	55,872 ?	Rennie	Phil. Trans. for 1818.
Welsh bar, (3 expts.)	60,238	Brown	Barlow's Essay, p. 233.
Bar of good quality	55,000	Rumford	Phil. Mag. vol. x. p. 51.
Swedish bar (3 expts.)	57,503	Brown	Barlow's Essay, p. 232.
CAST IRON.			
Bar, spec. grav. 7·807	68,295 ?	Muschenbroek	Introd. ad Phil. Nat. i. 417.
Bar, cast vertically	19,488	Rennie	Phil. Trans. for 1818.
Bar, cast horizontally	18,656	do.	ditto
Bar, Welsh pig	17,565	Brown	Barlow's Essay, p. 235.
COPPER.			
Wire	61,228	Sickingen	Ann. de Chimie, xxv. 9.
Wrought copper reduced by the hammer	33,792	Rennie	Phil. Trans. for 1818.
Cast, Barbary, spec. grav. 8·182	22,570	Muschenbroek	Introd. ad Phil. Nat. i. 417.
Cast, Japan, spec. grav. 8·726	20,272	do.	ditto
Cast	19,072	Rennie	Phil. Trans. for 1818.
PLATINUM.			
Platinum wire, sp. grav. 20·847	56,473	Morveau	Ann. de Chimie, xxv. 8.
Platinum wire	52,987	Sickingen	ditto, p. 9.
SILVER.			
Silver wire	38,257	do.	ditto
Silver cast, spec. grav. 11·091	40,902	Muschenbroek	Introd. ad Phil. Nat. i. 417.
GOLD.			
Gold wire	30,888	Sickingen	Ann. de Chimie, xxv. 9.
Gold cast, sp. gr. 19·238	20,450	Muschenbroek	Introd. ad. Phil. Nat. i. 417.
ZINC.			
Zinc wire	22,551	Morveau	Ann. de Chimie, lxxi. 194.
Zinc sheet	16,600	Tredgold	Phil. Mag. vol. l. p. 422.
Zinc cast	2,689	Muschenbroek	Introd. ad Phil. Nat. i. 407.
TIN.			
Tin wire	7,129	Morveau	Ann. de Chimie, lxxi. 194.
English block, cast	6,650	Muschenbroek	Introd. ad Phil. Nat. i. 417.
English, spec. grav. 7·295	5,322	do.	Introd. ad Phil. Nat. i. 417.
Cast	4,736	Rennie	Phil. Trans. for 1818.
Banca tin cast, sp. grav. 7·2165	3,679	Muschenbroek	Introd. ad Phil. Nat. i. 417.
Malacca tin cast, sp. gr. 6·1256	3,211	do.	ditto

Table A, *continued.*

Names of Materials.	Specific Gravity.	Cohesive power reduced to a square inch rod.	Experimenters.	Quoted from
LEAD.				
Milled sheet, specific gravity 11·407		3,328	Tredgold	Phil. Mag. vol. i. p. 422.
Wire		3,146	Muschenbroek	Introd. ad Phil. Nat. i. 452.
Wire, spec. grav. 11·282		2,581	do.	ditto
Wire		2,547	Morveau	Ann. de Chimie, lxxi. 194.
Cast lead		1,824	Rennie	Phil. Trans. for 1818.
Cast English, specific gravity 11·479		885	Muschenbroek	Introd. ad Phil. Nat. i. 452.
BISMUTH.				
Bismuth cast, specific gravity 9·810		3,250	do.	ditto
Bismuth, sp. grav. 9·926		3,008	do.	ditto
ANTIMONY.				
Antimony cast, spec. gravity 4·500		1,006	do.	ditto
ALLOYS.				
Copper 10 Tin 1	8·351	32093	Muschenbroek	Introd. ad Phil. Nat.
8 1	8·392	36088	ditto	ditto
6 1	8·707	44071	ditto	ditto
4 1	8·723	35739	ditto	ditto
2 1		1017	ditto	ditto
Gun metal, hard		36368	Rennie	Phil. Trans. for 1818.
Brass, fine yellow		17968	ditto	ditto
Tin, English 10 lead 1		6904	Muschenbroek	ditto
8 1		7922	ditto	ditto
6 1		7997	ditto	ditto
4 1		10607	ditto	ditto
2 1		7470	ditto	ditto
1 1		7074	ditto	ditto
Tin, Banca, 10 Antimony 1	7·359	11181	ditto	ditto
8 1	7·276	9881	ditto	ditto
6 1	7·228	12632	ditto	ditto
4 1	7·192	13480	ditto	ditto
2 1	7·105	12029	ditto	ditto
1 1	7·060	3184	ditto	ditto
Tin, Banca, 10 Bismuth 1	7·576	12688	ditto	ditto
4 1	7·613	16692	ditto	ditto
2 1	8·076	14017	ditto	ditto
1 1	8·146	12020	ditto	ditto
1 2	8·580	10013	ditto	ditto
1 4	9·009	7875	ditto	ditto
Tin, Banca, 10 Zinc, Indian 1	7·288	12914	ditto	ditto
2 1	7·000	15025	ditto	ditto
1 1	7·321	15844	ditto	ditto
1 2	7·100	16023	ditto	ditto
1 10	7·130	5671	ditto	ditto
Tin, English, 8 Zinc, Goslar 1		10607	ditto	ditto
4 1		10258	ditto	ditto
2 1		10964	ditto	ditto
1 1		9024	ditto	ditto
in, English, 1 Antimony 1	7·000	1450	ditto	ditto
3 2		3184	ditto	ditto
4 1		11343	ditto	ditto
Lead, Scotch, 1 Bismuth 1	10·931	7319	ditto	ditto
2 1	11·090	5840	ditto	ditto
10 1	10·827	2826	ditto	ditto

TABLE B.

Experiments on the Resistance of Cast Iron to pressure.

Size of prism.		Specific gravity.	Crushing weight.	Mean from each set.	Remarks.
Size of base.	Height.				
inch.	inch.		lbs.	lbs.	
1-8th	1-8th	7033	1,454	1,440	These specimens were from one block.
do.	do.	ditto	1,416		
do.	do.	ditto	1,449		
do.	2-8th	6977	1,922	2,116	Iron from a block.
do.	do.	ditto	2,310		
do.	3-8th	ditto	2,363	1,758	These specimens were from the same block.
do.	4-8th	ditto	2,005		
do.	5-8th	ditto	1,407		
do.	6-8th	ditto	1,743		
do.	7-8th	ditto	1,594		
do.	8-8th	ditto	1,439		
1-4th	1-4th	ditto	10,561		
do.	do.	ditto	9,596	9,773	These specimens were from the same block as above.
do.	do.	ditto	9,917		
do.	do.	ditto	9,020		
do.	do.	7013	12,665		
do.	do.	ditto	10,720	10,114	These specimens were from horizontal castings.
do.	do.	ditto	10,605		
do.	do.	ditto	8,699		
do.	do.	7074	12,665		
do.	do.	ditto	10,950	11,136	These specimens were vertical castings.
do.	do.	ditto	11,088		
do.	do.	ditto	9,844		
do.	do.	ditto	11,096		
do.	1-2d	7113	9,455	9,414	Horizontal casting.
do.	do.		9,374		
do.	do.	7074	9,938	9,982	Vertical casting.
do.	do.		10,027		
do.	3-8th	7113	9,006		Horizontal castings.
do.	5-8th	ditto	8,845		
do.	6-8th	ditto	8,362		
do.	7-8th	ditto	6,430		
do.	8-8th	ditto	6,321		
do.	3-8th	7074	9,328		Vertical castings.
do.	5-8th	ditto	8,385		
do.	6-8th	ditto	7,896		
do.	7-8th	ditto	7,618		
do.	8-8th	ditto	6,430		

TABLE C.

Similar Experiments on different Metals.

Size of prism.		Name of Metal.	Crushing weight.	Remarks.
Side of base.	Height.			
inch.	inch.		lbs.	
¼	¼	Cast Copper.	7,318	Crumbled by pressure.
do.	do.	Brass	10,304	Fine yellow brass, reduced one-tenth by 3213 lbs. and one-half with 10,304 lbs.
do.	do.	Wrought Copper	6,440	Reduced one-sixteenth with 3427 lbs. one-eighth with 6440 lbs.
do.	do.	Cast tin	966	Reduced one-sixteenth with 552 lbs. one-third with 960 lbs.
do.	do.	Cast lead.	483	Reduced one-half with 483 lbs.

TABLE D.

Exhibiting the experimental strength of various species of Timber opposed to a transverse strain.

Kinds of Wood.	Specific Gravity.	Length in feet.	Breadth in inches.	Depth in inches.	Deflection at the time of fracture.	Breaking weight in lb.	Value of constant strength.	Authorities.
Oak English, young tree	·863	2·	1	1	1·87	482	2892	Tredgold.
Do. old ship timber	·872	2·5	1	1	1·5	264	1980	do.
Do. from old tree	·625	2·	1	1	1·38	218	1308	do.
Do. medium quality......	·748	2·5	1	1		284	2150	Ebbels.
Do. green	763	2·5	1	1		219	1741	do.
Do. do.	1·063	11·75	8·5	8·5	3·2	24812	1785	Buffon.
Beech, medium quality ..	·690	2·5	1	1		271	2031	Ebbels.
Alder.....................	·555	2·5	1	1		212	1590	do.
Plane tree	·648	2·5	1	1		243	1821	do.
Sycamore	·590	2·5	1	1		214	1605	do.
Chesnut tree	·875	2·5	1	1		180	1350	do.
Ash, from young tree....	·811	2·5	1	1	2·5	324	2430	Tredgold.
Do. medium quality......	·690	2·5	1	1		254	1905	Ebbels.
Ash........................	·753	2·5	1	1	2·38	314	2355	Tredgold.
Elm, common	·544	2·5	1	1		216	1620	Ebbels.
Do. weych, green	·763	2·5	1	1		192	1440	do.
Acacia, green.............	·820	2·5	1	1		249	1866	do.
Mahogany, Spanish, seasoned...............	·852	2·5	1	1		170	1275	Tredgold.
Do. Honduras, seasoned	·256	2·5	1	1		255	1911	do.
Walnut, green	·925	2·5	1	1		195	1461	Ebbels.
Poplar, Lombardy	·375	2·5	1	1		131	981	do.
Ditto, Abele	·511	2·5	1	1	1·5	228	1710	Tredgold.
Teak	·744	7	2	2	4·00	820	2151	Barlow.
Willow....................	·405	2·5	1	1	3	146	1095	Tredgold.
Birch	·720	2·5	1	1		207	1551	Ebbels.
Cedar of Libanus, dry ..	·586	2·5	1	1	2·75	165	1236	Tredgold.
Riga fir	·480	2·5	1	1	1·3	212	1590	do.
Memel fir	·553	2·5	1	1	1·15	218	1635	do.
Norway fir from Long-sound	·639	2	1	1	1·125	396	2376	do.
Mar forest fir............	·715	7	2	2	5·5	360	945	Barlow.
Scotch fir, Eng. growth..	·529	2·5	1	1	1·75	233	1746	Tredgold.
Do. do.	·460	2·5	1	1		157	1176	Ebbels.
Christiana white deal....	·512	2	1	1	·937	343	2058	Tredgold.
American white spruce..	·465	2	1	1	1·362	285	1710	do.
Spruce fir, British growth	·555	2·5	1	1		186	1395	Ebbels.
American pine, Weymouth	·460	2·0	1	1	1·125	329	1974	Tredgold.
Larch, choice specimen..	·640	2·5	1	1	3·0	253	1896	do.
Do. medium quality......	·622	2·5	1	1		223	1671	do.
Do. very young wood	·396	2·5	1	1	1·78	129	966	do
English oak...............	·934	7	2	2	8·1	637	1672	Barlow.
Canadian, do..............	·872	7	2	2	6·0	673	1766	do.
Dantzic do.	·756	7	2	2	4·86	560	1457	do.
Adriatic do	·993	7	2	2	5·73	526	1383	do.
Ash........................	·760	7	2	2	8·92	772	2026	do.
Beech	·696	7	2	2	5·73	593	1556	do.
Pitch pine	·660	7	2	2	6·00	622	1632	do.
Red pine	·657	7	2	2	5·83	511	1341	do.
New England fir	·553	7	2	2	4·66	420	1102	do.

TABLE E.

Exhibiting the Strength of various descriptions of Cast Iron opposed to a transverse strain from experiments reported in Tredgold's Essay on the Strength of Cast Iron, Barlow's Essay, &c.

Kinds of iron.	Sp. grav.	Length.	Breadth.	Depth.	Breaking weight in lbs.	Value of constant weight.	Authorities and remarks.
Wakefield foundry, air furnace	6912	3	1	1	971	8739	Banks supported at the ends.
Do. cupola............		3	1	1	864	7776	Do.
Old park iron, ...		2	1·3	·65	184	8040	Tredgold fixed at one end.
Alfricton iron,.........		2	1·3	·65	153	6687	Do.
Scrap iron, ...		2	1·3	·65	168	7341	Do.
Old park and good old iron mixed, ...		2	1·3	·65	174	7604	Do.
Alloy pig iron 16, copper 1		2	1·3	·65	194	8477	Do.
Cast bars, ...		3	1	1	756	6804	Supported at the ends. Banks.
Do................		2·5	1	1	1008	7560	Do.
Do. mean of 3 experiments		3·0	1	1	972	8748	Do.
Do. mean of 3 experiments		3·0	1	1	869	7821	Do.
Cast bars		$2\frac{2}{3}$	1	1	250	8960	Rennie fixed at one end.

TABLE F.

Of experiments on the stiffness of different Woods.

Kinds of wood.	Spec. gravity.	Length in feet.	Breadth in inc.	Depth in inch.	Deflection.	Weight which produced deflection.	Value of a from $a = \frac{40\,bd^3\delta}{l^3\,W}$	Authorities.
Ash young tree, white coloured - - -	·811	2·5	1	1	0·5	141	·009	Tredgold.
Do. old tree, red coloured	·753	2·5	1	1	0·5	113	·0113	Do.
Do. medium quality, -	·690	2·5	1	1	0·5	78·5	·0163	Ebbels.
Ash - - - -	·760	7	2	2	1·27	225	·0105	Barlow.
Beech - - - -	·688	7	2	2	1·025	150	·01277	Do.
Teak - - -	·744	7	2	2	1·276	300	·0076	Do.
Elm,	·540	2·5	2	2	1·42	125	·0212	Do.
	·544	2·5	1	1	0·5	99·5	·0128	Ebbels.
Cedar of Lebanon, -	·486	2·5	1	1	0·5	36	·0355	Tredgold.
Maple, common - -	·625	2·5	1	1	0·5	65	·0197	Do.
Abele, - - -	·511	2·5	1	1	0·5	84	·0152	Do.
Willow, - - -	·405	2·5	1	1	0·5	41	·031	Do.
Horse chesnut - -	·483	2·5	1	1	0·5	79	·0162	Do.
Lime tree - - -	·483	2·5	1	1	0·5	84	·0152	Do.
Walnut, green - -	·920	2·5	1	1	0·5	62	·020	Ebbels.
Chesnut, Spanish -	·895	2·5	1	1	0·5	68·5	·0187	Do.
Acacia - - -	·820	2·5	1	1	0·5	125	·0102	Do.
Plane, dry - -	·648	2·5	1	1	0·5	99·5	·0128	Do.
Alder, do. - -	·555	2·5	1	1	0·5	80·5	·0159	Do.
Birch, do. - -	·720	2·5	1	1	0·5	90·5	·0141	Do.
Wych elm, green -	·763	2·5	1	1	0·5	92	·014	Do.
Lombardy poplar, dry -	·374	2·5	1	1	0·5	56·5	·0224	Do.
Mahogany, Honduras -	·560	2·5	1	1	0·5	118	·0109	Tredgold.
Do. Spanish - -	·853	2·5	1	1	0·5	93	·0137	Do.
Sycamore - - -	·590	2·5	1	1	0·5	76	·0168	Ebbels.
Pear, green - -	·792	2·5	1	1	0·5	59·5	·0215	Do.
Cherry, do. - -	·690	2·5	1	1	0·5	92·5	·0138	Do.
Beech, dry - -	·696	2·5	1	1	0·5	97·5	·0131	Do.

TABLE G.

Of experiments on the stiffness of Fir.

Kinds of fir.	Spec. gravity.	Length in feet.	Breadth in inc.	Depth in inch.	Deflection in inches.	Weight producing the deflection in lbs.	Value of a from $\frac{40\, b\, d^3\, \delta}{l^3\, W}$	Authorities.
Fir, Riga, yellow medium		1·8	2	7	0·25	103	·0015	Tredgold.
Do. Norway - -	·6398	2	1	1	0·5	261	·00957	Do.
Do. Riga yellow -	{ ·480	2·5	1	1	0·5	123	·0102	Do.
	{ ·464	2·5	1	1	0·5	116	·0110	Ebbels.
Do. Memel medium -	{ ·553	2·5	1	1	0·5	143	·0089	} Tred-
	{ ·544	2·5	1	1	0·5	145	·0088	} gold.
American pine - -	{ ·460	2	1	1	0·5	237	·0105	} Do.
	{ ·407	3	1	1	0·5	69	·0112	}
White spruce, Christiana	·512	2	1	1	0·5	261	·00957	Do.
Do. Quebec - -	·465	2	1	1	0·5	180	·0130	Do.
Pitch pine - - -	·712	7	2	2	1·33	150	·0166	Barlow.
Fir, New England -	·560	7	2	2	·970	150	·0121	Do.
Riga fir - - -	·765	7	2	2	·912	150	·01137	Do.
Mar forest, Scotland -	·715	7	2	2	1·560	125	·0233	Do.
Larch, Blair, Scotland, dry	·622	2·5	1	1	0·5	93	·0137	Tredgold.
Do. seasoned medium -	{ ·644	2·5	1	1	0·5	101	·0126	Do.
	{ ·554	2·5	1	1	0·5	112	·0111	Ebbels.
Do. very young wood -	·396	2·5	1	1	0·5	45	·0284	Tredgold.
Scots fir - - -	·529	2·5	1	1	0·5	89	·01437	Do.
Spruce, British -	·555	2·5	1	1	0·5	93	·0124	Ebbels.
Fir, (bois-disbrin) -		21·3	10·48	10·48	1·02	4·389	·0115	Girard.
Do. do. - -		10·65	10·58	10·48	0·2245	4·122	·0220	Do.

TABLE H.

Of experiments on the stiffness of Oak.

Kind of oak.	Spec. gravity.	Length in feet.	Breadth in inc.	Depth in inch.	Deflection in inches.	Weight producing the deflection in lbs.	Values of a from $\frac{40\, b\, d^3\, \delta}{l^3\, W}$	Authorities.
Old ship timber .	·872	2·5	1	1	0·5	127	00998	Tredgold.
Oak from young tree, King's Langley, Herts	·863	2·	1	1	0·5	237	·0105	Do.
Oak from Beaulieu, Hants	·616	2·5	1	1	0·5	78	·0164	Do.
Ditto, another specimen	·736	2·5	1	1	0·5	65	·0197	Do.
Oak from old tree .	·625	2	1	1	0·5	103	·0240	Do.
Oak Riga - - -	·688	2	1	1	0·5	233	·0107	Do.
Do. English - -	·960	7	2	2	1·275	270	·0119	Barlow.
Do. Canada - -	·867	7	2	2	1·07	225	·009	Do.
Do. Dantzic - -	·787	7	2	2	1·26	208	·0105	Do.
Do. Adriatic - -	·948	7	2	2	1·55	150	·0193	Do.
Do. Green - - -	·763	2·5	1	1	0·5	96	·0133	Ebbels.
Do. Dantzic seasoned -	·755	2·5	1	1	0·5	148	·0087	Tredgold.
Do. do. - -		12·8	3·19	3·19	{ 1·06	268	·008	} Aubry
					{ 4·25	803	·0105	}
Do. Green - - -		6·87	5·3	5·3	·433	7587	·005	Buffon.
Do. do. - - -		23·58	5·3	5·3	2·7	706	·0095	Do.
Do. - - - -		8·52	5·06	6·22	0·709	4146	·0013	Girard.
Do. (bois-disbrin) -		16·06	10·66	11·73	0·67	4559	·0213	Do.
Oak - - - -		2	1	1	0·35	149	·0117	Tredgold.
Do. - - - -		2	1	1	0·35	167	·0104	Do.

TABLE I.

Experiments on the Resistance of various materials to a crushing force.

Names of Materials.	Specific gravity.	Crushing weight.
		lbs.
1. Elm, cube of 1 inch		1284
2. American pine, do.		1606
3. White deal, do.		1928
4. English oak, do.		3860
5. Portland stone, 2 inches long		805
6. Statuary marble, 1 inch		3216
7. Craigleith, do.		8688
8. Chalk, cube of 1½ inch		1127
9. Brick, pale red do.	2085	1265
10. Roe-stone, Gloucestershire, do.		1449
11. Red brick, do.	2168	1817
12. do. Hammersmith, pavior's do.		2254
13. Burnt do. do.		3243
14. Fire brick, do.		3864
15. Derby grit do.	2316	7070
16. Do. another specimen, do.	2428	9776
17. Killaly white freestone, do.	2423	10264
18. Portland, do.	2428	10284
19. Craigleith white freestone, do.	2452	12346
20. Yorkshire paving with the strata, do.	2507	12856
21. Do. do. against strata, do.		12856
22. White statuary marble, do.	2760	13632
23. Bramley Fall sandstone, do.	2506	13632
24. Do. against strata, do.		13632
25. Cornish granite, do.	2662	14302
26. Dundee Sandstone, do.	2530	14918
27. Portland, a two inch cube	2423	14918
28. Craigleith, with the strata, 1½ inch cube,	2452	15360
29. Devonshire red marble,		16732
30. Compact limestone	2584	17354
31. Granite Peterhead		18636
32. Black compact limestone	2598	19924
33. Purbeck	2599	20610
34. Freestone very hard	2528	21254
35. Black Brabant marble	2697	20742
36. White Italian marble	2726	21783
37. Granite, Aberdeen, Blue-kind	2625	24556

TABLE K.

Of the elasticity of various Woods, as computed by Mr Tredgold.

Kinds of wood.	Elasticity = e.	Kinds of wood.	Elasticity = e.
English oak	0·0015	Mahogany, Honduras	0·00161
Beech	0·00195	Teak	0·00118
Alder	0·0023	Cedar, Lebanon,	0·0053
Chesnut, green	0·00267	Riga fir	0·00152
Ash	0·00168	Memel fir	0·00133
Elm	0·00184	Norway spruce	0·00142
Acacia	0·00152	Weymouth pine	0·00157
Mahogany, Spanish	0·00205	Larch	0·0019

TABLE L.

Experiments on the resistance of seasoned Oak beams to forces pressing in the direction of their lengths.

Kind of wood.	Length in feet.	Breadth in inch.	Depth in inches.	Deflexion in inch.	Weight producing the deflection in lbs.	Proportional elasticity.	Duration of the experiments in hours.	Weight that broke the pieces.	Authority.
Oak seasoned.	2·125	2·126	2·126	·0787	7,856	·0006	4	15·631	Lamande.
				·03937	13,525	·00033	6	21·296	
				·1181	14,119	·00032	18	19·993	
				·03937	11,750	·00042	8	21·060	
Do.	4·25	2·126	2 126	·0787	6,298	0002	21	11·844	do.
				·1574	6,298		27	12·225	
				·1574	6,298			13·565	
				·1574	6,298		6	12·458	
Do.	6·375	2·126	2·126	·1574	3,277	·00015	6	7·244	do.
				·1574	2,860	·00018		7·484	
				·2361	2,750	·00019	5	8·492	
				·1574	2,750			7·878	
Do.	2·125	3·18	3·18	·0787	34,599	·0007	27	50·958	do.
				·03937	45,168	·0005	24	50·955	
Do.	4·25	3·18	3·18	·1574	20,317	·0003	29	43·639	do.
				·1574	18,647	·00031	5	36·865	
				·19685	20,578	·0003	9	36·205	
				·27559	21,819	·00026	17	28·182	
Do.	6·375	3·18	3·18	·1574	9,121	·00028	7	26·939	do.
				·19685	9,713	·00027	19	28·987	
				·0787	11,000	·00023	4	23·929	
				·2361	10,142	·00025	18	33·048	
				·1574	12,746	·0002	6	36·902	
Do	2·125	4·25	4·25	·0787	61,883	·00118	11	95·262	do.
				·03937	56,691	·00129	8	66·112	
				·03937	56 693		23	105·826	
				·0787	67,467	·00107	28	94·476	
				·03937	57,780	·00125	30	88·442	
Do.	4·25	4·25	4·25	·03937	63,066	·00027	8	100·755	do.
				·0787	29,695	·0006	5	85·998	
				·0787	50,525	·00035	19	73·238	
				·03937	45,201	·0004	19	96·368	
Do.	6·375	4·25	4·25	·1574	21,589	·00038	7	64·090	do.
				·2361	17,331	·00047	5	59·373	
				·1574	18,517	·00044	22	54·062	
				·2361	27,599	·0003	22	65·608	

MATHEMATICAL, relating to mathematics.

MAXIMA et MINIMA, in Analysis and Geometry, are the greatest and least value of a variable quantity, and the method of finding these greatest and least values, is called the *Methodus de Maximis et Minimis;* which forms one of the most interesting inquiries in the modern analysis.

MEAN, is a middle state between two extremes; thus we say, arithmetical mean is half the sum of any two quantities: as $\frac{a+b}{2}$ = arithmetical mean between a and b.

Geometrical Mean, is the square root of the product of any two quantities; that is, $\sqrt{a\,b}$ is the geometrical mean between a and b.

Measure, denotes any certain quantity, with which other homogeneous quantities are compared. Geometrical measures are of different kinds, as lines, (straight and curved,) surfaces, capacities, and angles. —Measure of an angle, is the number of degrees, minutes, &c. contained in the arc of a circle comprised between the two lines forming that angle, its angular point being the centre.—Arithmetical measures, are commonly used to denote numbers which divide other numbers without remainder. When a number measures two or more numbers. it is called a common measure.—Measure of a line, is its length compared with some determinate line; as a foot, yard, &c.—Measure of a surface, is the number of square units contained in it, whether that unit be a foot, a yard, mile, or other quantity.—Measure of a solid, is the number of cubic units contained in it; as inches, feet, miles, &c.—Measure of a number, is such a number as will divide another number without a remainder.—Measure of a ratio, is its logarithm in any system of logarithm; thus, the measure of the ratio 2 : 3, or $\frac{2}{3}$, is the logarithm of $\frac{2}{3}$.—We subjoin the following Tables of Measures.

CLOTH MEASURE.

$2\frac{1}{4}$ inches make	1 nail.		3 quarters make	1 Flemish ell.
4 nails	1 quarter.		5 quarters	1 English ell.
4 quarters	1 yard,		6 quarters	1 French ell.

inches.			
$2\frac{1}{4}$ =	1 nail.		
9 =	4 =	1 qr.	
36 =	16 =	4 =	1 yard.
27 =	12 =	3 =	1 Flemish ell.
45 =	20 =	5 =	1 English ell.
54 =	24 =	6 =	1 French ell.

LONG MEASURE.

3 barleycorns make	1 inch.
12 inches	1 foot.
3 feet	1 yard.
6 feet	1 fathom.
$5\frac{1}{2}$ yards	1 rod, pole, or perch.
40 poles	1 furlong.
8 furlongs	1 mile.
3 miles	1 league.
60 miles	1 degree.

barleycorns.									
3 =	1 inch.								
36 =	12 =	1 foot.							
108 =	36 =	3 =	1 yard.						
216 =	72 =	6 =	2 =	1 fathom.					
594 =	198 =	$16\frac{1}{2}$ =	$5\frac{1}{2}$ =	..	1 pole.				
23760 =	7920 =	660 =	220 =	..	40 =	1 furlong.			
190080 =	63360 =	5280 =	1760 =	..	320 =	8 =	1 mile.		
570240 =	190080 =	15840 =	5280 =	..	960 =	24 =	3 =	1 league.	
34214400 =	11404800 =	950400 =	316800 =	..	57600 =	1440 =	180 =	60 =	1 deg.

WINE MEASURE.

2 pints make	1 quart.
4 quarts	1 gallon.
10 gallons	1 anker.
18 gallons	1 rundlet.
42 gallons make	1 tierce.
63 gallons	1 hogshead.
2 hogsheads	1 pipe or butt.
2 pipes	1 tun.

pints.
2 = 1 quart.
8 = 4 = 1 gallon.
80 = 40 = 10 = 1 anker.
144 = 72 = 18 = .. = 1 rundlet.
336 = 168 = 42 = .. = .. 1 tierce.
504 = 252 = 63 = .. = .. 1½ = 1 hogshead.
1008 = 504 = 126 = .. = .. 3 = 2 = 1 pipe.
2016 = 1008 = 252 = .. = .. 6 = 4 = 2 = 1 tun.

ALE AND BEER MEASURE.

2 pints make	1 quart.
4 quarts	1 gallon.
9 gallons	1 firkin.
2 firkins	1 kilderkin.
2 kilderkins make	1 barrel.
1½ barrel	1 hogshead.
2 barrels	1 puncheon.
3 barrels	1 butt.

pints.
2 = 1 quart.
8 = 4 = 1 gallon.
72 = 36 = 9 = 1 firkin.
144 = 72 = 18 = 2 = 1 kilderkin.
288 = 144 = 36 = 4 = 2 = 1 barrel.
432 = 216 = 54 = 6 = 3 = 1½ = 1 hogshead.
576 = 288 = 72 = 8 = 4 = 2 = .. = 1 puncheon.
864 = 432 = 108 = 12 = 6 = 3 = .. = 2 = 1 butt.

N. B.—The pint, quart, and gallon, in wine, ale and beer, and grain or corn, measure the same with regard to their magnitude; 8 of these gallons make 1 bushel; and 1 gallon contains 277·274 cubical inches, or 10 lbs. of distilled water, at 62 degrees.

GRAIN OR CORN MEASURE.

2 pints make	1 quart.
2 quarts	1 pottle.
4 quarts	1 gallon.
2 gallons	1 peck.
4 pecks	1 bushel.
2 bushels make	1 strike.
4 bushels	1 coomb.
2 coombs	1 quarter.
5 quarters	1 wey or load.
2 weys	1 last of corn.

pints.
2 = 1 quart.
4 = 2 = 1 pottle.
8 = 4 = 2 = 1 gallon.
6 = 8 = 4 = 2 = 1 peck.
64 = 32 = 16 = 8 = 4 = 1 bushel.
128 = 64 = 32 = 16 = 8 = 2 = 1 strike.
256 = 128 = 64 = 32 = 16 = 4 = 2 = 1 coomb.
512 = 256 = 128 = 64 = 32 = 8 = 4 = 2 = 1 quarter.
2560 = 1280 = 640 = 320 = 160 = 40 = 20 = 10 = 5 = 1 wey.
5120 = 2560 = 1280 = 640 = 320 = 80 = 40 = 20 = 20 = 2 = 1 last.

COAL MEASURE.

4 pecks make	1 bushel
3 bushels	1 sack.
12 sacks make	1 chaldron.
21 chaldrons	1 score.

pecks.
4 = 1 bushel.
12 = 3 = 1 sack.
144 = 36 = 12 = 1 chaldron.
3024 = 756 = 252 = 21 = 1 score.

CUBIC OR SOLID MEASURE.

1728 cubic inches . . 1 cubic foot.——27 cubic feet . . 1 cubic yard.
1728 cubic inches = 1 cubic foot.
46656 cubic inches = 27 cubic feet = 1 cubic yard.

SQUARE MEASURE.

144 inches make	1 foot.	4 roods make	1 acre of land.
9 feet	1 yard.	640 acres	1 square mile.
272¼ feet	1 rod, pole, or perch.	30 acres	1 yard of land.
40 rods	1 rood.	100 acres	1 hide of land.

inches.						
144 =	1 foot.					
296 =	9 =	1 yard.				
39204 =	272¼ =	30¼ =	1 rod.			
1568160 =	10890 =	1210 =	40 =	1 rood.		
6272640 =	43560 =	4840 =	160 =	4 =	1 acre.	
4014489600 =	27878400 =	3097600 =	102408 =	2560 =	640 =	1 sq. mile.
188179200 =	1306800 =	145200 =	4800 =	120 =	30 =	1 yd. land.
627264000 =	4356000 =	484000 =	16000 =	400 =	100 =	1 hide land.

HAY AND STRAW.

1 truss of new hay weighs 60 pounds.
1 truss of old hay weighs 56 pounds.
1 truss of straw weighs 36 pounds.
36 trusses make 1 load.

PAPER.

20 quires make	1 ream.	10 reams make	1 ball.
2 reams	1 bundle	12 skins of parchment make	1 roll.

MISCELLANEOUS INFORMATION.

12 units make	1 dozen.	3 inches make	1 palm.
12 dozen	1 gross.	4 inches	1 hand.
12 gross	1 great gross.	9 inches	1 span.
		18 feet	1 woodland pole.
20 units make	1 score.	21 feet	1 plantation pole.
6 score	1 great hundred.	24 feet	1 Cheshire pole.

1 anm of hock contains	36 gallons.
1 barrel (imperial measure)	9981·864 cubic inches.
1 barrel of anchovies	30 pounds.
1 barrel of soap	256 pounds.
1 barrel of herrings	32 gallons.
1 barrel of salmon or eels	42 gallons.
1 bushel (imperial measure)	2218·192 cubic inches.
1 bushel (Winchester measure)	2150·42 cubic inches.
1 bushel of coal	88 pounds.
1 bushel of flour	56 pounds.
1 butt of Sherry	130 gallons.
1 chaldron of coals, with ingrain	104809·572 cubic inches.
1 chaldron of coals, without ingrain	99818·64 cubic inches.
1 chaldron (Newcastle)	53 cwt.
8 chaldrons of coal (Newcastle)	15¾ London chaldrons.
1 clove of wool	7 pounds.
1 firkin of butter	56 pounds.
1 firkin of soap	64 pounds.
1 firkin of soap	8 gallons.
1 fodder of lead, at Stockton	22 cwt.
1 fodder of lead, at Newcastle	21 cwt.
1 fodder of lead, at London	19½ cwt.
1 gallon (imperial measure)	277·274 cubic inches.
1 gallon (do.) distilled water at 62°	10 pounds.
1 gallon (former wine measure)	231 cubic inches.
1 gallon (former ale measure)	282 cubic inches.
1 gallon (Irish measure)	217·6 cubic inches.

1 hogshead of claret	58 gallons.
1 hogshead of tent	63 gallons.
1 hundred of salt	7 lasts.
1 keg of sturgeon	4 or 8 gallons.
1 last of salt	18 barrels.
1 last of gunpowder	24 barrels.
1 last of beer	12 barrels.
1 last of potash	12 barrels.
1 last of cod-fish	12 barrels.
1 last of herrings	12 barrels.
1 last of meal	12 barrels.
1 last of soap	12 barrels.
1 last of pitch and tar	12 barrels.
1 last of flax	17 cwt.
1 last of feathers	17 cwt.
1 last of wool	4368 pounds.
1 pack of wool	240 pounds.
1 pipe of Madeira	110 gallons.
1 pipe of Cape Madeira	110 gallons.
1 pipe of Teneriffe	120 gallons.
1 pipe of Bucellas	140 gallons.
1 pipe of Barcelona	120 gallons.
1 pipe of Vidonia	120 gallons.
1 pipe of Mountain	120 gallons.
1 pipe of Port	138 gallons.
1 pipe of Lisbon	140 gallons.
1 stone of meat	8 pounds.
1 sack of wool	364 pounds.
1 stone of fish	8 pounds.
1 stone (horseman's weight)	14 pounds.
1 stone of glass	5 pounds.
1 seam of glass	124 pounds.
1 stone of wool	14 pounds.
1 tun of vegetable oil	236 gallons.
1 tun of animal oil	252 gallons.
1 tod of wool	28 pounds.
1 wey of cheese, in Suffolk	256 pounds.
1 wey of cheese, in Essex	336 pounds.
1 wey of wool	182 pounds.

FRENCH MEASURES.

OLD SYSTEM.

A point is	·0148025 English inches, or nearly 2-135th.
A line	·088815, or nearly 8-90th.
An inch, or pouce	1·06578, or 81-76th.
A foot	12·78933.
An ell, or aune	46·8947, or 44 French inches, or according to Vega. 43·9.
A sonde	63·9967, or 5 French feet, about 8-9th English fathom
A toise, or fathom	76·7360, or 6 French feet; formerly 76·71. Phil. Trans. for 1742.
A perche	230·280, or 18 French feet.
A perche, mesure royale,	22 French feet.
A league	2282 toises, or 1-25th of a degree.
A square inch	1·13582 English square inches.
An arpent	100 square perches, about 5-6th acre English, used near Paris.
An arpent, mesure royale,	about 1¼ English acre.
A cubic inch	1·21063 cubic inches.
A litron	65·34.
A boisseau	1045·44, or 16 litrons.
A minot	2090·875, or 3 boisseaux, nearly an English bushel.
A mine	4181·75, or 2 minots.
A septier	8363·5, or 2 mines, or 6912 inches French, double for oats.
A muid	100362, or 12 septiers.

The perch, which determines the measure of the acre, varies in different parts of the country; but the arpent of woodland is everywhere the same, the perch being 22 feet long, and this arpent contains 48400 French square feet, or 6108 English square yards. The arpent for cultivated land in the vicinity of Paris contains 900 square toises, or 4088 English yards.

NEW SYSTEM.

MEASURES OF LENGTH.

	English inches.
Millemetre	·039371.
Centimetre	·39371.
Decimetre	3·9371.
Metre	39·371, or 3·281 feet, or 1·09364 yards, or nearly 1 yard, 1½ nail, or 443·2959 French lines, or ·513074 toises.
Decametre	393·71, or 10 yards, 2 feet, 97 inches.
Hecatometre	3937·1, or 100 yards, 1 foot, 1 inch.
Chiliometre	39371, or 4 furlongs, 213 yards, 1 foot, 10·2 inches: so that 1 chiliometre is nearly ⅝ of a mile.
Myriometre	393710. or 6 miles, 1 furlong, 136 yards, 6 inches.

An inch = ·0354 metres; 2441 inches = 62 metres; 10000 feet = 305 metres nearly.

SUPERFICIAL OR SQUARE MEASURE.

Are — a square decametre 3·95 English perches, of 119·6046 square yards.

Decare	1196·0460 square yards.
Hecatare	11960·46 square yards, or 2 acres, 1 rood, 35·4 perches.

MEASURES OF CAPACITY.

	Cubic inches, English.
Millilitre	·06103.
Centilitre	·61028.
Decilitre	6·1028.
Litre, a cubic decimetre	61·028, or 2·113 wine pints.
Decalitre	610·28, or 2·64 wine gallons.
Hecatolitre	6102·8, or 3·5317 cubic feet, or 26·4 wine gallons.
Chiliolitre	61028· or 35·3170 cubic feet, or 1 tun, 12 wine gallons.
Myriolitre	610280· or 353·1700 cubic feet.

SOLID MEASURE.

	Cubic feet, English.
Decistre for fire wood	3·5317.
Stere, a cubic metre	35·3170.
Decastre	353·1700.

In order to express decimal proportions in this new system, the following terms have been adopted. The term *deca* prefixed denotes 10 times; *heca* 100 times; *chilio* 1000 times; and *myrio* 10,000 times. On the other hand, *deci* expresses the 10th part; *centi* the 100th part; and *milli* the 1000th part; so that *decametre* signifies 10 metres; and *decimetre* the 10th part of a metre, &c. &c. The *metre* is the element of long measures; *are* that of square measures; *stere* that of solid measures; the *litre* is the element of all measures of capacity; and the *gramme*, which is the weight of a cubic centimetre of distilled water, is the element for all weights.

Mechanical Powers, a phrase under which is classed all those simple machines that are separately employed for the purposes of raising great weights, overcoming great resistances, &c.; and from the combination of which the most complex engines are constructed.

Authors have differed as to the number of mechanical powers, some reckoning only three, others six, and others again seven: viz. the lever, wheel and axle, pulley, inclined plane, screw, wedge, and funicular machine.

MEDIUM, in physics, denotes that space or region through which a body passes in its motion towards any proposed point; being used in contradistinction to a vacuum, which is a simple void space. Thus, air, water, glass, &c. are mediums of different densities, and possessed of different powers of refraction, resistance, &c.

METALS, are elementary bodies, being all capable of combining with oxygen; and many of them, during this combination, exhibit the phenomena of combustion. Formerly only seven metals were known, but modern discoveries have added to the number greatly. Metals are distinguished by their great specific gravity, considerable tenacity and hardness, opacity and property of reflecting the greater part of the light which falls on their surface, giving rise to what is denominated the metallic lustre or brilliancy. The lightest metal is about six times heavier than water, while the specific gravity of the heaviest substance with which we are acquainted, that is not metal, is less than five times heavier than water. Opacity is another leading property of metals; even when beat to the greatest possible thinness, they transmit scarcely any light; from the union of the two qualities density and opacity, arises that of lustre. By their opacity and the denseness of their texture, they reflect the greatest part of the light that falls on their surface. From their density they are susceptible of a fine polish by which their lustre is increased. Colour is not a characteristic property of metals, but it serves to distinguish them from each other. Their colours are generally shades of white, grey, or yellow. Tenacity distinguishes a number of the metals, and is not possessed in any great degree by other bodies; hence arises their malleability and ductility. Some of the metals are neither malleable nor ductile. Metals are less hard than the diamond and many fossils, and their elasticity follows the same order as their hardness. Both these qualities are greater in combinations of the metals than in the individual metals, and both may be increased by raising the metal to a high temperature, and then suddenly cooling it. Metals are the best conductors of caloric; their expansibilities are various, and are probably nearly in the order of their fusibilities. Mercury melts at so low a temperature, that it can be obtained in the solid state only at a very low temperature; others, as platina, can scarcely be melted by the most intense heat, which we can excite. In congealing, some of the metals expand considerably, especially iron, bismuth, and antimony; the others contract, one twenty-third of the whole volume. Metals may be volatilized; at the degree of 600, quicksilver may be volatilized; and zinc and arsenic at a temperature not very remote from this; many others may be dissipated in the focus of a large burning mirror, or by a powerful galvanic battery. Metals are the best conductors of electricity.

TABLE OF THE PROPERTIES OF THE METALS.

Name.	When discovered.	By whom.	Colour.	Spec. Gravity.	Fusing point, Fahrenheit.	Scale of ductility.	Scale of malleability.	Tenacity.	Ratio of hardness.
Gold	Known from the earliest ages.	....	Pure yellow.	19·257	5237	1	1	68·216	8
Silver		....	White.	10·474	3677	2	2	85·062	6
Iron		....	Blue-grey.	7·788	17977	4	8	269·659	3
Copper		....	Red.	8·895	4587	5	3	157·399	5
Mercury		....	White.	13·568	—39	...	...	...	None.
Lead		....	Blue.	11·352	594	8	6	...	14
Tin		....	White.	7·291	442	7	4	24·200	12
Zinc	1541	Paracelsus.	Bluish-white.	6·661	700	6	7	12·720	9
Bismuth	1520	Agricola.	Yellowish-white.	9·822	476	...	...	...	7
Antimony	XVth Cent.	B. Valent.	Bluish white.	6·702	932	...	...	...	10
Arsenic	1723	Brandt.	Grey.	8·308	...	...	...	...	13
Cobalt	..	Ditto.	Grey-white.	8·538	16677	...	...	...	11
Platinum	1741	Wood.	Bluish-white.	21·500	G. B. P.	3	5	124·000	4
Nickel	1751	Cronstedt.	White.	8·279	21877	9	9	..	...
Manganese	1774	Scheele.	Grey-white.	5·850	Ditto.	..	..	...	2
Tungsten	1781	D'Elhuyart.	...	17·600	G. B. P.	..	...	...	1
Tellurium	1782	Muller.	...	6·115	...	...	...	...	...
Molybdenum	Ditto.	Hjelm.	Grey.	7·400	G. B. P.	...	...	...	...
Titanium	1781	Gregor.	Red.	....	Ditto.	...	...	...	...
Uranium	1789	Klaproth.	Grey.	9·000	Ditto.	...	...	...	...
Chromium	1797	Vauquelin.	...	....	Ditto.	...	...	...	...
Columbium	1802	Hatchett.	...	....	Ditto.	...	...	...	...
Palladium	1803	Wollaston.	Bluish-white.	11·300	...	10	10	...	1
Rhodium	Ditto.	Ditto.	Greyish-white.	....	G. B. P.	...	...	...	...
Iridium	Ditto.	Descotils.	...	....	...	...	...	...	...
Osmium	Ditto.	Tenant.	Bluish-black.	....	Ditto.	...	...	...	...
Cerium	1804	Berzelius.	Grey-white.	....	G. B. P.	...	...	...	...
Potassium	1807	Davy.	Ditto.	0·865	136	...	...	...	100
Sodium			Ditto.	0·972	194	...	...	...	100
Barium			...	....	...	...	...	...	...
Strontium			...	....	...	...	...	...	...
Calcium			...	....	...	...	...	...	...
Cadmium	1818	Stromeyer.	White.	8·604.	...	11	11	...	...
Lithium	1818	Arfvedson.	...	....	...	...	...	...	...

Mile, a long measure, which the English, Italians, and some other nations use to express the distance between places; the same as the French use the word league. See *Measure*.

Mill. The term is most commonly applied to machines for grinding corn, but it is likewise used in a more loose sense to denote machines intended for other purposes, as the grinding of bark, for felling wood, for preparing flax, &c. It would be inconsistent for us, in a work like this, to enter into details regarding the structure of any of these mills, this Dictionary not being intended to explain any machines, but those commonly called prime movers, as water wheels, wind mills, and steam engines. We shall, however, insert a series of tables connected with corn mills, which will be found useful for the reference of the practical millwright.

Ferguson gave the following rules for the construction of undershot water-mills. When the float-boards of the water-wheel move with a third part of the velocity of the water that acts upon them, the water has the greatest power to turn the mill: and when the mill-stone makes about 60 revolutions in a minute, it is found to do its work the best. For, when it makes but about 40 or 50 it grinds too slowly, and when it makes more than 70, it heats the meal too much, and cuts the bran so small, that a great part thereof mixes with the meal, and cannot be separated from it by sifting or boulting. Consequently, the utmost perfection of mill-work lies in making the train so, as that the mill-stone shall make about 60 turns in a minute, when the water-wheel moves with a third part of the velocity of the water. To have it so, observe the following rules:

1. Measure the perpendicular height of the fall of water, in feet, above the middle of the aperture, where it is let out to act by impulse against the float-boards on the lowest side of the undershot-wheel.

2. Multiply this constant number 64·2882, by the height of the fall in feet, and extract the square root of the product, which shall be the velocity of the water at the bottom of the fall, or the number of feet the water moves per second.

3. Divide the velocity of the water by 3, and the quotient shall be the velocity of the floats of the wheel, in feet, per second.

4. Divide the circumference of the wheel in feet, by the velocity of its floats, and the quotient will be the number of seconds in one turn or revolution of the great water-wheel on whose axis the cog-wheel that turns the trundle is fixed.

5. Divide 60 by the number of seconds in a turn of the water-wheel, or cog-wheel, and the quotient will be the number of turns of either of these wheels in a minute.

6. By this number of turns divide 60, (the number of turns the mill-

stone ought to have in a minute,) and the quotient will be the number of turns the mill-stone ought to have for one turn of the water or cog-wheel. Then,

7. As the required number of turns of the mill-stone in a minute is to the number of turns of the cog-wheel in a minute, so must the number of cogs in the wheel be to the number of staves in the trundle on the axis of the mill-stone, in the nearest whole number that can be found. By these rules the following table is calculated; in which the diameter of the water-wheel is supposed to be 18 feet, (and consequently its circumference 56$\frac{4}{7}$ feet,) and the distance of the mill-stone to be five feet.

Perpendicular height of the fall of water in feet.	Velocity of the water, in feet, per second.	Velocity of the wheel, in feet, per second.	Number of turns of the wheel in a minute.	Required number of turns of the mill-stones for each turn of the wheel.	Nearest number of cogs and staves for that purpose.		Number of turns of the mill-stone for one turn of the wheel by these cogs and staves.	Number of turns of the mill-stone in a minute by these cogs and staves.
					cogs	staves		
1	8·02	2·67	2·63	21·20	127	6	21·17	59·91
2	11·40	3·72	4·00	15·00	105	7	15·00	60·00
3	13·89	4·63	4·91	12·22	98	8	12·25	60·14
4	16·04	5·35	5·67	10·58	95	9	10·56	59·87
5	17·93	5·98	6·34	9·46	85	9	9·44	59·84
6	19·64	6·55	6·94	8·64	78	9	8·66	60·10
7	21·21	7·07	7·50	8·00	72	9	8·00	60·00
8	22 68	7·56	8·02	7·48	67	9	7·44	59·67
9	24·05	8·02	8·51	7·05	70	10	7·00	59·57
10	25·35	8·45	8·97	6·69	67	10	6·70	60·09
11	26·59	8·86	9·40	6 38	64	10	6·40	60·16
12	27·77	9·26	9·82	6·11	61	10	6·10	69·90
13	28·91	9·64	10·22	5·87	59	10	5·90	60·18
14	30·00	10·00	10·60	5·66	56	10	5·60	59·36
15	31·05	10·35	10·99	5·46	55	10	5·40	50·48
16	32·07	10·69	11·34	5·29	53	10	5·30	60·10
17	33·06	11·02	11·70	5·13	51	10	5·10	59·67
18	34·12	11·34	12·02	4·90	50	10	5·00	60·10
19	34·95	11·65	12·37	4·85	49	10	4·80	60·61
20	35·86	11·92	12·68	4·73	47	10	4·70	59 59
1	2	3	4	5	6		7	8

Example.—Suppose an undershot-mill is to be built where the perpendicular height of the fall of water is nine feet; it is required to find how many cogs must be in the wheel, and how many staves in the trundle, to make the mill-stone go about 60 times round in a minute, while water-wheel floats move with a third part of the velocity with which the water spouts against them from the aperture at the bottom of the fall.

Find 9 (the height of the fall) in the first column of the table; then against that number, in the sixth column, is 70 for the number of cogs in the wheel, and 10 for the number of staves in the trundle; and by these numbers we find in the eighth column that the mill-stone will make $59\frac{57}{100}$ turns in a minute, which is within half a turn of 60, and near enough for the purpose; as it is not absolutely requisite that there should he just 60 without any fraction: and throughout the whole table the number of turns is not quite one more or less than 60.

The diameter of the wheel being 18 feet, and the fall of water nine feet, the second column shows the velocity of the water at the bottom of the fall to be 24·005 feet per second; the third column the velocity of the float-boards of the wheel to he 8·002 feet per second; the fourth column shows that the wheel will make 8·0052 turns in a minute; and the sixth column shows that for the mill-stone to make exactly 60 turns in a minute, it ought to make 7·005 (or seven turns and one-twentieth part of a turn) for one turn of the wheel.

Sir D. Brewster, in the Appendix to his edition of Mr Ferguson's works, shows, that the principles upon which the above table is calculated, are erroneous.

Proceeding upon the practical deductions of Smeaton, as confirmed by theory, and employing a more correct constant number, and a more suitable velocity for the mill-stone, we may construct a new Mill-wrights' Table by the following rules:

1. Find the perpendicular height of the fall of water in feet above the bottom of the mill-course, and having diminished this number by one-half of the natural depth of the water at the bottom of the fall, call that the height of the fall.

2. Since bodies acquire a velocity of 32·174 feet in a second, hy falling through 16·087 feet, and since the velocities of falling bodies are as the square roots of the heights through which they fall, the square root of 16·087 will be to the square roots of the height of the fall, as 32·174 to a fourth number, which will he the velocity of the water. Therefore the velocity of the water may be always found by multiplying 32·174 by the square root of the height of the fall, and dividing that product by the square root of 16·087. Or it may be found more easily by multiplying the height of the fall by the constant number 64·348, and extracting the square root of the product, which, abstracting the effects of friction, will he the velocity of the water required.

3. Take one-half of the velocity of the water, and it will be the velocity which must he given to the float-boards, or the number of feet they must move through in a second, in order that the greatest effect may be produced.

4. Divide the circumference of the wheel by the velocity of its float-boards per second, and the quotient will he the number of seconds in which the wheel revolves.

5. Divide 60 hy this last numher, and the quotient will he the number of revolutions which the wheel performs in a minute. Or the number of revolutions performed by the wheel in a minute, may be found by

multiplying the velocity of the float-boards by 60, and dividing the product by the circumference of the wheel, which in the present case is 47·12.

6. Divide 90 (the number of revolutions which a mill-stone five feet diameter should perform in a minute) by the number of revolutions made by the wheel in a minute, and the quotient will be the number of turns which the mill-stone ought to make for one revolution of the wheel.

7. Then, as the number of revolutions of the wheel iu a minute is to the number of the revolution of the mill-stones in a minute, so must the number of staves in the trundle be to the number of teeth in the wheel, in the nearest whole numbers that can be found.

8. Multiply the number of revolutions performed by the wheel in a minute, by the number of revolutions made by the mill-stone for one of the wheel, and the product will be the number of revolutions performed by the mill-stone in a minute.

In this manner the following table has been calculated for a water-wheel 15 feet in diameter, which is a good medium size, the mill-stone being five feet in diameter, and revolving 90 times in a minute.

DR BREWSTER'S MILLWRIGHTS' TABLE.

In which the velocity of the wheel is three-sevenths of the velocity of the water, and the effects of friction on the velocity of the stream reduced to computation.

Height of the fall of water.	Velocity of the water per second, friction being considered.	Velocity of the wheel per second, being 3 7ths that of the water.	Revolutions of the wheel per minute, its diameter being 15 feet.	Revolutions of mill-stone, for one of the wheel.	Teeth in the wheel, and staves in the trundles.		Revolutions of the mill-stones per minute by these staves and teeth.
Feet.	Feet. 100 parts of a foot.	Feet. 100 parts of a foot.	Rev. 100 parts of a rev.	Rev. 100 parts of a rev.	teeth.	staves.	Rev. 100 parts of a rev.
1	7·62	3·27	4·16	21·63	130	6	89·98
2	10·77	4·62	5·88	15·31	92	6	90·02
3	13·20	5·66	7·20	12·50	100	8	90·00
4	15·24	6·53	8·32	10·81	97	9	89·94
5	17·04	7·30	9·28	9·70	97	10	90·02
6	18·67	8·00	10·19	8·83	97	11	89·98
7	20·15	8·64	10·99	8·19	90	11	90·01
8	21·56	9·24	11·76	7·65	84	11	89·96
9	22·86	9·80	12·47	7·22	72	10	90·03
10	24·10	10·33	13·15	6·84	82	12	89·95
11	25·27	10·83	13·79	6·53	85	13	90·05
12	26·40	11·31	14·40	6·25	72	12	90·00
13	27·47	11·77	14·99	6·00	72	12	89·94
14	28·51	12·22	15·56	5·78	75	13	89·94
15	29·52	12·65	16·13	5·58	67	12	90·01
16	30·48	13·06	16·63	5·41	65	12	89·97
17	31·42	13·46	17·14	5·25	63	12	89·99
18	32·33	13·86	17·65	5·10	61	12	90·01
19	33·22	14·24	18·13	4·96	64	13	89·92
20	34·17	14·64	18·64	4·83	58	12	89·84
1	2	3	4	5	6		7

Tables, showing the quantity of water (ale measure) requisite to grind different quantities of corn, from one to five bolls (Winchester measure) per hour, applied on overshot water-wheels from 10 *to* 32 *feet diameter; also the size of the cylinder of the common steam engine to do the same work.*

The water-wheel, 10 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite, in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	786	12·5
1½	1056	14 6
2	1341	16·75
2½	1617	18·5
3	1894	20·2
3½	2220	21·75
4	2541	23·25
4½	2891	24·75
5	3242	26·25

The water-wheel, 11 feet diameter.

1	705	12·5
1½	945	14·6
2	1188	16·75
2½	1454	18·5
3	1723	20·2
3½	2014	21·75
4	2306	23·25
4½	2626	24·75
5	2944	26·25

The water-wheel, 12 feet diameter.

1	655	12·5
1½	873	14·6
2	1091	16·75
2½	1343	18·5
3	1576	20·2
3½	1840	21·75
4	2117	23·25
4½	2408	24·75
5	2700	26·25

The water-wheel, 13 feet diameter.

1	606	12·5
1½	806	14·6
2	1009	16·75
2½	1234	18·5
3	1458	20·2
3½	1705	21·75
4	1952	23·25
4½	2223	24·75
5	2494	26·25

The water-wheel, 14 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	564	12·5
1½	740	14·6
2	927	16·75
2½	1140	18·5
3	1353	20·2
3½	1583	21·75
4	1811	23·25
4½	2060	24·75
5	2306	26·25

The water-wheel, 15 feet diameter.

1	535	12·5
1½	710	14·6
2	894	16·75
2½	1090	18·5
3	1290	20·2
3½	1503	21·75
4	1717	23·25
4½	1967	24·75
5	2211	26·25

The water-wheel, 16 feet diameter.

1	491	12·5
1½	650	14·6
2	811	16·75
2½	993	18·5
3	1176	20·2
3½	1380	21·75
4	1582	23·25
4½	1802	24·75
5	2023	26·25

The water-wheel, 17 feet diameter.

1	458	12·5
1½	628	14·6
2	770	16·75
2½	943	18·5
3	1117	20·2
3½	1300	21·75
4	1482	23·25
4½	1695	24·75
5	1906	26·25

Tables on Overshot water-wheels, continued.

The water-wheel, 18 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite, in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	410	12·5
1½	595	14·6
2	730	16·75
2½	860	18·5
3	1054	20·2
3½	1227	21·75
4	1400	23·25
4½	1600	24·75
5	1800	26·25

The water-wheel, 19 feet diameter.

1	411	12·5
1½	550	14·6
2	690	16·75
2½	845	18·5
3	1000	20·2
3½	1165	21·75
4	1330	23·25
4½	1517	24·75
5	1707	26·25

The water-wheel, 20 feet diameter.

1	392	12·5
1½	530	14·6
2	675	16·75
2½	808	18 5
3	945	20·2
3½	1110	21·75
4	1270	23·25
4½	1445	24·75
5	1623	26·25

The water-wheel, 21 feet diameter.

1	370	12·5
1½	500	14·6
2	635	16·75
2½	767	18·5
3	900	20·2
3½	1060	21·75
4	1212	23·25
4½	1379	24·75
5	1547	26·25

The water-wheel, 22 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite, in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	350	12·5
1½	473	14·6
2	594	16·75
2½	722	18·5
3	860	20·2
3½	1007	21·75
4	1153	23·25
4½	1313	24·75
5	1472	26·25

The water-wheel, 23 feet diameter.

1	338	12·5
1½	454	14·6
2	570	16·75
2½	707	18·5
3	824	20·2
3½	964	21·75
4	1124	23·25
4½	1258	24·75
5	1412	26·25

The water-wheel, 24 feet diameter.

1	327	12·5
1½	436	14·6
2	545	16·75
2½	671	18·5
3	788	20·2
3½	920	21·75
4	1050	23·25
4½	1204	24 75
5	1350	26·25

The water-wheel, 25 feet diameter.

1	316	12·5
1½	418	14·6
2	520	16·75
2½	635	18·5
3	752	20·2
3½	876	21·75
4	985	23·25
4½	1150	24·75
5	1300	26 25

Tables on Overshot water wheels, continued.

The water-wheel, 26 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite, in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	303	12·5
1½	403	14·6
2	504	16·75
2½	617	18·5
3	730	20·2
3½	852	21·75
4	975	23·25
4½	1111	24·75
5	1247	26·25

The water-wheel, 27 feet diameter.

1	293	12 5
1½	385	14·6
2	482	16 75
2½	593	18·5
3	703	20·2
3½	822	21·75
4	940	23·25
4½	1070	24·75
5	1200	26·25

The water-wheel, 28 feet diameter.

1	282	12·5
1½	370	14·6
2	463	16·75
2½	570	18·5
3	676	20·2
3½	791	21·75
4	905	23·25
4½	1030	24·75
5	1153	26·25

The water-wheel, 29 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite, in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	274	12·5
1½	363	14·6
2	455	16·75
2½	557	18·5
3	660	20·2
3½	770	21·75
4	880	23·25
4½	1005	24·75
5	1130	26·25

The water-wheel, 30 feet diameter.

1	267	12·5
1½	355	14·6
2	447	16·75
2½	545	18·5
3	645	20·2
3½	750	21·75
4	858	23·25
4½	983	24·75
5	1106	26·25

The water-wheel, 31 feet diameter.

1	256	12·5
1½	340	14·6
2	426	16·75
2½	520	18·5
3	620	20·2
3½	717	21·75
4	827	23·25
4½	940	24·75
5	1058	26·25

The water-wheel, 32 feet diameter.

1	245	12·5
1½	325	14 6
2	406	16·75
2½	496	18·5
3	588	20·2
3½	690	21·75
4	791	23·25
4½	900	24·75
5	1012	26·25

To make the foregoing tables applicable to mills intended to be turned by undershot or breast water-wheels: from Smeaton's experiments it appears that the power required on an undershot water-wheel, to produce an effect equal to that of an overshot (to which the tables are applicable,) is as 2·4 to one; and also the power required on a breast water-wheel, which receives the water on some point of its circumference, and afterwards descends on the ladle boards, to produce an equal effect with an overshot water-wheel, is as 1·75 to 1.

A Table, showing the necessary size of the cylinder of the common steam-engine to grind different quantities of corn, from 1 *to* 12 *bolls* (4 *to* 48 *bushels Winchester measure) per hour.*

Bolls of corn ground per hour.	Diameter of the cylinder of a steam-engine to do the same work, in inches.	Bolls of corn ground per hour.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	12·5	7	29·8
1½	14·6	7½	31·1
2	16·75	8	32·
2½	18·5	8½	33·3
3	20·2	9	34·2
3½	21·75	9½	35·2
4	23·25	10	36·
4½	24·75	10½	37·3
5	26·25	11	38·
5½	27·25	11½	38·85
6	28·1	12	39·5
6½	29·		

N. B. This table will be applicable to any improved steam-engine, as well as that of the common kind, if the ratio of their efficacies be known.

Application of the Tables.

Example 1.—If a stream of water, producing 808 gallons, ale measure, per minute, can be applied to an overshot water-wheel 20 feet diameter, what quantity of corn will it be able to grind per hour?

Look in the tables under a 20 feet water-wheel, and opposite 808 gallons will be found 2½ bolls of corn ground per hour.

Example 2.— If a stream of water producing 808 gallons, ale measure, per minute, can be applied to an undershot water-wheel 20 feet diameter, what quantity of corn can it grind per hour?

It is found by the tables, that, if applied on an overshot water-wheel 20 feet diameter, the stream will grind 2½ bolls per hour, and the power required by the undershot to that of the overshot water-wheel, to produce an equal effect, is as 2·4 to 1; therefore, as 2·4 : 1 : 2·5 : 1·04 bolls of corn ground per hour by means of the stream.

Example 3.—If a stream of water, producing 808 gallons, ale measure, per minute, can be applied on a breast water-wheel 20 feet diameter, what quantity of corn can it grind per hour?

It is found by the tables, that, if applied to an overshot water-wheel of equal size, $2\frac{1}{2}$ bolls of corn will be ground per hour, and as the power of a breast water-wheel to that of an overshot water-wheel, to produce an equal effect, is as 1·75 to 1; therefore, as 1·75 : 1 : : 2·5 : 1·42 bolls of corn ground per hour by the stream.

Example 4.—Of what diameter must the cylinder of a common steam-engine be made, to grind 10 bolls of corn per hour?

By looking on the table, given above, opposite 10 bolls ground per hour, the diameter of the steam cylinder will be found to be 36 inches.

MINES, ENGINES FOR. The locality of a mine will determine the manner in which it ought to be drained. Where the mine is situated on the top or side of a hill, a shaft is led from the bottom of the mine to the nearest valley, and the water runs off in this way without the application of pumps wrought by steam engines. Where the mine is situated in a level country pumping becomes necessary; and should the mine be deep, say from 100 to 150 fathoms, very powerful steam engines are required. Where the pumping requires great power, suppose of 200 horses, it is better to construct two small engines than one large one. Where a single engine is used one set of pumps are wrought, and the ascending motion of the piston is employed to raise a weight equal to half the pressure of the water in the pumps. Where two engines are used there are commonly two set of pumps, one set wrought by a diagonal spear attached to the piston end of the beam, and the other set are wrought by the other end. Steam engines for mines should be simple in form and proportioned to the work they have to perform. The pump shaft is divided into lifts, which should not exceed 180 feet each; there is a cistern for the reception of the water, at the top of each lift.—See *Pump*. Rather than make the diameter of the pump more than sixteen inches an additional set should be added. Mining work is irregular, more resistance having to be overcome at one time than another. Mr Tredgold gives it as his opinion that an engine does good duty when it raises 70,000 lbs. of ore by the consumption of one pound of coal. The weight to be raised and one draught varies from 3 to 7 hundred weights. The weight attached to a rope should never be more than 700 times the weight of a fathom of the rope. An approximate rule for determining the weight of a fathom of rope is:—multiply the circumference in inches into itself and that product by 0·27. Thus if the circumference be 9 inches, we have $9 \times 9 \times 0{\cdot}27 = 21{\cdot}87$ lbs. the weight of one fathom of the rope, wherefore $21{\cdot}87 \times 700 = 15309$ lbs. the greatest load it will bear with safety. Engines at mines are sometimes used to break the ore by means of stampers. Two-thirds of the stampers should be on the rise at all times; the weight of each stamper is usually about $1\frac{1}{2}$ cwts.

MINUTE, the sixtieth part of a degree; or, in time, the sixtieth part of an hour.

MOMENTUM, in Mechanics, is the same with impetus, or quantity of motion, and is generally estimated by the product of the velocity and mass of the body. This is a subject which has led to various controversies between philosophers, some estimating it by the mass into the velocity, as stated above, while others maintain that it varies as the mass into the square of the velocity. But this difference seems to have arisen rather from a misconception of the term, than from any other cause. Those who maintain the former doctrine, understanding momentum to signify the momentary impact; and the latter, as the sum of all the impulses till the motion of the body is destroyed.

MOTION, or LOCAL MOTION, in Mechanics, is a continued and successive change of place, or it is that affection of matter by which it passes from one point of space to another. Motion is of various kinds, as follows:—*Absolute Motion*, is the absolute change of places in a moving body independent of any other motion whatever; in which general sense, however, it never falls under our observation. All those motions which we consider as absolute, are in fact only relative; being referred to the earth, which is itself in motion. By absolute motion, therefore, we must only understand that which is so with regard to some fixed point upon the earth; this being the sense in which it is delivered by writers on this subject.—*Accelerated Motion*, is that which is continually receiving constant accessions of velocity.—*Angular Motion*, is the motion of a body as referred to a centre, about which it revolves.—*Compound Motion*, is that which is produced by two or more powers acting in different directions.—*Equable Motion*, or *Uniform Motion*, is when the body moves continually with the same velocity, passing over equal spaces in equal times.—*Natural Motion*, is that which is natural to bodies, or that which arises from the action of gravity.—*Relative Motion*, is the change of relative place in one or more moving bodies; thus two vessels at sea are in absolute motion (according to the qualified signification of this term) to a spectator standing on the shore, but they are only in relative motion with regard to each other.—*Retarded Motion*, is that which suffers continual diminution of velocity, the laws of which are the reverse of those for accelerated motion.—*Projectile Motion*, is that which is not natural, but impressed by some external cause; as when a ball is projected from a piece of ordnance, &c.—*Rectilinear Motion*, that which is performed in right lines.

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Navigation, Steam. In a book by Valturius, entitled "De re Militari," printed at Verona, in 1472, a method is described of propelling vessels by means of paddles or wheels. The vanes, or paddles, were made of pitched sail cloth, and were put in motion by means of cranks. It is beyond doubt that troops were often transported across rivers, during the 15th and 16th centuries, by means of boats, or pontoons, moved by paddles, the paddles being turned by animal strength. Jonathan Hull was the first who proposed to apply steam power to the propelling of vessels. His method of converting the reciprocating into the rotatory motion was ingenious, though by no means so simple as the crank. The steam-boat was patented in December, 1736, and a description, with a drawing, published in a small pamphlet, in 1737, under the title of "A description and draught of a new invented machine for carrying vessels or ships out of or into harbour, port, or river, against wind, or tide, or in a calm." From the date of this invention it is manifest that the engine must have been the old atmospheric engine of Newcommen. The paddle was situated behind the boat. It would appear that, from want of encouragement, the steam-boat of Jonathan Hull was never actually constructed. Two Americans, James Ramsey of Virginia, and John Fitch of Philadelphia, claimed the honour of inventing steam-boats, about 1785, so also did Thomas Paine, but none of their plans were ever brought into practice. Robert Fulton, an American engineer, claimed the honour of being the inventor and constructor of the first steam-boat actually brought into use, but the following extract from his life in the Popular Encyclopedia, will show that his claim is unfounded.

"We must now advert to Mr Fulton's connexion with the practical establishment of navigation by steam. The real inventors of the steamboat were Mr Millar of Dalswinton, and the tutor of his family, Mr James Taylor. The former was the first to suggest the application of paddle-wheels in the propelling of vessels, and the latter to suggest the employment of steam as the moving-power of these wheels. So far back as the year 1788, they constructed a boat on this principle, the engine of which was made by Mr Symington, then a young engineer in Edinburgh. Experiments were made with this boat on the lake of Dalswinton, Dumfries-shire, which proved highly satisfactory, the vessel being driven at the rate of five miles an hour. In the Scots Magazine, for November, 1788, p. 566, we find the following account of these experiments:—

'On Oct. 14, a boat was put in motion by a steam engine, upon Mr Millar of Dalswinton's piece of water at that place. That gentleman's improvements in naval affairs are well known to the public. For some time past, his attention has been turned to the application of the steam-engine to the purposes of navigation. He has now accomplished, and evidently shown to the world, the practicability of this, by executing it upon a small scale. A vessel, twenty-five feet long and seven broad, was, on the above date, driven with two wheels by a small engine. It answered Mr Millar's expectations fully, and afforded great pleasure to the spectators. The success of this experiment is no small accession to the public. Its utility in canals, and all inland navigation, points it out to be of the greatest advantage, not only to this island, but to many other nations of the world. The engine used is Mr Symington's new patent engine.'—The same gentleman, in the following year, constructed, at the Carron foundry, a larger vessel, which was tried on the Forth and Clyde canal in November and December, 1789, and went at the rate of seven miles an hour. An account of various experiments made with this vessel will be found in the Edinburgh newspapers for February, 1790. Soon after this, a misunderstanding arose between Messrs Millar and Taylor, and the prosecution of the invention was by them for some time neglected. Mr Symington, the engineer, meanwhile, did not abandon the project. Having commenced business at Falkirk, he, in 1801, built another experimental steam vessel, which was also tried with success on the Forth and Clyde canal, but was interdicted by the canal company, on account of its motion destroying the banks. This vessel, which lay at Lock Sixteen, was inspected by Mr Fulton, accompanied by Mr Henry Bell of Glasgow, when on a visit to the Carron works; and the consequence was, that, in 1807, Mr Fulton launched a steam vessel on the Hudson, and, in 1812, Mr Bell another upon the Clyde, being respectively the first vessels of the kind used for the service of the public in the new and old hemispheres. Before, however, carrying the discovery to America, Mr Fulton, in company with Robert R. Livingston, American minister to France, made several experiments on the subject. After some trials on a small scale, they built a boat upon the Seine, in 1803, which was completely successful. On Mr Fulton's arrival at New York, in 1806, they immediately engaged in building a boat of what was then deemed very considerable dimensions. This boat began to navigate the Hudson river in 1807: its progress through the water was at the rate of five miles an hour. February 11, 1809, Mr Fulton took out his first patent for navigation by steam; and, February 9, 1811, he obtained a second patent for some improvements in his boats and machinery. In 1811 and 1812, two steam-boats were built under Mr Fulton's directions, as ferry-boats for crossing the Hudson river, and soon after, one of the same description for the East river. Of the former Mr Fulton wrote and published a description, in the American Medical and Philosophical Register, for October, 1812. These boats were what are called *twin-boats ;* each of them being two complete hulls, united by a deck or bridge; sharp at both ends, and moving equally well with either end foremost; so that they cross and recross without losing any time in turning. He contrived, with great ingenuity, floating docks for the reception of these boats, and a means by which they are brought to them without a shock."

To Mr Fulton, however, belongs the great honour of having been the first who endeavoured to investigate on principle, the difficulties of the subject. M. Marestier, in an able report on the steam navigation of America, drawn up by command of the French minister of marine, and published at Paris, in 1824, has described at some length his method of proceeding. It is in principle this: having determined the resistance of the vessel, he inferred that the paddles must experience the same resistance, and that the engine must exert a force at the centre of effort of the paddles, equal to the resistance of the paddles. Assuming then the velocities of the piston and paddles as known, and equivalent to V and v, and the forces on the same as equivalent to F and f, he formed the proportion $V : v : : f : F$; and by dividing the whole force on the piston, by the force exerted by the steam on any given portion of its surface, he obtained the surface of the piston itself, and thence its diameter.

Knowing then the whole resistance on the paddles, and supposing only one paddle on each side to act at the same instant, the area, corresponding to that resistance becomes known, the half of which determines the surface of one paddle. Knowing also from the number of strokes made by the piston, the number of revolutions made by the paddle wheels, the diameter of the wheel may be determined so as to ensure to the paddle the velocity originally assumed. Fulton having in this manner determined the force necessary to propel his boat, and accurately considered the mode by which it might be most successfully applied, avoided the great error of his predecessors, viz. attempting too much with an inadequate power, and gave to steam navigation that splendid and triumphant character which it now possesses; so that within little more than the half of a century after so transcendent a philosopher as Bernouilli had declared the utter improbability of its success, and within less than twenty years after its first successful attempt, has steam navigation arrived at such a perfection, that even a voyage to India has been accomplished, and a passage across the Atlantic by no means regarded as an uncommon thing. What other achievements it is destined to perform, time must develop.

The form of a steam boat must in some degrees assimilate to that of a sailing vessel, but there are many peculiar circumstances to be taken into account in considering of their construction; such as the particular kind of navigation for which they are destined—whether for the open sea, or for the shallower water of rivers and lakes. If for the former, an increased draught of water becomes necessary; but for the latter this element must be less considerable. These considerations are to be inferred from the experiments on the resistance of fluids, in which it has been proved, that the quantity of water beneath the body in motion, has a very important influence on the resistance it experiences; and also, that if the water be at all confined, the resistance is very considerably increased. This circumstance indeed is one of common observation among watermen; and it has been moreover observed in steam boats of different sizes on the same river, that as long as water continued shallow, the smaller boat has had the advantage; but that as the water has gradually deepened, the velocity of the larger boat has increased. A similar observation applies to the area of the midship section, which it is necessary to have as small as possible in boats destined for canals or narrow rivers, since the resistance depends on the relation of the area of the section of the boat, to the area of the section of the fluid.

Steam boats have a very considerable rolling motion, owing to the small proportion their breadth bears to their length, and to the height of the common centre of gravity of the principal weights. This motion arises from a deficiency in stability, and it would be advantageous therefore to adopt that form for tho body most conducive to that very desirable quality. It is also of importance to have the greatest displacement with the least direct resistance, that is, with the least area of the midship section. Supposing the area of the midship section and the breadth to be given, the condition here alluded to, is in favour of a form, full near thc load water line, and lean below. In such a body also, the centre of gravity of the displacement is high, which is favourable to the stability. It moreover enables the body forward and aft to be made finer, than could be the case with a flat-floored midship section. The rising of the floor must, however, be limited by the consideration, that if the engines and other material weights are raised by it, the advantages might be counterbalanced by the effect this would have in raising the centre of gravity of the vessel. There is one great advantage in the extra draught of water, resulting from the rising floor, viz. that the keel, which, by its direct opposition to the water must tend very much to diminish the rolling motion, is at a greater distance from the axis of rotation, and consequently has a proportional greater effect. The rising floor is now generally adopted in the English steam boats.

We have already remarked in a former part of this article, that the form of the sides between wind and water has a very material effect on the rolling of the vessel, and the observation equally applies to steam boats. For this purpose, the moment of stability should increase rapidly but uniformly, and as the vessel performs its alternate oscillations, the centre of gravity of the displacement should remain in the same transverse section. The form of the body also above and below the plane of flotation, should so accord with the position of the centre of gravity, as to cause the different oscillations of the vessel to be performed with the axis of rotation in the same constant plane. The elevation of the chimney, moreover, should be diminished as much as other circumstances will allow, in order that its weight, by raising the centre of gravity of the vessel, does not diminish in too great a degree the stability. The momentum also that the chimney acquires by its almost incessant vibrations, not only increases the rolling of the vessel, but creates also the chance of its being carried away, if the stability be not very well graduated. Not only indeed for the comfort of the passengers, and the perfect ease and security of the engines, but also for the general advantage of the vessel, ought the motions and strains of a steam boat to be rendered as moderate and uniform as possible.

In the English steam boats, the engines are so adapted as to have the axis of the paddle wheel generally *below* the surface of the deck. In the American steamers on the contrary, it is as generally *above*, and even some of their boats which are destined for merchandise have, according to M. Marestier, their engines on the deck. The sides of those vessels being, however, in general nearly vertical for some distance both above and below the water section, it would be advantageous with regard to easiness of motion, to endeavour to adjust the different weights so that the centre of gravity of the boat should be as nearly as possible in the plane of the deck.

In the earlier steam boats it was usual to give great comparative length, in imitation it is said of the relative proportion of row gallies. Thus in the following table, it will be remarked, that the length of the Clermont is to its breadth as 9·3 to 1; whereas the Connecticut, which had precisely the same length, had its breadth so increased as to present the relation of 4·2 to 1. The Clermont was constructed in 1807, and the Connecticut at a much later period. But the Enterprize presents an alteration in this particular of a still more striking kind, her length being 24·38 metres and her breadth 8·84, the two elements presenting the ratio of 2·8 to 1. The objects and destinations of these boats are without doubt very different; but it will be apparent, that in a mechanical structure like a steam boat, wherein the weights are so very unequally distributed, the length ought not to exceed the breadth in any thing like the ratio first mentioned. In steam boats intended for river navigation, the length may without much impropriety be increased, because the strains are much less considerable than in the open sea. In the construction of steamers for rivers, some attention should be paid to length on account of the space necessary for turning them—a circumstance which may sometimes be productive of inconvenience.

The report of M. Marestier is replete with numerous and important tables, one of which we introduce, for the purpose of illustrating the relative dimensions of the length and breadth. The vessels are arranged according to the numerical relations of these dimensions, and not as M. Marestier has given them, according to the places at which they were built.

Names of the Vessels.	Length.	Breadth.	Relation of the length to the breadth.	Draughts of water.
	Metres.	Metres.		
The Clermont in 1807	42·67	4·57	0·107	
The Clermont in 1808	45·72	4·87	0·107	
The Car of Neptune	53·34	7·16	0·134	
Boat of the Union Line	41·50	5·75	0·139	1·37
The Philadelphia	42·75	6·10	0·143	1·22
The Delaware	41·34	6·10	0·148	
Boat being broken up	42·00	6·32	0·150	1·30
The New Jersey	38·00	5·88	0·155	
The Paragon	52·73	8·23	0·156	1·25
The Ætna	34·75	5·50	0·158	1·22
The Washington	40·00	6·40	0·160	1·73
The Surprise	28·65	4·75	0·166	1·22
The Eagle	34·00	5·88	0·173	
The Vesuvius	48·77	8·53	0·175	1·80
The United States	42·64	7·62	0·179	1·52
The Virginia	41·45	7·56	0·182	1·52
The Richmond	46·63	8·53	0·183	1·60
The Fire Fly	30·48	5·64	0·185	
The Norfolk	41·00	7·70	0·188	1·52
The Maryland	41·76	7·92	0·190	1·52
The Robert Fulton	48·16	10·06	0·209	3·05
The Chancellor Livingston	47·55	10·06	0·212	1·83
The Fulton	40·54	8·84	0·218	1·90
The Massachusetts	25·00	5·50	0·220	1·30
The Bellona	28·00	6·25	0·223	
The Olive Branch	37·80	8·84	0·234	1·37
The Connecticut	42·67	10·06	0·236	2·08
The Savannah	30·48	7·92	0·260	4·27
The Enterprize	24·38	8·84	0·363	

The column devoted to the relation of the length to the breadth, was found by dividing the latter dimension by the former. The average length of these boats is 39·82 metres, or 130·64 English feet, and their average breadth 7·15 metres, or 23·46 English feet. The draughts of water, it will be observed, are very variable, arising necessarily from the particular purposes for which the vessels are destined. The Savannah is the steamer that first crossed the Atlantic, and her draught of water, it will be perceived, is the greatest of the whole series. The Robert Fulton, which navigates the magnificent waters of the Mississippi, has a draught of 3·05 metres; whereas the Vesuvius, built for the purpose of navigating the same mighty stream, has only a draught of 1·8 metre, her breadth, however, being 1·53 metre less than the same dimensions of the Robert Fulton, but her length two-thirds of a metre more.

With respect to the draught of steam vessels, there is, however, no necessity for its being so considerable as in sailing vessels, because their great length and straightness of breadth will, in the event of their using sails, supply the place of depth, any useless degree of which serves only to increase the resistance; neither can there be any advantage in a difference of draught of water forward and aft in boats constructed with a rising floor; but, probably with flat floors, it may be necessary to assist the action of the water on the rudder.

Mr Augustin Creuze has lately deduced from M. Marestier's drawings of the steam boat, the Chancellor Livingston, and also from several English boats, and from two which have been lately constructed in England for the service of the Norwegian Government, by Lieut. A. G. Carlsund, of the Swedish Royal Naval Engineers, the exponents of their different elements, as recorded in the following table, according to the parabolical method of Chapman, before alluded to.

	Length of the construction water line.	Depth to the tangent of the midship section.	Exponent of the line of sections.	Exponent of the midship section.	Exponent of the water line	Exponent of the displacement.
	Feet.	Feet.				
English boats,	117·7	7·8	2·7	3·45	5·002	2·10
	98·8	6·2	2·47	5·75	5·206	2·60
	99·8	7·1	2·32	6·96	6·39	2·41
Norwegian,	106·8	6·85	2·5	3·55	6·10	2·00
	95·75	6·25	2·4	4·54	6·54	2·13
American,	150·47	5·41	2·12	4·72	4·03	2·27

It is of importance that the displacement and also the position of the centre of gravity should be accurately determined, on account of the great and constant weights on board a steam vessel being so considerable. It is usual to distribute the coals as much about the centre as possible, and to adjust the position of the centre of gravity of the engine, to the intended purposes of the vessel. It would be proper also to form an estimate of the stability of a steamer with regard to its length, by calculating what effect the removal of a weight to a certain distance either before or aft the centre of gravity, will produce a given difference in the draught of water. This weight being known might be employed as a scale by which to regulate the disposition of other weights; and it is from a neglect of this important particular, that steam boats float at a different draught of water from what was intended.

Unless the displacement is correctly determined, and the area of the midship section also known, and limited moreover to a constant quantity, the power of the engine cannot be determined, so as to ensure a given velocity. Another necessary cause for accuracy with regard to the displacement is, that any alteration from the water-line, in relation to which the height of the axis of the paddle-wheels was determined, might materially affect the action of the paddles themselves; the height of the axis being adjusted in such a manner, that the wheels having a specific diameter, the paddles may obtain such an immersion in the water, as shall cause their inner edge to have a velocity at least equal to that of the vessel, to ensure the absence of resistance on the fore side of the paddle. Hence it appears, that the depth of the paddle depends on the proportion of the velocity of the vessel to that of the velocity of the outer edge of the paddle wheel. It is, moreover, found in practice, that the paddles will not work well if immersed in the water more than eighteen inches or two feet. This circumstances arises from the great loss of power occasioned by the obliquity of the stroke on their entrance into the fluid, and also on their leaving it, and the great quantity of water, moreover, they will lift.

The breadth of the paddle must be regulated by local circumstances, attending to the condition, that the greater the arc of the paddle, the less is the loss of power occasioned by the motion it communicates to the fluid. Bernouilli estimates this loss for the common oar to be $\frac{297}{1000}$ of the whole force applied. Sea-going boats should in general have their paddles narrower than boats intended for smooth water.

The number of paddles on a wheel is at present wholly determined by practice. One paddle for every foot the wheel is in diameter, is the general rule followed. If they are too near each other, they do not meet the water with all the advantage they ought; and if too far apart, the motion which their successive and distinct impact with the water communicates to the vessel is unpleasant.

Neither theory nor practice has yet determined where the axis of the paddle wheel should be placed with regard to the length of the vessel. M. Marestier has given us the following of its situation in several American boats. Its position is, however, always very much limited by that of the engine.

Positions of the Paddle Axis.			
Names of the Vessels.	Distance of the axis from forward.	Distance of the axis from aft.	Ratios of the preceding distances, the antecedent terms being unity.
	Metres.	Metres.	
The Chancellor Livingston	23·775	23·775	1 : 1·00
The Philadelphia of Trenton	18·25	24·50	1 : 1·34
The New Jersey	17·00	21·00	1 : 1·24
The Delaware	16·64	24·70	1 : 1·48
The Powhatan	16·50	18·50	1 : 1·12
The Norfolk	16·00	25·00	1 : 1·56
The United States	15·64	27·00	1 : 1·73
The Virginia	15·26	26·19	1 : 1·72
The Washington	14·50	25·50	1 : 1·76
The Philadelphia of Baltimore	14·00	27·00	1 : 1·93
The Eagle	14·00	20·00	1 : 1·43
The Bellona	12·00	16·00	1 : 1·33
The Fulton	10·12	10·42	1 : 1·03

This table proves that the position of the paddle axis is very variable in different vessels. In the Chancellor Livingston it is placed in the middle of its principal axis, and very nearly so in the Fulton; but in the Philadelphia of Baltimore, the deviation from the centre is very considerable, and the greatest of the whole series. In the United States, the Virginia, and the Washington, the deviation is also very great.

Many of the boats on the Mississippi have their wheels abaft, that they may be protected from the logs of timber incessantly floating on that mighty river, thus practically exemplifying the original idea of Hulls. Many vessels also, intended only for short passages, and where a small draught of water is necessary, are built with two bodies, with the wheel placed between them. This plan, however, is not found advantageous for boats with any considerable draught of water.

When there are two paddle wheels on each side, their relative velocities, with respect to the water, should be equal, in order that they may exert an equal force on the vessel. If this were not the case, the aftermost wheel would operate disadvantageously: for as the water on which the aftermost wheel acts, has had an increased velocity communicated to it by the action of the foremost wheel, the absolute velocity of the aftermost wheel must be proportionally greater than that of the foremost; a circumstance which would require a greater quantity of steam, and consequently a greater consumption of fuel. There would also be a waste of power, unless each pair of wheels had separate engines: and it is probable that the aftermost wheels would lose a portion of their effect, in consequence of the disturbed state of the water they acted on.

The following important table was communicated to M. Marestier by one of the principal engineers of New York, as the result of his experience with regard to the proportions between the dimensions of a vessel and its engine; and, in order to make this part of his useful and important work as complete as possible, he has added another table, the result of his own inquiries, containing the principal proportions of the engines and paddle wheels, &c. of the steam boats, the dimensions of which have been given in the preceding tables.

A Table of the principal Proportions of Steam Engines as adapted to Vessels of known dimensions.

	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Dimensions of the vessel. Burden	160	200	260	320	400	500
	Metres.	Metres.	Metres.	Metres.	Metres.	Metres.
Length	22·5	27·0	33·0	37·5	40·5	42·0
Breadth	6·6	7·2	8·1	9·6	10·2	10·8
Draught of water	1·2	1·5	1·8	2·1	2·4	2·55
	No.	No.	No.	No.	No.	No.
Horse power of the Engine	20	30	40	60	80	100
	Metres.	Metres.	Metres.	Metres.	Metres.	Metres.
Diameter of the cylinder	0·60	0·75	0·93	1·00	1·10	1·20
Height of the cylinder	1·50	1·50	1·55	1·55	1·80	1·80
Length of the boiler	4·80	6·00	6·00	6·60	6·60	7·20
Breadth of ditto	2·40	2·55	2·70	3·00	3·15	3·60
Height of ditto	2·10	2·40	2·40	2·70	3·00	3·00
Diameter of the paddle-wheels	4·80	5·10	5·40	5·40	5·70	6·00
Length of the paddles	1·50	1·65	1·80	1·80	2·10	2·10
Depth of ditto	0·60	0·60	0·75	0·90	0·90	0·90
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Weight of the engine	20	25	30	35	40	45

Dimensions of the Engines and Paddle-wheels of the Vessels contained in the former Tables.

Names of the Vessels.	Date of the construction.	Diameter of the piston.	Stroke of the piston.	Diameter of the wheels.	Number of the paddles.	Length of the paddles.	Depth of the paddles.
		Metres.	Metres.	Metres.	No.	Metres.	Metres.
The Clermont	1807	0·610	1·22	4·60	8	1·20	0·60
The Car of Neptune	1808	0·838	1·32	4·25	—	1·20	0·70
The Paragon	1811	0·813	1·22	4·90	8	1·30	0·75
The Fire Fly	1812	0·508	1·14	3·80	—	1·05	0·60
The Richmond	1813	0·838	1·32	4·60	8	1·20	0·60
The Washington	1813	0·711	1·22	4·50	8	1·35	0·45
The Fulton	1813	0·914	1·22	4·70	8	1·50	0·70
The Olive Branch	1816	0·914	1·22	5·00	10	1·45	0·75
The Connecticut	1816	1·016	1·37	5·20	10	1·45	0·75
The Chancellor Livingston	1816	1·016	1·52	5·50	8	1·75	0·90
The Philadelphia of Trenton	—	—	—	5·20	12	—	0·55
The Delaware	—	0·812	1·37	5·50	12	1·75	0·75
An old boat at Baltimore	—	0·740	1·22	5·30	12	0·95	0·55
The New Jersey	—	—	—	5·20	10	1·80	0·65
The Philadelphia of Baltimore	—	0·830	—	5·60	16	—	—
The Virginia	—	0·889	1·22	5·40	—	1·75	0·75
The Norfolk	—	—	—	6·00	12	1·75	—
The Maryland	1818	1·016	1·42	6·00	12	1·75	0·65
The United States	1818	1·016	1·42	5·50	10	2·00	0·75
The Massachusetts	—	—	—	5·00	8	1·80	0·80
The Robert Fulton	1819	1·130	1·52	5·50	10	2·00	—
The Savannah	1819	1·035	1·52	4·90	10	1·42	1·08

M. Marestier has also given the following comparative table of the results he has observed, and calculated for ten boats, of which he was able correctly to ascertain the velocities.

Table of the comparative proportion and dimensions deduced from ten American Steam Boats.

Names of the Vessels.	Elasticity of the steam.	Number of revolutions of the wheels in a minute.	Velocity of the piston in a second.	Proportion of the paddles.	Velocity of the inner edge of the paddles in a second.	Velocity of the vessel.		Factor of the diameter of the wheels.	Multiplier.
						in a second.	in an hour.		
	Metrs.		Metrs.		Metres.	Metres.	Miles.		
The Washington .	0·95	20	0·81	18·1	3·77	2·57	5·0	35·0	23·70
The Fulton . . .	1·10	$18\frac{1}{2}$	0·75	16·0	3·20	2·8	5·4	31·0	23·50
The Olive Branch .	0·95	$18\frac{1}{2}$	0·75	11·1	3·39	3·0	5·8	30·8	23·72
The Connecticut . .	0·35	17	0·78	19·2	3·29	3·15	6·1	28·1	23·78
The Chancellor Livingston	0·95	17	0·86	11·7	3·29	2·9	5·6	32·2	23·90
The Delaware . .	1·30	$17\frac{1}{2}$	0·80	6·4	3·67	3·5	6·8	27·5	21·90
The Virginia . .	1·10	$18\frac{1}{4}$	0·74	8·8	3·73	3·3	6·4	29·9	25·24
The United States .	1·15	$16\frac{1}{2}$	0·78	7·7	3·43	3·3	6·4	27·5	20·29
The Maryland . .	1·05	17	0·80	10·6	4·18	3·6	7·0	28·3	24·66
The Savannah . .	0·90	16	0·81	31·0	2·71	2·6	5·0	30·2	27·65

In the first column, the measure of the elasticity of the steam, is represented by the height of the column of mercury it will support in a vacuum.

The column devoted to the proportion of the paddles, is the quotient of the rectangle of the breadth and draught of water of the boat, divided by the area of one of the paddles.

The number which he terms the factor of the diameter of the wheels, he obtained by considering, that if the vessels were similar, and the resistances to the paddles bore in all of them the same invariable relation to the resistance of the hull, the diameter of the paddle wheels would be equal to the velocity of the boat multiplied by a constant factor, and divided by the number of double oscillations of the piston. The mean of these factors being between 29 and 30, it follows, that if the proportion the velocity of a steam boat bears to the number of strokes of the piston, be multiplied by 29 or 30, the result will give nearly the dimensions of paddle wheels similarly proportioned to those in the American boats.

The last column denominated the multiplier, is a number which Marestier deduced, to show the relation which the true velocity of a boat bears to the following quantity: The square root of the product of the height of the column of mercury the steam will support, the stroke of the piston, and the square of its diameter, divided by the square root of the product of the rectangle of the breadth and draught of water of the vessel, and the diameter of the paddle wheel.

If the different boats were equally perfect in their respective elements, there would be no necessity for a different multiplier for each boat; but, as the forms of their bodies, and the qualities of their engines differ considerably, the multipliers must necessarily vary.

M. Marestier finds, that the variation for the first nine boats recorded in the table is between twenty and twenty-five. The Savannah he did not include in his computation, as he had no precise information respecting her.

To accomplish this he supposes the motion of the vessel to become uniform, and the force of the steam constant; and on this hypothesis, and the data he has collected in the preceding table, he investigates the proportions which exist between the power of the engine, the dimensions of the vessel, of the paddles, and the wheel. He assumes, moreover, that the resistance of the paddles is equal to the resistance of a surface moved in the fluid in a direction perpendicular to itself, and having a velocity equal to the mean velocity of the paddles. This surface, which ho denominates

The resisting surface of the paddles, is represented by a^2
The velocity of the resisting surface by . U
The resisting surface of the vessel by . . b^2
And the velocity of the vessel by . . V

Each of these quantities he proposes to derive from experiment.

1. The resistance of the hull being supposed proportional to the square of the velocity, is equivalent to $k\, b^2\, V^2$, the function k being the measure of the direct resistance corresponding to the unity of surface and velocity.

Then the velocity with which the paddles strike the fluid being U—V, the resistance they experience will be

$$k\, a^2\, (U-V)^2.$$

and $$U = \left(1 + \frac{b}{a}\right)V.$$

The velocity of the vessel is therefore always proportional to that of the paddles, while the resisting surface of the vessel bears a constant relation to the surface of the paddles.

2. The moments arising from the action of the paddles on the water, and the steam on the piston, are equivalent to each other, omitting the effects of friction. The absolute velocity of the paddles being also U, and the resistance they meet with $k\, a^2\, (U-V)^2$ the moment of their action, will be $k\, a^2\, (U-V)^2\, U$.

Supposing q to represent the density of the mercury, h the altitude of the column the steam will support, P the surface of the piston, and v

the measure of its mean velocity; then will the moment of the piston be equivalent to $q\,h\,P\,v$, and consequently

$$q\,h\,P\,v = k\,a^2\,(U-V)^2\,U.$$

3. Since the effect of the friction of the machine is to diminish the effect of the moving force communicated from the piston to the paddles, a portion only of the moving force $q\,h\,P$ is taken, and which is represented by $m\,q\,h\,P$. Hence we obtain

$$V = \sqrt[3]{\left(\frac{m\,q\,h\,P\,v}{k\,b^2\left(+\frac{b}{a}\right)}\right)}, \text{ and}$$

$$U = \sqrt[3]{\left(\frac{m\,q\,h\,P\,v}{k\,b^2}\left(1+\frac{b}{a}\right)^2\right.}$$

4. From these formulæ we may draw the following conclusion:—that the cube of the velocity of the vessel is less than the power of the engine, divided by the resistance of the vessel; and that the cube of the mean velocity of the paddles is also greater than the same quantity—a limit only to be attained when the paddles are infinite.

5. If we suppose a second boat to exist, the elements U', V' a', b', &c. of which are analogous to those of U, V, a, b, &c. adopted for the former boat, we may obtain by the common processes of reduction

$$\frac{V'}{V} = \sqrt[3]{\left(\frac{m'\,h'\,P'\,v'}{m\,h\,P\,v}\cdot\frac{b^2}{b'^2}\cdot\frac{1+\frac{b}{a}}{1+\frac{b'}{a'}}\right)},$$

$$\text{and } \frac{U'}{U} = \sqrt{\left(\frac{m'\,h'\,P'\,v'}{m\,h\,P\,v}\cdot\frac{b^2}{b'^2}\cdot\left(\frac{1+\frac{b}{a'}}{1+\frac{b}{a}}\right)^2\right)}.$$

So also when the resisting surfaces of the paddles are, in both vessels, proportional to the resisting surfaces of their hulls,

$$\text{we obtain } \frac{b'}{a'} = \frac{b}{a};$$

$$\text{and consequently } \frac{V'}{V} = \frac{U'}{U} = \sqrt[3]{\left(\frac{m'\,h'\,P'\,v'}{m\,h\,P\,v}\cdot\frac{b^2}{b'^2}\right)}.$$

Hence it follows, that the velocities of the boats are proportional to the velocities of the paddles, and they are also in a direct proportion to the cube root of the power of the engines, and in an inverse proportion to the cube root of the resistance of the vessels. M. Marestier considers this proposition nearly general; because, unless there is a very great disproportion in the dimension of the vessels, the relation of $1 + \frac{b}{a}$ to $1 + \frac{b'}{a'}$, cannot differ much from unity.

Throughout these investigations, M. Marestier has regarded h as the altitude of the column of mercury, which the steam when acting on the piston will support, and determined the effort of the piston, under the supposition that the vacuum on the contrary side of the piston is perfect; but as such a condition cannot exist, the quantity h should be diminished by the height, which, the steam remaining on the contrary side of the piston, will depress the mercury from the altitude at which it would stand in a common barometer. This is an important consideration when comparing one boat with another, because the degree of the vacuum must depend wholly on the goodness of the engine.

6. From the equations $b\,V = a\,(U—V)$,

and $m\,q\,h\,P\,v = k\,a^2\,(U—V)^2\,U$,

we may deduce $UV^2 = \frac{m\,q\,h\,P\,v}{k\,b^2}$.

Therefore whatever may be the dimensions of the paddles, the product of their velocity and the square of the velocity of the vessel is in proportion to the power of the engine.

Although the power of the engine has been considered as known, it is seldom that the velocity of the piston can be taken arbitrarily. The relation of this velocity to that of the paddles is almost always invariable, and therefore the velocity of the piston alters with any increase or diminution in the size of the paddles. This however will not make any change in the conditions of the preceding question; but the value of v will vary according to the alteration. It may happen either that the velocity of the piston is too great to admit of an adequate supply of steam, or that the supply of vapour is too great, and some necessarily escapes by the safety valve. In the first case, the elastic force of the vapour will diminish until the movement of the piston shall correspond to the quantity of steam supplied; and in the second case, to prevent the loss of steam, the intensity of the fire must be diminished; but then the power of the engine will be reduced in the proportion of the actual velocity of the piston to that which it ought to have.

That the velocity of the piston may correspond to the quantity of steam furnished by the boilers, the mechanism must be so arranged as to satisfy the equation

$$U = \sqrt[3]{\left(\frac{m\,q\,h\,P\,v}{k\,b^2}\left(1 + \frac{b}{a}\right)^2\right)};$$

or if r represents the relation between the velocities of the piston and paddles, we may obtain the equation

$$r = \frac{U}{v} = \sqrt[3]{\left(\frac{m\,q\,h\,P}{k\,b^2\,v^2}\left(1 + \frac{b}{a}\right)^2\right)},$$

Of the quantities a, b, h, P, r, U, V, and v contained in the equations.

$$U = \left(1 + \frac{b}{a}\right)V,$$

$$m\,q\,h\,P\,v = k\,a^2\,(U - V)^2U$$

$$\text{and } U = r\,v,$$

any five being known, the remaining three may be readily determined. Thus, if the values of the elements a, b, h, P, r, are known, and it be required to determine the values of U, V, and v, we shall obtain from the preceding equations

$$U = \left(\frac{1}{b} + {}_{a}\right)\sqrt{\frac{m\,q\,h\,P}{k\,r}}$$

$$V = \frac{1}{b}\sqrt{\frac{m\,q\,h\,P}{k\,r}},$$

$$\text{and } v = \left(\frac{1}{b} + \frac{1}{a}\right)\sqrt{\frac{m\,q\,h\,P}{k\,r^3}}.$$

Since the velocity of the vessel is independent of the element a, it follows, that as long as the value of r remains unchanged, the surface of the paddles may be either increased or diminished without producing any alteration in the velocity of the boat. At the same time also it appears, from an inspection of the function representing the value of v, that we cannot augment the dimensions of the paddles, without diminishing the velocity of the piston, and causing a greater consumption of steam and fuel.

If the diameter of the wheels be diminished, the velocity of the steam boats will be increased; but the velocity of the piston and the power of the machine being increased also, will require a greater consumption of steam and fuel. Hence an increase of velocity may be obtained by diminishing the diameter of the wheels, provided that the boiler will furnish more steam than the engine consumes.

If, on the contrary, the diameter of the wheels be increased, the vessel will lose velocity; but this cannot be avoided, if after having increased the surface of the paddles as much as is consistent with other circumstances, it is found that the engine has too great a velocity for the supply of steam furnished by the boiler.

If, again, the diameter of the wheels be diminished by taking away a portion of each paddle, the velocity of the vessel will be increased, because the value of the element r is diminished; but then it must be remarked, that more steam will be consumed than if the change had been made in the diameter, without diminishing the surface of the paddles.

When any alteration is made in the mechanism which communicates motion from the piston to the wheels, the elements r, U, V, and v, become respectively r', U$'$, V$'$, and v'. Hence we have

$$V' = \frac{1}{b}\sqrt{\frac{m\,q\,h\,P}{k\,r'}},$$

$$\text{and } v' = \left(\frac{1}{b} + \frac{1}{a}\right)\sqrt{\frac{m\,q\,h\,P}{k\,r'}};$$

$$\text{Consequently, } V' = V\sqrt{\frac{r}{r'}} = V\sqrt[3]{\frac{v'}{v}},$$

$$v' = v\sqrt{\frac{r^3}{r'^3}},$$

$$\text{and } r' = r\sqrt[3]{\frac{v^2}{v'^2}}$$

Hence it follows, that when the piston does not partake of the velocity which the steam furnished by the boiler would admit in any change of the mechanism, the velocity of the boat will be reduced in proportion to the cube root of the velocity of the piston; and in order that the vessel may acquire the velocity which the engine is capable of imparting, the value of r must be diminished inversely as the cube root of the square of the velocity of the piston.

The value of $V = \frac{1}{b}\sqrt{\frac{m\,q\,h\,P}{k\,r}}$ being more simple than that before deduced for the same element, admits of an easier comparison with the velocities before observed. It admits, however, of further simplification.

For this purpose let p represent the diameter of the piston, and π the relation of the diameter to its circumference, then will

$$P = \frac{p^2\,\pi}{4}$$

In the American vessels, the wheels generally make one turn for every double stroke of the piston; and, therefore, supposing c to represent the length of a stroke of the piston, and n the number of revolutions of the wheel in a minute, we shall have

$$v = \frac{2\,n\,c}{60} = \frac{n\,c}{30}$$

Calling also the absolute diameter of the paddle wheels D, its mean diameter will be δ D, where δ denotes a quantity to be determined by experiment. Hence we have

$$U = \frac{n \times \pi \delta D}{60},$$

$$\text{and consequently, } r = \frac{U}{v} = \frac{\pi \delta P}{2 c}.$$

The resisting surface of the vessel before assumed as equivalent to b^2, depends essentially on the shape of the vessel, and perhaps on its velocity; but as it is known that it increases in proportion as the draught of water and breadth are augmented, we may suppose it proportional to the rectangle B of the dimensions alluded to, and which therefore furnishes the equation

$$b^2 = \beta B,$$

the element β being determined by experiment.

Substituting this value of b^2 in the equation

$$V = \frac{1}{b}\sqrt{\frac{m q h P}{k r}},$$

$$\text{and we shall have } V = \sqrt{\frac{m q}{2 k \beta \delta}}\sqrt{\frac{h c p^2}{BD}}.$$

The density of the mercury $q = 13{\cdot}6$; and it may also be remarked that the value of k, when the body exposed to the impulse of the water is thin, as in the case of the paddles, is about $\frac{6}{100}$, unity being the weight of a cubic metre. There are several causes, however, which render it difficult to determine the values of m, β, and δ, as they vary under different circumstances. The best boats, M. Marestier observes, will be found to be those where the value of $\frac{m}{\beta \delta}$ is the greatest.

8. For the object in view, it is sufficient to know the value of $\sqrt{\frac{m q}{2 k \beta \delta}}$, which has been designated the multiplier. Supposing it to be represented by M, we have

$$V = M\sqrt{\frac{h c p^2}{BD}}.$$

In the last table it will be perceived that M. Marestier has deduced the multipliers for several vessels, the values of which, omitting the instance of the Savannah, vary from about 20 to 25, and the mean he fixes at 22. Since, however, the value of the multiplier, all other things remaining the same, depends on the perfection of the engine and vessel, it cannot be strictly correct to apply to one vessel a number deduced by experiments on others far inferior to it. It is to be remarked that the velocities which M. Marestier has given of the American boats are small in comparison with those of the more modern English boats. The latter boats require therefore higher multipliers than the former.

9. The equation $U = \left(1 + \frac{b}{a}\right) V$ before given, will undergo some convenient modifications, by substituting in it the values of b and U deduced from the equations $b^2 = \beta B$, and $U = \frac{n \pi \delta D}{60}$, and also adopted for a^2 the resisting surface of the paddles, the quantity A α, the function A representing the area of one of them. These substitutions will transform the first-mentioned equation $U = \left(1 + \frac{b}{a}\right) V$, into

$$\frac{n \pi \delta D}{60} = \left(1 + \sqrt{\frac{\beta}{\alpha}} \sqrt{\frac{B}{A}}\right) V,$$

and from which we may deduce

$$D = \frac{60 \left(1 + \sqrt{\frac{\beta}{\alpha}} \sqrt{\frac{B}{A}}\right)}{\pi \delta} \cdot \frac{V}{n}.$$

The function $\frac{60}{\pi \delta}\left(1 + \sqrt{\frac{\beta}{\alpha}} \sqrt{\frac{B}{A}}\right)$ is that which has been denominated the factor of the diameter of the wheels, and of which the mean value is thirty. If we designate this function by F, we shall obtain the equation

$$D = F. \frac{V}{n}$$

10. By means of the equations

$$V = M \sqrt{\frac{h\, c\, p^2}{BD}}, \text{ and } D = F. \frac{V}{n}$$

in which the co-efficients M and F, taken at their mean experimental values are 22 and 30, we can resolve such questions as relate to the proportions and principal dimensions of engines and vessels constructed on principles similar to those of the Americans. We obtain, for example, from the equations referred to

$$n = M\, F \sqrt{\frac{h\, c\, p^2}{BD^3}},$$

which enables us to remark, that though from the first of the two equations given, it appears to be advantageous to diminish the diameter of the wheels, that cannot be done unless the boiler will produce enough of steam to admit of their performing a greater number of revolutions.

Again, by eliminating D from the same equations, we obtain,

$$V = \sqrt[3]{\left(\frac{M^2}{F} \cdot \frac{n\,h\,c\,p^2}{B}\right)};$$

or since,

$$\sqrt[3]{\frac{M}{F}} = 2{\cdot}53 \text{ nearly}$$

we may have,

$$V = 2{\cdot}53 \sqrt[3]{\frac{n\,h\,c\,p^2}{B}}$$

Hence it appears that the velocity of a steam boat is equal to the cube root of the product of the following quantities: The altitude of the column of mercury the steam will support, the square of the diameter of the piston, the length of its stroke, and the number of times it is raised in a minute; divided by the cube root of the product of the breadth of the vessel into its draught of water, and the quotient multiplied by a constant coefficient.

By employing this expression for calculating the velocities of the first nine vessels contained in the comparative table, it will be found, says M. Marestier, that the error is generally less than one-tenth of the actual value.

The coefficient 2·53 above deduced, depends on the form of the vessel. Its value might be 2·25 for a form experiencing apparently a great resistance; or it may be 2·75, or even more, for a contrary form.

11. If the value of B be regarded as unknown, we shall obtain,

$$B = \frac{M^2}{F} \cdot \frac{n\,h\,c\,p^2}{V^3}$$

or since the value of the coefficient $\frac{M^2}{F}$ is nearly equivalent to 16, we shall have,

$$B = \frac{16\,n\,h\,c\,p}{V^3}$$

Hence, the engine being given, we can determine the area of a parallelogram, whose base shall be the breadth of a vessel which the engine can move with a given velocity, and altitude equal to the draught of water.

12. From the equation $n\,c\,h\,p^2 = \frac{B\,V^3}{16}$ we may also find the power it is requisite an engine should possess, to enable it to move a given vessel with a determinate velocity. We see, moreover, that this force increases as the cube of the velocity.

13. Having found that

$$v = \frac{c\,n}{30}, \text{ or } c\,n = 30\,v,$$

we shall obtain, by substituting in the value of V before given, that

$$V \quad \sqrt[3]{\left(\frac{M^2}{F} \cdot \frac{30\,v\,h\,p^2}{B}\right)};$$

and when the velocity of v is equivalent to $\frac{8}{10}$ of a metre, which is the case in most of the American boats, we shall farther have

$$V = 7{\cdot}3\,\sqrt[3]{\frac{h\,p^2}{B}}.$$

This equation may be employed in the same manner as the preceding, to determine the size of a vessel, or the power of an engine, by supposing B or $h\,p^2$ as unknown.

M. Marestier objects to the method commonly employed of estimating the power of a steam engine, by the number of horses it would require to perform the same quantity of work, since the nominal power of the engine under these circumstances, must very much depend on the estimated power of a horse. He proposed a method, certainly of a much more philosophic character, and capable of affording more accurate results. Multiply, says he, the height of the column of mercury the steam will support, by the square of the diameter of the cylinder, and the mean velocity of the piston; sixty-six and two-thirds of this product will be the number representing the horse power. Then will the velocity be equal to twice the cube root of the quotient of the number of horses, divided by the rectangle of the draught of water, and the breadth of the vessel.

The power of an engine capable of communicating a required velocity to a boat may be found, he informs us, by multiplying the cube of the velocity by the breadth, and by the draught of water, and dividing the resulting product by 7·26, or by 6, as the circumstances of the vessel may require.

The surface of the parallelogram also, which has the breadth of the vessel for its base, and the draught of water for its altitude, may be determined, by dividing the number of horse power of the engine, by the cube of the required velocity, and multiplying the resulting quotient by 7·26, or 6, as the conditions of the vessel may require.

In considering the motions of steam vessels in rivers, M. Marestier introduces the consideration of the velocity of the current, and also attends to the effect produced, by causing the action of the engine to be applied to winding a rope round a roller, the outer end of the rope being attached to a fixed point on the shore. His general results are as follow: To stem a current with the least consumption of fuel, the absolute velocity of the vessel should be only half the velocity of the steam. That the velocity resulting from the use of the rope and roller is greater than that which results from the use of the paddle-wheel, in the proportion of the cube root of the velocity of the paddle to the cube root of the velocity communicated by the paddles to the vessel. That to enable the vessel to stem a current with an absolute velocity equal to half the velocity of the current, it requires three times the motive power, if that power acts on board the vessel, that would be necessary if the power were applied to the rope. That when the current is rapid, it is advantageous to use the rope for hauling, in order to stem it; but that if the current is not strong, it is preferable to use the paddles; and that the paddles should always be used in descending a stream, when the absolute velocity of the vessel is greater than the velocity of the paddles, or when the velocity of the stream is greater than the velocity with which the paddles strike the water, which will generally be the case.

Much remains to be done to perfect the theory and practice of steam boats; yet in a department of knowledge so comparatively new, it is remarkable what rapid steps have been already made towards its improvement. "The motion of boats, their forms, and proportions," says Mr Tredgold, in an ingenious and able paper on the subject, "will afford many fine subjects for the application of science." Let us hope, that "Man, nature's minister and interpreter," will not cease his endeavours to carry it onwards to perfection.

Mr Tredgold, in his ingenious disquisition, observes, that in still water, it may be assumed, that the resistance of the same vessel is sensibly proportional to the square of the velocity; the variation from the law being, he considers, too small to produce a sensible effect within the range to which the velocity is limited in practice. Therefore if a be the force that will keep the boat in uniform motion at the velocity u, the force that will keep it in motion at the velocity, will be found by the analogy,

$$u^2 : v^2 : : a : \frac{a\,v^2}{u^2},$$

which is the measure of the resistance with the velocity v. Hence the mechanical power required to keep the boat in motion with the same velocity, will be $\frac{a\,v^3}{u^2}$; and from which it follows, that the power of a steam engine to impel a boat in still water, must be as the cube of its velocity. Therefore, if an engine of twelve horses power will impel a boat at the rate of seven miles an hour in still water, and it be required to determine what power will move the same boat at ten miles per hour, we shall have

$$7^3 : 10^3 : : 12 : \frac{10^3 \times 12}{7^3} = 35;$$

or an engine of thirty-five horses power.

This immense increase of power to obtain so small an increase of velocity, says Mr Tredgold, ought to have its influence in fixing upon the speed of a boat for a long voyage, and its proportion ought to be adapted for that speed, with a proper excess of power for emergencies. A low velocity should be chosen, when goods as well as passengers are to be conveyed. The example before given, places this in a very striking point of view; for to increase the velocity of the same boat from seven to ten miles an hour, requires very nearly three times the power, and of course three times the quantity of fuel, and three times the space for stowing it, besides the additional space occupied by a larger engine. Therefore if seven miles per hour will answer the purposes of the trade the vessel is to conduct, the advantages of the lesser speed must be evident.

According to these principles, Mr Tredgold has computed the following table, illustrating the power necessary to communicate to a boat different velocities.

3 miles per hour	$5\frac{1}{2}$ horses power.
4 . . .	13
5 . . .	25
6 . . .	43
7 . . .	69
8 . . .	102
9 . . .	146
10 . . .	200

In short voyages, the extra quantity of engine room and tonnage for fuel is not so objectionable; but in a long voyage, it reduces the useful tonnage to so small a proportion, as to render it doubtful whether such vessels will answer or not. The consumption of fuel to produce a given effect, is much greater than in engines on land; and perhaps much in consequence of the draught of the chimney, and the limited space for the boiler.

When the paddles of a steam boat are in action, there is a point in each paddle, wherein if the whole reaction of the fluid was concentrated, the effect would not be altered. This point Mr Tredgold denominates the centre of reaction.

By supposing the fluid at rest, the velocity of the centre of reaction

V, and the velocity of the boat v, the velocity with which the paddles strike the water will be $V - v$. Or the difference between the velocity of the paddles and the velocity of the boat, is equal to the velocity with which the paddles act on the water. Hence when these velocities are the same, the paddles have no force to impel the boat; and if the paddles were to move at a slower rate, they would retard it.

Now, as $V - v$ represents the velocity, the force of the reaction will be as $(V - v)^2$, since this quantity is proportional to the pressure producing the velocity $V - v$. But during the action of the paddles, the water yields with a velocity $V - v$; and since the velocity of the boat is v, the effective power is as

$$V - v : v :: (V - v)^2 : v\,(V - v).$$

The effect of this power in a given time, is a maximum, when $v^2 (V - v)$ is a maximum; that is when $2\,V = 3\,v$; or when the velocity of the centre of reaction of the paddles is $1\frac{1}{2}$ time the velocity of the boat.

It is desirable that the action of the paddles should be as equable and continuous as possible, unless they be arranged so that the variation of the power of the engine may coincide with the variation in the action of the paddles. But in attempting to render the action of the paddles equable, their number ought not to be increased more than can be avoided, because there is not then time for the water to flow between them, so as to afford a proper quantity of reaction; neither do they clear themselves so well in quitting the water.

To determine the radius of the wheel, or the depth of the paddles, when the number of the paddles is given, becomes an easy problem, when the preceding conditions are to be adhered to.

Mr Tredgold gives the following rules for finding the radius of the wheel, when the number and depth of the paddles are given. Divide 360 by the number of paddles, which will give the degrees in the angle contained between two adjacent paddles. From unity subtract the natural cosine of this angle, and the depth of the paddles divided by the remainder will give the radius of the wheel.

Thus, if the number of paddles be 8, and their depth $1\frac{1}{2}$ foot, we shall have $\frac{360^\circ}{8} = 45^\circ$, the cosine of which is ·7071. Therefore $\frac{1{\cdot}5}{1 - {\cdot}7071}$ $= 5{\cdot}12$ feet, the radius of the wheel.

Again, if the number of paddles be 7, and their depth 1·5 foot as before, we again have $\frac{360^\circ}{7} = 51^\circ\ 26'$, the cosine of which is ·6234. Consequently $\frac{1{\cdot}5}{1 - {\cdot}6534} = 4$ feet, the radius of the wheel desired.

It is obvious, continues Mr Tredgold, that, by enlarging the wheel, the obliquity of the action on entering the water may be reduced; but it also may be done by lessening the depth of the paddles, where the angles are the same in both wheels. Hence it is useful to be able to find the depth; and if the number of the paddles and the radius of the wheel be given, the depth may be found by the foregoing rule:

Multiply the radius of the wheel by the difference between unity and the natural cosine of the angle contained between two paddles, and the product is the depth required. Suppose, for example, the radius to be 4·5 feet, and the number of paddles eight, there will be 4·5 (1—·7071) = 1·318 feet, for the depth of the paddles.

Mr Tredgold thinks eight paddles to be as small a number as ought to be adopted, and where large wheels can be admitted, nine or ten might be used with advantage, but where many paddles are employed, the wheels must necessarily be of large diameter, to keep them narrow. The advantages of wheels of large diameter consist in the favourable direction they strike the water, and also quit it; the paddles are also more distant from one another, and while they have more re-action on the water, they splash it about much less; the weight of the wheel also renders it more effective as a regulator of the forces acting upon it. On the contrary, there are some strong practical objections to very large wheels for sea vessels; they give the force of the waves a greater hold on the machinery, they are cumbersome and unsightly, and they raise the point of action too high above the water line, so that the choice requires both experience and judgment.

The best position for the paddles appears to be in a plane passing through the axis, as represented in the figures. If they be in a plane which does not coincide with the axis, they must either strike more obliquely on the fluid in entering, or lift up a considerable quantity in quitting it. With respect to the shape of the paddle, it is clear that it should be such that the resistance to its motion should be the greatest possible, and the pressure behind it the least possible. These conditions appear to be fulfilled in a high degree by the simplest of all forms, the plane rectangle; but we might learn much from a judicious set of experiments on this subject.

As there is some variation in the force of re-action against the paddles, it may in some measure be compensated by making its periods coincide with the variation in the force of the engine. To effect this, the stroke of the engine should be made in the same time as is occupied by that part of the revolution of the paddle wheel, which is expressed by a fraction, having the number of paddles for its denominator, and the piston should be at the termination of its stroke, when one of the paddles is in a vertical position. For, when one of the paddles is in a vertical position, the re-action is the least, and it is greatest when two paddles are equally immersed, at which time the force would be acting at right angles to the crank.

Having shown the power that is necessary to keep a boat in motion in still water, it will be some advantage to resume the inquiry in the case where it moves in a stream or current; and, for that purpose, let v be the velocity of the boat, and c that of the current; a being the resistance when the boat is in motion with the velocity u.

Then the resistance to be overcome to give the boat the velocity v, is, when the motion is with the stream,

$$u^2 : (v-c)^2 : : a : \frac{a\,(v-c)^2}{u^2}.$$

And, when the boat moves against the stream, we have

$$u^2 : (v+c)^2 : : a : \frac{a\,(v+c)^2}{u^2}.$$

Hence the power is expressed in either case by

$$\frac{a\,(v \mp c)^2}{u^2},$$

the upper sign of which is to be attended to when the motion is with the current, and the lower sign when it is against it.

When c the velocity of the current, is nothing, the result is the same as before. But the resistance in still water is not the mean between the resistances in the direction of the current, and against the current; consequently, the mean rate of a boat, which alternately goes with and against a current, must be less than the mean rate in still water. The mean resistance is

$$\frac{a\,v\,(v^2 + c^2)}{u^2},$$

while the resistance in still water is only $\frac{a\,v^3}{u^2}$, the difference between which and the former is $\frac{a\,v\,c^2}{u^2}$; a quantity depending on the velocity of the current, and for any particular case, should be calculated from the mean motion of the current.

When a boat advances with a current, the velocity with which the paddles act on the water will be $V + c - v$; and when the boat moves against the current, it will be $V - c - v$; consequently in either direction it is $V + c - v$; and the force of re-action $(V \pm c - v)^2$. But the effective resistance of the boat is as

$$V \pm c - v : v : : (V \pm c - v)^2 : v\,(V \pm c - v);$$

and its effect in a given time is a maximum, when $v^2 (V + c - v)$ is a maximum, that is when

$$V = \frac{3v + 2c}{2},$$

or when $V = 1{\cdot}5\, v \mp c$. Moreover,

$$v = \frac{2(V \mp c)}{3}.$$

When c vanishes, or the boat moves in still water, $\frac{2V}{3} = v$, the same as before. The mean also between moving against and with the current is $\frac{2V}{3} = v$. Therefore, where the velocity cannot be changed to suit the circumstances, this will be the best proportion for all cases. Where the force of a current is considerable, it would be extremely desirable to have the power of altering the velocity of the wheels; but this should not be accomplished by any alteration of velocity in the steam piston, since whatever change is made in its velocity must affect the power of the engine. There is no difficulty, Mr Tredgold imagines, in adopting such a train of mechanism as would produce the alteration of velocity required, and yet be as strong and durable as the ordinary combination, and not at all expensive, compared with the object to be gained by introducing it. It will only be necessary to provide for an increase of velocity; for, when the boat goes with the stream, the rate of the paddles is already too great; whereas, when a boat moves against the current, both an increase of the velocity of the wheel, and an increase of surface of the paddle, is necessary to maintain the mean rate.

Mr Tredgold concludes his very interesting investigations, by inquiring into the velocity a boat may be expected to acquire when the power is the same. The power P of the engine may be represented, as we have before determined, by the equation

$$P = \frac{a\, v\, (v \mathbin{\bar{\times}} c)^2}{u^2};$$

and if the ratio of the current to the velocity of the boat be as $1 : n$: that is, $1 : n :: v : c = n\, v$, we shall have

$$P = \frac{a\, v^3 (1 \mp n)^2}{u^2},$$

$$\text{or, } v = \left(\frac{P\, u^2}{a\,(1 \mp n)^2}\right)^{\frac{1}{3}}$$

If the boat moves in a current, of which the velocity is n times the velocity of the boat, we shall have

	Velocity of the current with the stream, 4 miles per hour.	Velocity of the boat, 8 miles per hour.
	2·2	6·6
	1·53	6·12
Still water	0·00	5·00
Against the stream	1·08	4·34
	1·38	4·16
	1·92	3·85
	2·38	3·58
	3·17	3·17

This table shows that a power capable of moving a boat at the rate of five miles per hour, in still water, will only move it at the rate of a little more than three miles per hour against a current of the same velocity as the boat; and that the speed of the same boat would be eight miles per hour, when moving with a current of which the velocity is four miles per hour. It should be remarked, that these calculations suppose the area of the paddles, and their velocity, to be adjusted to the maximum proportions in each case; were it otherwise, the velocity with the current would be increased, and the velocity against the current diminished.

The investigation of this subject to any greater extent would be inconsistent with the nature of this work. We shall however give the results of the investigations of Mr W. Barlow, in a paper *On the laws which govern the motion of Steam Vessels*, which appeared in the Philosophical Transactions for 1834.

1. That when the vessels are so laden that the wheel is but slightly immersed, there is little advantage in the vertically acting paddle.

2. In cases of deep immersion, it has considerable advantage over the common wheel, as at present constructed.

3. That in the common wheel, while the paddle passes the lower part of the arc, or when its position is vertical, it not only affords less resistance to the engine, but is less effective in propelling the vessel than in any part of its revolution.

4. That in the new wheel, the paddle, while passing the lower part of the arc, affords more resistance to the engine, and is more effective in propelling the vessel, than in any part of its revolution.

This property of the vertical paddle is a serious deduction from the value of the wheel; for in consequence of the total resistance to all the paddles being so much less than in the common wheel, much greater velocity is required to obtain the requisite pressure, which is attended with the consumption of an additional quantity of steam, and, in course, of a proportionate loss of power.

This loss of power is most sensible when the wheel is slightly immersed; whereas the lost power, from the oblique action of the common wheel, is then scarcely perceptible. When the vessel is more immersed, and the angle of inclination at which the paddle enters is greater, the proportion of lost power in the common wheel is much increased, while that of the vertical paddle remains nearly constant, so that in cases of deep immersion, the vertical paddle has considerably the advantage.

5. That in any wheel, the larger the paddles the less is the loss of power; because the velocity of the wheel is not required to exceed that of the vessel in so high a degree, in order to acquire the resistance necessary to propel the vessel.

6. That with the same boat and the same wheel, no advantage is gained by reducing the paddle, so as to bring out the full power of the engine; the effect produced being simply that of increasing the speed of the wheel, and consuming steam to no purpose.

7. That with the same boat and the same wheel an increase of speed will be obtained by reducing the diameter, or by reefing the paddle floats at least within certain limits, viz. as long as the floats remain immersed in the water, and the velocity of the engine does not exceed that at which it can perform its work properly.

This is very evident; for, as the engine will exert a greater power at a less radius or lever, it will cause the velocity of the paddles through the water to increase, and, consequently, an increased resistance upon them, which is the true measure of the force that propels the wheel.

The resistance on the paddle will of course be increased in the ratio of the radius or lever; the velocity of the vessel will therefore be increased inversely as the square root of the radii.

The reverse will of course be true, viz. that by increasing the diameter of the wheel, the velocity of the boat will be decreased in the above ratio.

8. That an advantage would be derived from a wheel of large diameter, so far as the immersion of the paddle produced by loading the vessel would not so sensibly affect the angle of inclination of the paddle; this, however, cannot be attained advantageously with an engine of the same length of stroke, because to allow it to make its full number of strokes with the large wheel, the size of the paddles must be diminished, which is a much greater evil than a wheel of small diameter with larger paddles. To have larger wheels, it is therefore either necessary to have the engines made with longer strokes, or to have the paddle wheel on a different shaft to the engine, in order to diminish their speed. These are both practical inconveniences in sea boats, and we must therefore consider the wheels to have gained their greatest limit in point of diameter. For the navigation of rivers, as the construction of the boats will admit of

much greater speed given to them than is at present attained, larger wheels may be employed.

The ill effect resulting from making the wheel of too large diameter, and the paddles too small, is very sensibly exhibited in the experiment on the Medea. Her engines have the same length of stroke as those of the Salamander, Phœnix, and Rhadamanthus, and the wheel is twenty-one feet in diameter to the centre of pressure, while those of latter vessels are not above eighteen feet five inches, or eighteen feet six inches. The consequence is a considerable loss of power, from the greater velocity of the wheel than of the ship, the whole power of the engine being brought out in both cases. This loss of power is, of course, still small, compared with that of the common wheel when deeply immersed, so that in the experiment at Sheerness, her superiority of speed is perfectly consistent with the preceding calculations; at the same time we have no hesitation in saying, that an increase of speed of half a mile per hour at least might be obtained by a smaller wheel and more surface of paddle board.

A great portion of the foregoing article has been taken, but with very considerable modifications, from the article Ship Building, in the Edinburgh Encyclopedia. The whole article is replete with valuable information.

The following tables will be found very useful for reference.

Table of Proportions and Dimensions of several Steam Boats.

Name of Engineer	Robert Napier, Glasgow.				
Name of vessel	CITY OF GLASGOW.	DUNDEE.	SOVEREIGN	COLERAIN.	DUCHESS OF SUTHERLAND.
Name of Builder	J. Wood.	J. Wood.	J. Wood.	J. Wood.	C. Wood.
Length of keel, fore rake	155 feet	170 feet	136 feet	133 feet	150 feet
Breadth of beam	24 ft. 4 in.	28 feet	23 ft. 6 in.	24 ft. 6 in.	26 feet 6 inches
Draught of water	10 ft 6 in.	11 ft 6 in.	10 feet	9 feet	10 feet 6 inches
Depth of hold	16 feet	17 ft. 6 in.	14 ft. 11 in.	11 ft. 6 in.	15 feet 6 inches
Diameter of paddle	21 feet	24 feet	21 feet	18 feet	21 feet
Tonnage, register	550 tons	650	..	..	..
Horse power	250	300	288	170	220
Engines, number	2 engines	2 engines	2 engines	2 engines	2 engines
Average speed	$12\frac{1}{2}$ knots per hour	13 knots per hour	$11\frac{1}{2}$ knots per hour	11 knots per hour	$12\frac{1}{2}$ knots per hour
Used for	Liverpool & Glasgow packet, 90 passengers	Dundee and London packet, 108 passengers	Aberdeen & Leith, 62 passengers	Port Rush & Liverpool packet, 50 passengers	Inverness and London, 89 passengers
Date of construction	1835	1834	1836	1835	1835

Table of Experiments to ascertain the Speed of the following Steam Vessels, in which is also stated the Power of the Engines, the Diameter of the Wheels, the size of Paddle, Number of Strokes of the Piston, &c., made by O. Lang, Esq.

Names of Vessels.	Tonnage.	Horse power.	Chaldrons of coals on board.	Stores.	Diameter of wheel.	Length of paddle.	Depth of paddle.	Immersion of paddle.	Number of strokes per minute.	Diameter of cylinders.	Length of stroke.	Speed miles per hour.
					Ft. In.	Ft. In.	Ft. In.	Ft. In.		Inches.	Ft. In.	
Alban	294	100	14	None.	13 0	9 0	1 6	Not known.	27	40	3 6	8·84
Messenger	730	200	60	Channel service.	19 4	10 0	2 0	..	20½	53¼	5 0	9·75
Messenger	730	200	130	Ditto.	19 4	10 0	2 0	..	18	..	5 0	8·0
Pluto	365	100	14	None.	14 4	9 0	1 10	1 9	26½	40	3 6	10·15
Hermes	730	140	130	Channel service.	17 6	9 0	2 0	Not known.	18	44	4 6	6·3
Meteor	296	100	8	Ditto.	13 0	9 0	1 6	1 6	32	40	3 6	9·0
Firebrand	494	140	10	None.	17 0	9 0	2 0	2 4	24	44	4 6	10·15
Firebrand, Morgan's wheels	494	120	12	Channel service.	14 6	Diam. polygon.		2 11½	28	42	4 0	10·55
Flamer, Morgan's wheels	494	120	15	None.	13 0	Ditto ditto		3 11½	27	42	4 0	10·9
Carron	291	100	8	None.	13 0	9 0	1 6	1 4	28	40	3 6	9·15
Carron, Galloway's wheels	294	100	8	None.	17 0	Not known.		3 2	22½	40	3 6	8·33
Dee	710	200	30	None.	19 4	10 0	2 0	1 6	23	53¾	5 0	10 61
Rhadamanthus	820	220	46	None.	20 4	9 0	2 6	Not known.	20	55½	5 0	10·39
Salamander	820	220	210	Channel service.	20 4	9 0	2 6	5 6	15	55½	5 0	8·15
Firefly	550	140	152	Ditto.	17 6	9 0	2 0	3 4	20	44	4 6	8·3
Magnet	360	140	6	None.	16 0	10 0	1 6	1 8	29½	44	4 6	11 75
Phœnix	820	220	12	None.	20 4	9 0	2 6	2 6	21	55½	5 0	11·7
Medea, Morgan's wheels	840	220	15	None.	21 0	Of the polygon area of paddle 21 ft.		3 11	23	55½	5 0	11·33
Columbia, Morgan's wheels	360	100	80	Channel service.	14 0	Of the polygon area of paddle 11·85		1 10	24	40	3 6	8·5
Firebrand, Morgan's wheels	494	120	40	Ditto.	14 6	Diam. polygon.		3 7	27	42	4 0	10·1
Flamer, Morgan's wheels second experiment	494	120	112	Channel service.	13 0	Ditto ditto		5 6	24	42	4 0	9·57

NOTE.—The wheels distinguished as Morgan's wheels are of a particular construction, by which the paddle is made to enter the water nearly perpendicularly, and leave it also in a like position; thereby avoiding the shock otherwise caused by the paddle striking the water on its entrance, and the back water thrown up by the common wheel on its exit.

These paddles are not always rectangular, but frequently of the shape shown in the annexed figure, and they turn on an axle in the line $a\ b$, which generally about bisect their area, and on which line the centre of pressure may be supposed to be situated, as they pass nearly perpendicularly through the water; whereas the common paddle, passing through the water circularly, different parts of it move with different velocities, which bring the mean centre of action below the middle. Moreover, the more remote parts act longer than those nearer the centre of motion, which brings this centre still lower. Calculation makes this point divide the depth of the paddle in the ratio of sixty-two to thirty-eight: but it will be enough for our purpose to take the ratio as three to two; and according to this proportion, the effective diameters of the several wheels given in the preceding Table, are computed and inserted in the following Table; at least in all the common wheels. Those of Morgan's construction, from what is above stated require no deduction.

In this Table is also shown the tonnage per horse power; the area of paddle per horse power; the relative velocity of the boat, the paddle, and piston; and the computed horse power employed in propelling one vertical paddle in each wheel, and the proportion of the whole power of the engines expended on the paddles.

Table of Proportional Numbers deduced from the preceding Data.

Names of Vessels.	Tonnage.	Horse power	Tons per horse.	Area of paddle per horse.	Depth of paddle.	Effective diameter of wheels.	Ratio of velocity of wheel and piston	Ratio of velocity of vessel and piston.	Ratio of velocity of vessel and wheel.	Ratio of the whole power to that on one paddle in each wheel.
				Feet.	Ft. In.	Ft. In.				
Alban	294	100	2·94	·27	1 6	12 0	5·4	4·1	·74	6·9
Messenger	730	200	3 65	·20	2 0	18 0	5·6	4·0	·73	5·7
Ditto	730	200	3·65	·20	2 0	18 0	5·6	3·9	·69	5·6
Pluto	365	100	3·65	·34	1 10	13 2	5·9	4·8	·82	6·6
Hermes	730	140	5 21	·25	2 0	16 2	5·6	3·4	·72	3·2
Meteor	296	100	2 96	·27	1 6	12 0	5·4	3·5	·65	2·3
Firebrand	494	140	3·51	·25	2 0	15 8	5·4	4·1	·76	4·9
Carron	294	100	2·94	·27	1 6	12 0	5·4	4·1	·76	6·3
Dee	710	200	3·55	·20	2 0	18 0	5·6	4·1	·72	3·8
Rhadamanthus	820	220	3.66	·204	2 6	18 8	5·9	4·5	·78	7·5
Salamander	820	220	3·66	·204	2 6	18 8	5·9	4·8	·80	18·0
Firefly	550	140	3.93	·245	2 0	16 2	5·6	4·1	·72	5·8
Phœnix	820	220	3·66	·204	2 6	18 8	5·7	4·5	·83	12·0
Magnet	360	140	2·57	·214	1 6	15 0	5·3	3·9	·74	6·0
Firebrand, Mor. wheels	494	120	4·11	·212	..	14 6				
Flamer, Morgan's wheels	494	120	4·11	·220	..	13 0				
Flame; 2d exp. ditto	494	120	4·11	·220	..	13 0				
Medea, ditto	820	220	3·66	·172	..	21 0	6·7	4·4	·66	1·9
Columbia	360	100	3·60	·237	..	14 0	6·2	4·3	·70	4·2

Proportions and Dimensions of several English Steamers.

	Engine Builders, Maudslay, Son, and Field, London.								
Name of the vessel	DEE.	ENTERPRISE.	COMMERCE.	BEURS VAN AMSTERDAM.	LONDON ENGINEER.	LIGHTNING.	HARLEQUIN.	IVANHOE.	CRUSADER.
Name of the builder of the vessel	..	..	..	..	Brent.				
Length of deck	166 ft. 7 in.	..	..	..	..	126 feet			
Breadth, extreme	30 feet.	26 feet	22 feet 4 in.	25 ft. 10 in.	24 feet	22 ft. 4 in.	21 feet	18 ft. 6 in.	16 ft. 2 in.
Draught of water	10 feet.	14 feet	10 feet	8 feet	5 feet	8 ft. 2 in.	7 ft. 8 in.	7 feet	6 ft. 3 in.
Paddle wheels, diameter	20 feet.	15 feet	18 feet	16 feet	12 ft. 6 in.	15 feet	13 feet	12 ft. 6 in.	11 ft. 6 in.
Paddle wheels, breadth	10 feet.	7 feet	7 feet	8 feet	6 ft. 6 in.	9 feet	7 feet	6 feet	5 ft. 6 in.
Paddle wheels velocity of extremity in miles per hour	..	12·8 miles							
Paddles depth									
Tonnage (register)	700 tons.	500 tons	400 tons	500 tons	315 tons	296 tons	232 tons.	160 tons	95 tons
Total power of engines	200 h. p.	120 h. p.	140 h. p.	120 h. p.	70 h. p.	100 h. p.	80 h. p.	60 h. p.	50 h. p.
Velocity in still water									
Coals per hour	..	..	..	..	630 pounds Weylm coals	1240 pounds average.			
Engines, number	2 engines	2 engines	2 engines	2 engines	2 engines	2 engines	2 engines	2 engines	2 engines
Engines, diameter of cylinders	53 inches	43 inches	46½ inches	43 inches	36 inches	40 inches	36 inches	32 inches	29½ inches
Engines, length of stroke	60 inches	48 inches	54 inches	48 inches	30 inches	48 inches	42 inches	36 inches	36 inches
Engines, strokes per minute	20 strokes	24 strokes	22 strokes	25 strokes	28 strokes	25 strokes	28 strokes	30 strokes	32 strokes
Engines, diameter of air pump									
Used for	Navy.	East Indies.	Liverpool and Dublin	Amsterdam and London	Margate Packet	Navy	Post Office Packet	Post Office Packet	Post Office Packet
Date of construction	1827	1825	1826	1826	1818	1824	1824	1826	1827
Calculated power of engines at the best velocity and full pressure	272 h. p.	160 h. p.	197 h. p.	160 h. p.	88 h. p.	137 h. p.	104 h. p.	76 h. p.	68 h. p.

Table of the Proportions and Dimensions of several English Steamers, continued.

	Engine Builders, Boulton and Watt, Soho, Birmingham.							Fenton & Co. Leeds.
Name of the vessel	SOHO.	JAMES WATT.	CITY OF EDINBURGH.	SHANNON.	SOVEREIGN GEORGE IV.	CALEDONIA.	METEOR.	HERO.
Name of builder of vessel	..	Wood and Co.	Wigram.	Fletcher & Son	Evans	Wood and Co.	Evans	Bancham.
Length of deck	163 feet	146 feet	143 feet	180 feet	126 feet	95 ft. 6 in.	..	..
Breadth (extreme)	27 feet	25 ft. 8 in.	25 ft. 6 in.	49 feet	21 ft. 10 in.	15 ft. 0 in.	20 feet	..
Draught of water	..	10 ft. 0 in.	..	..	8 ft. 6 in.	4 ft. 6 in.	..	6 ft. 4 in.
Paddle wheels diameter	15 ft. 8 in.	18 ft. 0 in.	18 feet	..	16 feet	..	..	14 ft. 0 in.
Paddle wheels, breadth	8 feet	9 ft. 0 in.	8 feet	..	8 feet	..	8 feet	8 ft. 0 in.
Paddle wheels, velocity of extremity in miles per hour	14·6 miles	12 miles.	12 miles.	..	..	..	..	15 miles.
Paddles depth	2 feet	2 ft. 0 in.	2 feet	..	..	..	..	1 ft. 6 in.
Tonnage (register)	510 tons	448 tons	400 tons	513 tons	210 tons	102 tons	190 tons	233 tons
Nominal power of engines	120 h. p	100 h. p.	80 h. p.	160 h. p.	80 h. p.	28 h. p.	60 h. p.	90 h. p.
Velocity per hour in still water	..	10 miles	..	..	9 miles	8½ miles	..	11½ miles
Coals per hour	..	..	..	..	896 pounds	..	560 pounds	2240 pounds
Engines, number	2 engines	2 engines	2 engines	2 engines	2 engines	2 engines	2 engines	2 engines
Engines, diameter of cylinders	42 inches	39 inches	36 inches	..	..	..	..	..
Engines, length of stroke	48 inches	42 inches	42 inches	..	..	..	..	..
Engines, strokes per minute	26 strokes	27¼ strokes	27¼ strokes	..	..	..	..	30 strokes
Engines, diameter of air pump	23 inches	21 inches	19½ strokes	..	..	..	..	..
Used for	Passengers	Passengers	Passengers	Passengers and 200 tons goods	Post Office Packet	..	Post Office Packet	Margate Packet
Date of construction	1823	1821	1821	1826	1821	1815	1821	1821
Calculated power of engines at the best velocity and full pressure	151 h. p.	122 h. p.	104 h. p.	..	..	..	..	..

Table of the Proportions and Dimensions of several English Steamers, continued.

	Engine Builder, Napier, Glasgow.				Engine Builders, Faucett & Littledale, Liverpool.				
Name of the vessel	UNITED KINGDOM.	MAJESTIC.	SUPERB.	TALBOT.	ST PATRICK.	PRINCE LLEWELLYN.	ALBION.	DUKE OF LANCASTER.	CAMBRIA.
Name of builder of vessel	..	Scott and Co.	Scott and Co.	Wood and Co.		Nottershead	and	Hayes.	
Length of deck	175 feet	..	..	92 feet	130 feet	..	103 ft. 6 in.	103 feet	91 ft. 1 in.
Breadth (extreme)	45 ft. 6 in.	..	..	17 ft. 11 in.	20 ft. 1 in.	..	18 ft. 1 in.	17 feet	17 ft. 6 in.
Draught of water	..	..	..	..	13 ft. 8 in.	..	9 ft. 6 in.	9 ft. 6 in.	8 ft. 4 in.
Paddle wheels, diameter									
Paddle wheels, breadth									
Paddles, velocity of extremity									
Paddles, depth									
Tonnage (register)	1000 tons	350 tons	241 tons	140 tons	200 tons	170 tons	103 tons	94 tons	86⅓ tons
Power of engines	200 h. p.	100 h. p.	70 h. p.	60 h. p.	100 h. p.	70 h. p.	60 h. p.	50 h. p.	50 h. p.
Velocity per hour in still water	..	10 miles	9 miles						
Coal per hour	2240 pounds	2240 pounds Scotch coals	1670 pounds Scotch coals	784 pounds Scotch coals					
Engines, number	2 engines	2 engines	2 engines	..	2 engines	2 engines	2 engines	2 engines	2 engines
Engines, diameter of cylinders	..	..	..	..	42 inches	..	32 inches	..	30 inches
Engines, length of stroke	..	..	..	..	42 inches	..	33 inches	..	30 inches
Engines, stroke per minute	..	28							
Engines, diameter of air pump									
Used for	Edinburgh packet, 175 passengers	..	..	Post Office Packet					
Date of construction	1826	1816	1820	1819	1822	1822	1822	1822	1822
Calculated power of engines at the best velocity and full pressure		..	..	..	142 h. p.	..	73 h.p.	..	67 h. p.

One of the largest steam vessels, now afloat, is the Monarch, belonging to the London and Leith Steam Packet Company; it was built by Messrs Green, Wigram, and Green, in 1833, from the plan of Mr Charles Wood, of Port Glasgow. It was superintended while building by the present scientific commander, William Bain, Esq., a master in the Royal Navy, by whom we have been favoured with the following dimensions of the hull, and other particulars.

Length of keel . .	180 feet.
Over all	208
Beam for tonnage .	32
Hold	18·4
Extreme breadth . .	55·4

It is propelled by two engines of one hundred horse power each, constructed by Boulton and Watt. Cylinders 53 inches; diameter stroke 5 feet; extreme diameter of paddles 21 feet, floats 10 feet by $2\frac{1}{2}$ feet; the average speed is $10\frac{1}{2}$ miles. The voyage from London to Leith has been performed in 39 hours. The space occupied by the machinery and the coal space measure 60 feet by 32 feet; the coal space will contain 140 tons. The weight of the machinery and boilers is 226 tons. The average consumption of coals is 21 hundred-weight per hour.

This vessel makes up one hundred and fifty beds for passengers, and one hundred are comfortably and elegantly accommodated in the saloon at dinner.

The appointments of the vessel are as below:

Commander . . .	1
Officers	3
Seamen	12
Engineers	2
Fire men and coal trimmers	8
Boatswain and mate . .	2
Carpenter	1
Cook and mate . . .	2
Stewards	10
Female attendants . . .	2
Total	43

Node, in the doctrine of curves, is a small oval figure, made by the intersection of one branch of a curve with another.

Nonagon, a figure of nine angles and nine sides. The angle at the centre of a nonagon is 40°, the angle subtended by its sides 140°, and its area when the side is $1 = 6{\cdot}1818242$, consequently the square of the side $\times$ 6·1818242 will give the area of the figure.

Non-condensing Engines, that class of steam engines commonly called high pressure. Such engines act by the excess of the pressure of steam above the pressure of the atmosphere. The steam commonly employed is such as to exert a pressure on the piston of between 30 and 40 lbs. on the square inch. Mr Tredgold divides non-condensing engines into two classes, the first comprehending those in which the generative force of steam alone is employed; the second, in which the generative and expansive forces are brought into action. See *Steam Engine.*

The power of a non-condensing engine may be determined by ascertaining the force of the steam in the boiler, above the atmospheric pressure, by means of the steam guage, and reckoning that the effective pressure upon the piston is six tenths of this, then will the rule be: Take the force of the steam in the boiler in lbs. per circular inch, above the pressure of the atmosphere, and multiply it by 0·6, subtract from this product the constant number 4·6, multiply the remainder by the square of the diameter of the cylinder in inches, and this last product by the number of feet that the piston travels per minute, the result will be the number of pounds' weight that the engine will raise per minute. By symbols the rule will stand thus

$$(F \times 0{\cdot}6 - 4{\cdot}6) \times d^2 \times v = E,$$

where F is the force of the steam in the boiler, d the diameter of the cylinder in inches, v the velocity of the piston in feet per minute, and E the effect of the engine. Thus, let the force of steam in the boiler be 30 lbs. to the circular inch, the diameter of the cylinder 15 inches, the length of stroke 3 feet, and the number of strokes per minute 30, we have

$$(30 \times 0{\cdot}6 - 4{\cdot}6) \times 15^2 \times 2 \times 3 \times 30 = 541800 \text{ lbs.}$$

raised one foot high per minute, which being divided by 33000 will give

$$\frac{541800}{33000} = 16{\cdot}41 \text{ horses power.}$$

This rule only holds when the steam does not act expansively.

When the engine acts expansively the problem becomes a little more complex. The first thing to be done in this case is to find the mean pressure of the steam upon the piston, for since it is cut off before the termination of the stroke, the pressure must decrease from the moment that it is cut off. The steam may be cut off at any fractional part of the stroke, as ½, or ⅓, or ¼, &c., or in general we may say at the $\frac{1}{n}$ part of the stroke. Let the steam then be cut off at the $\frac{1}{n}$ part of the stroke, find the hyperbolic logarithm of n, (see *Logarithms*,) and multiply it by 2·3, and add 1 to the product; divide this sum by n, and from the quotient subtract 0·4, multiply the remainder by the force of the steam in the boiler per circular inch, subtract 11·55, and the result is the mean pressure of the steam on the piston.

This being found, the power of an engine under such circumstances is easily determined by the following rule.—Multiply the mean pressure on the piston by the square of the diameter of the cylinder in inches, and that product by the velocity of the piston in feet per minute, the result will be the number of pounds the engine can raise one foot high per minute, which, divided by 33000, gives the number of horses power. Suppose a cylinder 12 inches diameter, the force of the steam in the boiler 46 lbs. to the circular inch, the velocity of the piston 160 feet per minute, the steam being cut off at the 1–1·5th part of the stroke

Log. 1·5 × 2·3 is =	0·405	
Add	1·	
Divide by 1·5	1·404	
	0·936	
Subtract	0·4	
	536	
Multiply by	46	the full pressure on the boiler.
	24·656	
Subtract	11·55	the atmospheric resistance.
	13·106	lbs. mean pressure on the piston.

	144	diameter of cylinder squared.
Multiply by	160	speed of piston.
	23040	
Multiply by	13·1	mean pressure.
	301824	lbs. raised one foot high per minute.
Divide by	33000	gives 9·146 horses' power.

Normal, is the same as perpendicular.

Nozzles, that portion of a steam engine in which the apparatus for opening and shutting the commuuication between the cylinder and the boiler and condenser, in low pressure or condensing engines; and between the cylinder and boiler and atmosphere in high pressure or non-condensing engines. For an account of the form of nozzles, and valves, &c. see *Steam Engine*, and *Valve*, in this Dictionary.

NUT; a short internal screw, which acts in the thread of an external screw, and is employed to fasten any thing that may come between it and a flang on the bottom of the external screw or bolt. See *Screw*.

Table of the sizes of Nuts, equal in strength to their bolts.

Diameter of the bolts in inches.	Size of the nut, or its short diameter, in inches.	Diameter of the bolts, in inches.	Size of the nut or its short diameter, in inches.
1/4	3/8	1 3/4	3 1/8
3/8	5/8	1 7/8	3 3/8
1/2	7/8	2	3 9/16
5/8	1 1/16	2 1/8	3 3/4
3/4	1 5/16	2 1/4	4
7/8	1 9/16	2 3/8	4 1/4
1	1 3/4	2 1/2	4 7/16
1 1/8	2	2 5/8	4 3/4
1 1/4	2 1/4	2 3/4	4 15/16
1 3/8	2 7/16	2 7/8	5 1/8
1 1/2	2 11/16	3	5 3/8
1 5/8	2 7/8	4	7 1/8

Note.—The depth of the nut should be equal to the diameter of the bolt.

O

OAK. There are several varieties of this valuable tree; but the common English oak claims precedence of every other. The oak timber imported from America is very inferior to that of this country; the oak from the central parts of Europe is also inferior, especially in compactness and resistance of cleavage. The knotty oak of England, the "unwedgeable and gnarled oak," when cut down at a proper age (from 50 to 70 years), is the best timber known. Some timber is harder, some more difficult to rend, and some less capable of being broken across; but none contains all the three qualities in so great and equal proportions; and thus, for at once supporting a weight, resisting a strain, and not splintering by a cannon shot, the timber of the oak is superior to every other.

The colour of oak wood is a fine brown, and is familiar to every one: it is of different shades; that inclined to red is the most inferior kind of wood. The larger transverse septa are in general very distinct, producing beautiful flowers when cut obliquely. Where the septa are small, and not very distinct, the wood is much the strongest. The texture is alternately compact and porous; the compact part of the annual ring being of the darkest colour, and in irregular dots, surrounded by open pores, producing beautiful dark veins in some kinds, particularly pollard oaks. Oak timber has a particular smell, and the taste is slightly astringent. It contains gallic acid, and is blackened by contact with iron when it is damp. The young wood of English oak is very tough, often crossgrained, and difficult to work. Foreign wood, and that of old trees, is more brittle and workable. Oak warps and twists much in drying; and in seasoning, shrinks about 1-32d of its width. Oak of a good quality is more durable than any other wood that attains a like size. Vitruvius says it is of eternal duration when driven into the earth; it is extremely durable in water; and in a dry state it has been known to last nearly 1,000 years. The more compact it is, and the smaller the pores are, the longer it will last; but the open, porous, and foxy coloured oak, which grows in Lincolnshire aud some other places, is not near so durable.

Besides the common British oak, the sessile fruited bay oak is pretty abundant in several parts of England, particularly in the north. The wood of this species is said by Tredgold to be darker, heavier, harder, and more clastic than the common oak; tough, and difficult to work; and very subject to warp and split in seasoning. Mr Tredgold seems disposed to regard this species as superior to the common oak for ship-building. But other, and also very high authorities, are opposed to him on this point; and, on the whole, we should think that it is sufficiently well established, that for all the great practical purposes to which oak timber is applied, and especially for ship-building, the wood of the common oak deserves to be preferred to every other species.—*M'Culloch*.

English oak has a specific gravity of 0·83, one cubic foot weighs 52 lbs. The weight of a beam, one foot long and one inch square, is 0·36 lbs., will bear without permanent alteration a weight of 3960 lbs. upon a square inch, and may be extended 1-430th part of its length without being torn. The modulus of elasticity is 4730000 feet, and the weight of the modulus on an inch square is 1700000 lbs. Compared with cast iron, as unit, its strength is 0·25, extensibility 2·8, and stiffness 0·093.

Oblate, flattened or shortened.

Oblique, aslant, indirect, or deviating either from perpendicularity or parallelism.

Oblong, is properly a right-angled parallelogram, of which the length and breadth are unequal. It is commonly employed to denote any figure which is longer than it is broad, or even a solid; thus a prolate sphere is sometimes called an oblong spheroid.

Obtuse, literally implies any thing blunt or dull, in contradistinction to acute, sharp, or pointed. Au obtuse angle is one that is greater than a right angle, or contains more than 90°.

Octagon, a figure of eight sides and angles, which, when the sides and angles are all equal, is called a regular octagon, and when they are not both equal, an irregular octagon.

The angle at the centre of an octagon is 45 degrees, and the angle of its sides 135 degrees. The area of a regular octagon whose side is $1 = 4{\cdot}8284271$; and therefore when the side is s, the area $= 4{\cdot}8284271 \times \text{side}^2$. *To construct a regular octagon on a given line.*—From the extremities of the line, draw perpendiculars to that side of it, upon which the octagon is to be constructed, and produce them indefinitely. Produce also the line both ways. Then bisect the angles made by the perpendiculars and line produced, and from the extremities of the line draw lines through the points of section. Make them equal to the given line, and three sides will be constructed. Two sides more are obtained by drawing parallels to the indefinite perpendiculars, and the remaining three, by cutting the perpendiculars from the extremities of them, with a distance equal to the given side.—*To inscribe an octagon in a given circle.*—Inscribe a square in the given circle; then bisect each of the four equal arcs intercepted by the sides of the square, which will be the arcs subtended by the sides of the octagon.

Table of the Diagonals of Octagons.

Short diameter.	Long diameter, or diagonal.	Short diameter.	Long diameter, or diagonal.	Short diameter.	Long diameter, or diagonal.
¼	·271	2⅜	2·577	4½	4·884
⅜	·407	2½	2·713	4⅝	5·020
½	·543	2⅝	2·848	4¾	5·156
⅝	·678	2¾	2·984	4⅞	5·292
¾	·814	2⅞	3·119	5	5·426
⅞	·959	3	3·255	5¼	5·697
1	1·085	3⅛	3·391	5½	5·968
1⅛	1·221	3¼	3·527	5¾	6·239
1¼	1·356	3⅜	3·663	6	6·510
1⅜	1·492	3½	3·798	6¼	6·781
1½	1·628	3⅝	3·934	6½	7·052
1⅝	1·763	3¾	4·070	6¾	7·323
1¾	1·900	3⅞	4·206	7	7·595
1⅞	2·034	4	4·341	7¼	7·866
2	2·170	4⅛	4·477	7½	8·137
2⅛	2·306	4¼	4·613	7¾	8·408
2¼	2·441	4⅜	4·749	8	8·680

Rule:—Multiply the short diameter by 1·085.

Octahedron, or Octaedron, one of the five regular bodies, contained under eight equal and equilateral triangles. Or an octahedron may be conceived to be made up of eight equal triangular pyramids, whose vertices unite in one common point, which is the centre of the solid, and of its circumscribed spheres. To find the surface and solidity of an Octahedron, the side of one of its equal faces being given. Let s represent the given side, then

$$\text{surface} = 3{\cdot}4341016\, s^2$$
$$\text{solidity} = {\cdot}4714045\, s^3$$

OCTANT, the eighth part of a circle.

ORB, a spherical shell, or hollow sphere.

ORDERS, ARCHITECTURAL. Five different species of columns were in use among the Greeks and Romans; and continue still to be used among architects. These columns are chiefly distinguished from one another by their capitals; and as the orders are often used as supports in machinery, we deem it proper to introduce the following description and engravings. The description is not minute enough for the purpose of the practical architect, but it is sufficiently minute for this work.

A complete order is divisible into three grand divisions, which are occasionally executed separately, viz. The *column*, including its base and capital; the *pedestal*, which supports the column; the *entablature*, or part above and supported by the column.

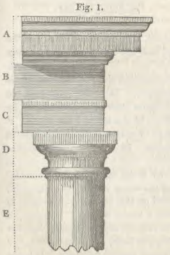
These are again each subdivided into three parts. The *pedestal* into base or lower mouldings; *dado* or *die*, the plain central space; and *surbase*, or upper mouldings. The *column* into base or lower mouldings, *shaft* or central plain space, and *capital* or upper mouldings. The *entablature* into *architrave*, or part immediately above the column; *frieze* or central flat space; and *cornice* or upper projecting mouldings.

These parts may be again divided thus: the lower portions, viz. the base of pedestal, base of column, and architrave, divide each into two parts; the first and second into plinth and mouldings, the third into face or faces, and upper moulding or tenia. Each *central* portion, as dado of pedestal, shaft of column, and frieze, is undivided. Each *upper* portion, as surbase of pedestal, capital of column, cornice of entablature, divides into three parts: the first into *bedmould*, or the part under the corona; corona, or plain face; and *cymatium*, or upper moulding. The *capital*, into *neck*, or part below the ovolo; *ovolo* or projecting round moulding; and *abacus* or *tile*, the flat upper moulding, mostly nearly square. These divisions of the capital, however, are less distinct than those of the other parts. The *cornice* into *bedmould*, or part below the corona; *corona*, or flat projecting face; *cymatium*, or moulding above the corona.

Besides these general divisions, it will be proper to notice a few terms often made use of. The ornamental moulding running round an arch, or round doors and windows, is called an *architrave*. An ornamental moulding for an arch to spring from, is called an *impost*. The stone at the top of an arch, which often projects, is called a *key-stone*. The small brackets under the corona in the cornices, are called *mutules* or *modillions;* if they are square, or longer in front than in depth, they are called *mutules*, and are used in the Doric order. If they are less in front than their depth, they are called *modillions*, and in the Corinthian order have carved leaves spread under them. A *truss* is a modillion enlarged, and placed flat against a wall, often used to support the cornice of doors and windows. A *console* is an ornament like a truss carved on a key-stone. Trusses, when used under modillions in the frieze, are called *cantalivers*. The space under the corona of the cornice, is called a *soffit*, as is also the under side of an arch. *Dentils* are ornaments used in the bedmould of cornices; they are parts of a small flat face, which is cut perpendicularly, and small intervals left between each. A flat column is called a *pilaster;* and those which are used with columns, and have a different capital, are called *antæ*. A small height of pannelling above the cornice, is called an *attic*, and in these pannels, and sometimes in other parts, are introduced small pillars, swelling towards the bottom, called *balustres*, and a series of them a *balustrade*. If the joints of the masonry are channelled, the work is called *rustic*, which is often used as a basement for an order. Columns are sometimes ornamented by channels, which are called *flutes*. These channels are sometimes partly filled by a lesser round moulding; this is called *cabling* the flutes.

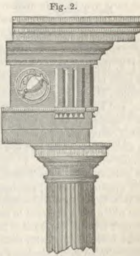
Some of these definitions require illustration to make them intelligible.

Fig. 1.



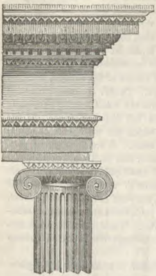
Tuscan Capital.

Fig. 2.



Doric Capital.

Fig. 3.



Ionic Capital.

Fig. 4.

Corinthian Capital.

The letters refer to only two of the figures, figs. 1 and 5. Fig. 1 is the capital of one order, i. e. the Tuscan, and fig. 5 is the base of another order, i. e. the Corinthian.

The parts marked A B and C, form together the entablature. A is the cornice, B the frieze, C the architrave. D is the capital of the column, and E its shaft. The second figure shows the base formed by the parts marked G H I. G is the fillet, H the torus, I the plinth. F is a fluted column placed upon the base. I may mention that a base is not an absolutely essential part of a column. In some buildings columns are formed without bases.

The plainest order is the Tuscan. In it the capital and the entablature are without ornament, and indeed the whole column is quite plain, with a great appearance of strength; and on this account it was used in columns which were supposed to sustain a heavy weight.

The next order is the Doric. In it also the capital is plain, but the architrave is ornamented with little drops or bells, cut in the stone, and the frieze with an equal number of channels termed triglyphs. It is the most ancient of the Grecian orders, the Tuscan being considered of

Fig. 5.

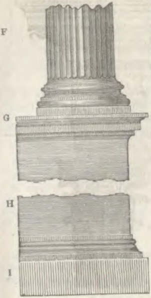


Fig. 6.

Corinthian Base.

Composite Capital.

modern origin. It was supposed to be formed according to the proportions between the foot of a man and the rest of his body, reckoning the foot to be the sixth part of a man's height. They gave to a Doric column six of its diameters, that is to say, they made it six times as high as it was thick; but a seventh diameter was afterwards added.

The third order is the Ionic, which is more light and elegant than the other two. It is characterized by a peculiar curve or curl in the capital, called a volute, resembling a curl of hair or a ram's horn. The frieze is plain; but there are little ornaments on the cornice, named dentils. The volutes are said to have been intended to represent the curls in the female head-dress, and the column was formed according to the proportions of a woman, making its height eight times greater than the diameter.

The Corinthian is the fourth order, and is still more highly ornamented. It is in the capital chiefly that its decorations are placed, and these consist of a representation of leaves, and stalks with numerous little volutes, forming an ample exercise for the taste of the architect and the skill of the artist. The capital of this order, according to an ancient report, was copied from an appearance noticed by an Athenian sculptor in passing the tomb of a young lady. A basket covered with a tile had been placed upon it, and round this an acanthus spread its leaves, the tops of which were bent downwards, in the form of volutes, by the resistance of the superincumbent tile. This hint is the reputed origin of the order. The height of a Corinthian column is ten diameters, in which the base and capital are both included.

The fifth architectural order is the Composite, so called because it is composed by uniting the characteristics of two orders, namely, the Ionic and the Corinthian. It has the rich flowery decorations of the latter, with the well marked volute of the Ionic curving over them.

These five are what may be termed the classic orders of architecture; having been those in use by the ancients, whose works have never been surpassed. The columns are not necessarily of equal thickness throughout their whole height, but vary according to certain rules, or the taste of the artist. A column is either quite smooth and plain, or it is fluted, that is, having channels or furrows cut lengthways. The names of most of these orders are derived from the countries where they were first brought into use.

OSCILLATION, vibration, or the reciprocal ascent and descent of a pendulum.

Axis of Oscillation, is a right line passing through the point of suspension parallel to the horizon.

OSCILLATION, CENTRE OF, that point in a vibrating body into which, if all its matter were collected, the vibrations would be performed in the same time: or more explicitly, the centre of oscillation is that point in the axis of suspension of a vibrating body into which, if all the matter of the body were collected, any force applied there would generate the same angular velocity in a given time, as the same force at the centre of gravity, all the parts of the system revolving in their respective places.

Let several bodies oscillate about a point of suspension, as if the mass of each were concentrated into points referred to the same plane perpendicular to the axis of motion. Then the gravity of each of them may be decomposed into two forces, of which the one passing through the centre of suspension is destroyed by its resistance; and so the other, perpendicular in direction to the former, is alone efficacious in moving the body or system. Now gravity tends to impress the same velocity upon the points in the vertical direction; which velocity we shall denote by g, and by m, n, p, the sines of the angles, which the supposed inflexible bars, joining the bodies with the centre of suspension, form with the perpendicular. Drawing lines parallel to this perpendicular, and each equal to g, they will represent the accelerating forces of the bodies, or the spaces which they would describe in the first unit of time, if they were left to themselves. But because of the obliquity of these forces upon the inflexible bars, if rectangles be constructed, the spaces run over will be only the sides of those rectangles which are at right angles to the bars; and as the angles have for their sines m, n, p, we shall have these respectively equal to gm, gn, and gp. Hence it follows, that the bodies taken separately, move with different velocities. But if we suppose them connected together, so that they all perform their vibrations in the same time, the velocity of some will be augmented while that of others will be diminished; and as the aggregate of the forces which solicit the system is always the same, it is necessary that the sum of the motions lost should be equal to that of the motions gained.

Let us represent, by A, B, C, the masses of the three bodies, by a, b, c, their distances from the point of suspension, and by α, β, γ, the initial velocities which they lose; the quantities of motion lost will be $A\,\alpha$, $B\,\beta$, $C\,\gamma$, which must be in equilibrio; therefore, the sum of their momentums taken with regard to the point of suspension is nothing; and as these respective distances from that point are a, b, c, we shall have

$$A\,a\,\alpha + B\,b\,\beta + C\,c\,\gamma = 0.$$

Let f be the velocity which the point A subjected to the laws of the system would receive in the first unit of time; as all the points describe similar arcs, their initial velocities are proportional to the distances from the centre of suspension; therefore that of B will be $\frac{bf}{a}$ and that of C will be $\frac{cf}{a}$. Now the velocity lost by each body is equal to the velocity which it would have had, minus that which it really has; therefore

$$\alpha = gm - f,\ \beta = gn - \frac{bf}{a},\ \gamma = gp - \frac{cf}{a};$$

whence, by substituting these values in the preceding equation, we have

$$Aa\,(gm - f) + Bb\left(gn - \frac{bf}{a}\right) + Cc\left(gp - \frac{cf}{a}\right) = 0.$$

Multiplyiug by a to clear this equation of fractions, and finding the value of f, we have

$$f = \frac{g\,(A\,a^2m + B\,a\,b\,n + C\,a\,c\,p)}{A\,a^2 + B\,b^2 + C\,c^2}.$$

From A, B, C, let fall the perpendiculars upon the line passing vertically through the point of suspension, and from the centre of gravity of the system draw perpendicular to the same line. The sum of the momentums of the weights, referred to the point of suspension, is equal to the momentum of their resultant which passes through the centre of gravity.

Whence,

$$f = \frac{ga\,(A + B + C)\,hr}{Aa^2 + B\,b^2 + C\,c^2}.$$

To ascertain the actual position of the point whose invariable connection with the system does not change its velocity, let x be its distance from the centre of suspension, and S the sine of the angle which the inflexible rod that retains it to that point makes with the vertical: its accelerating force when it moves singly is gs; in the contrary case it is proportional to its distance from the point S, and of consequence is equal to $\frac{x}{a}f$, but these two forces, or the initial velocities they produce must be equal; therefore $\frac{x}{a} = gs$, or putting the preceding value of f for it, there arises

$$\frac{(A + B + C)\,g\,h\,r\,x}{Aa^2 + B\,b^2 + C\,c^2} = gs,$$

from which we find

$$x = \frac{s}{r} \cdot \frac{A\,a^2 + B\,b^2 + C\,c^2}{(A + B + C)\,h}.$$

That the point sought may be the centre of oscillation, it is not merely necessary that these two velocities be equal in the first instant, they must continue so in every instant of the descent; therefore x remaining the same, this equation should hold whatever be the position of the point sought, and that of the centre of gravity, relatively to the vertical, that is to say, whatever be s and r, the ratio $\frac{s}{r}$ is therefore constant; and consequently we have at the same time $r = 0$, $s = 0$; which shows that the centre of oscillation, the centre of gravity, and the point of suspension, are in one and the same right line. Hence it results that $s = r$, and that

$$x = \frac{A\,a^2 + B\,b^2 + C\,c^2}{(A + B + C)\,h}.$$

The same kind of reasoning applies exactly, however many the number of particles may be; therefore, to find the centre of oscillation of a system of particles or of bodies, we must multiply the weight of each of them by the square of its distance from the point of suspension, and divide the sum of these products by the weights multiplied by the distance of the centre of gravity from the centre of suspension: this quotient expresses the distance of the centre of oscillation from the point of suspension measured on the continuation of the line joining the centre of gravity and that point.

Call S the point of suspension, O the centre of oscillation, or SO the distance of the centre of oscillation from the point of suspension; also let $\dot{s}$ be the fluxion of the body at the distance x; then the above formula becomes

$$SO = \frac{flu.\ x^2 \dot{s}}{flu.\ x\ \dot{s}}.$$

As an example, let it be proposed to find the centre of oscillation of a right line, or cylinder, suspended at one end.

In this case

$$SO = \frac{flu.\ x^2 \dot{x}}{flu.\ x\ \dot{x}} = \frac{\frac{1}{3} x^3}{\frac{1}{2} x} = \frac{2}{3} x$$

that is, the centre of oscillation is $\frac{2}{3}$ of the whole length from the point of suspension.

If the centre of osoillation be made the point of suspension, the point of suspension will become the centre of oscillation. See *Percussion, centre of*, and *Pendulum.*

Oval, an oblong curvilinear figure, having two unequal diameters, and bounded by a curve line returning into itself, resembling the outline of an egg. Under this general definition of an oval is included the ellipse, which is a regular oval; and all other figures which resemble the ellipse, though without possessing its properties, are classed under the same general denomination. See *Ellipse.*

Overshot Water Wheel. In this species of water wheel the circumference is furnished with buckets so fashioned and disposed as to receive the water at the top of the wheel and retain it until they reach, as nearly as possible, the lowest point. This wheel acts by the weight of the water. For a description and engraving of the most improved form of the overshot water wheel, and for the proper form that ought to be given to the buckets, see *Water Wheel.* In this article we will confine ourselves to the estimation of its mechanical effect, and some other numerical particulars.

The weight or momentum of the arch of loaded buckets may be found by multiplying 4-9ths of the number of buckets in the wheel by the number of ale gallons in each bucket, and that product by the number 6·465. Thus, if the number of buckets be 96, and each bucket holds 17 ale gallons, then $\frac{4}{9} \times 96 \times 17 \times 6{\cdot}465 = 4638{\cdot}5463$ lbs. the momentum of the loaded side of the wheel.

With respect to the relation that the diameter of the wheel ought to bear to the height of the fall, theoretical mechanics have stated that an overshot wheel will produce its maximum effect when the diameter is two-thirds of the height of the fall, the water being supposed to enter the buckets with the same velocity as the wheel. Experience proves this to be erroneous. Smeaton has satisfactorily shown that the maximum effect will be when the distance from the spout to the receiving bucket is two or three inches. The same engineer also showed that the maximum effect will take place when the velocity of the buckets is three feet per second.

The wheel which Mr Smeaton used was 25 inches in diameter. The depth of the buckets or of the shrouding, was 2 inches, and the number of buckets 36. When it made about 20 turns in a minute, the effect was nearly the greatest. When the number of turns was 30, the effect was diminished 1-20th part. When the number was 40, the diminution was ¼th; when the number was less than 18¼ its motion was irregular; and when it was loaded so as not to be able to make 18 turns, the wheel was overpowered by its load. It is an advantage in practice, says Mr Smeaton, that the velocity of the wheel should not be diminished farther than what will procure some solid advantage in point of power; because, *cæteris paribus*, as the motion is slower the buckets must be made larger; and the wheel being more loaded with water, the stress upon every part of the work will be increased in proportion. The best velocity for practice, therefore, will be such, as when the wheel here used made about 30 turns in a minute; that is, when the velocity of the circumference is little more than three feet in a second. Experience confirms, that this velocity of three feet in a second is applicable to the highest overshot wheels as well as the lowest; and all other parts of the work being properly adapted thereto, will produce very nearly the greatest effect possible; however, this also is certain from experience, that high wheels may deviate farther from this rule before they will lose their power by a given aliquot part of the whole, than low ones can be admitted to do; for a wheel of 24 feet high may move at the rate of 6 feet per second without losing any considerable part of its power; and, on the other hand, I have seen a wheel of 33 feet high, that has moved very steadily and well with a velocity but little exceeding two feet.

The experiments of the Abbe Bossut afford the same results. He used a wheel three feet in diameter. The height of the buckets was three inches, their width five inches, and their number 48; and the canal which conveyed the water furnished uniformly 1194 cubic inches in a minute. When the wheel was unloaded, it made 40¾ turns in a minute. The following Table, for which we have computed the fourth column, contains the results which he obtained.

Number of pounds raised.	Number of seconds in which the load was raised.	Number of revolutions performed by the wheel.	Effect of the wheel, or the product of the number of turns multiplied by the load.
11	60″	$11\frac{45}{48}$	$131\frac{22}{48}$
12	60	$11\frac{11}{48}$	$134\frac{35}{48}$
13	60	$10\frac{25}{48}$	$136\frac{38}{48}$
14	60	$9\frac{40}{48}$	$137\frac{32}{48}$
15	60	$9\frac{10}{48}$	$138\frac{6}{48}$
16	60	$8\frac{31}{48}$	$138\frac{15}{48}$
17	60	$8\frac{9}{48}$	$139\frac{9}{48}$
18	60	$7\frac{34}{48}$	138
19	The wheel turned very slowly.		
20	The wheel stopped, though first put in motion by the hand to make it catch the water.		

From this Table it appears, that the effect is a maximum when the number of turns is $8\frac{9}{48}$, or when the velocity of the circumference is 1 foot 4 inches per second. The effect diminished by diminishing the velocity, and the wheel was at last overpowered by its load, as in Smeaton's experiments, which ought always to happen when the resistance or load is equal to the effect of all the buckets when acting upon a semi-circumference of the wheel with their respective quantities of water.

In comparing the relative effects of water wheels, the Chevalier de Borda maintains, that an overshot wheel will raise through the height of the fall a quantity of water equal to that by which it is driven; while Albert Euler affirms that the effect is greatly inferior to this. The experiments of Mr Smeaton show, that when the heads and quantities of water are least, the ratio between the power and the effect at the maximum is nearly as 4 : 3; but when the heads and quantities of water were greater, it is as 4 : 2; and by a medium of the whole, it is as 3 : 2. When the powers of the water, computed for the height of the wheel only, are compared with the effects, they observe a more constant ratio, the variation being only between the ratio of 10 : 8·1 and 10 : 8·5. Hence the ratio of the power, computed upon the height of the wheel only, is to the effect, at a maximum, as 10 : 8, or as 5 : 4 nearly; and the effects, as well as the powers, are as the quantities of water and perpendicular heights multiplied together respectively.

The form of the delivering sluice, and the method of introducing the water into the buckets, will be best explained in another part of the work.

M. Lambert has investigated the subject; but from a table of overshot wheels which he has given it appears that he makes the diameter of the wheel too small. The table is however inserted here.

Table for Overshot Mills.

Height of the fall reckoning from the surface of the stream.	Radius of the wheel reckoning from the extremity of the buckets.	Width of the buckets.	Depth of the buckets.	Velocity of the wheel per second.	Time in which the wheel performs one revolution.	Turns of the mill-stone for one of the wheel.	Force of the water upon the buckets.	Quantity of water required per second to turn the wheel.
Feet.	Feet.	Feet.	Feet.	Feet.	Seconds.		Lb. avoir.	Cub. feet.
7	2·63	1·00	2·02	5·27	3·38	8·45	636	10·55
8	3·22	1·14	1·44	5·63	3·61	9·02	595	9·23
9	3·63	1·27	1·07	5·94	3·83	9·57	565	8·21
10	4·04	0·43	0·82	6·30	4·04	10·10	531	7·38
11	4·45	0·57	0·65	6·60	4·23	10·57	511	6·71
12	4·86	0·71	0·52	6·89	4·42	11·05	486	6·15

P

Packing. See *Piston*.

Paddle. See *Navigation, Steam*.

Parabola, one of the conic sections formed by the intersection of a plane and a cone, when the plane passes parallel to the side of the cone.

The abscisses of the parabola are to each other, as the squares of their corresponding ordinates. The distance from the vertex to the focus is equal to one-fourth of the perameter, or to half the ordinate at the focus. A line drawn from the focus to any point in the curve, is equal to the sum of the focal distance, and the absciss of the ordinate to that point. If through a point in the axis produced, taken so that the distance from the vertex is the same as that of the focus, a line be drawn perpendicular to the axis, that line is called the directrix of the parabola, which has this property; viz. that if there be drawn any number of lines parallel to the axis and meeting the curve, they will be equal to the lines from the same points in the curves to the focus. The absciss of any ordinate is equal to the distance of the vertex, from the point where the tangent to the parabola at the extremity of that ordinate cuts the axis produced. The same properties as have been stated above, and a variety of others belonging to the axis, abscisses, and ordinates of the axis, are equally true of any other diameters.

Cartesian Parabola, is a curve containing four infinite legs; viz. two hyperbolic and two parabolic.

Cubic Parabola, is a curve having two infinite legs tending contrary ways. If the absciss touch the curve in a certain point, the relation between the absciss and ordinate is expressed by an equation. The area of the cubic parabola is equal to three quarters of its circumscribing cylinder; but it cannot be rectified even by means of the conic sections.

Parabolic Pyramidoid, is a solid generated by supposing all the squares of the ordinates applicate to the parabola, so placed that the axis shall pass through all their centres at right angles: in which case the aggregate of the planes will form the solid called the Parabolic pyramidoid; the solidity of which is equal to the product of the base, and half the altitude.

Parabolic Spindle, is the solid generated by the rotation of a parabola about any double ordinate; the solidity of which is found as follows:

Let m denote the middle diameter, and l the length of the spindle; then

$$\text{Solidity} = \cdot 418879 \times l \times m^2$$

And the solidity of a middle frustrum of such solid, is

$$\text{Solidity} = \cdot 05236 \times l \times (8\, m^2 + 3 \times d^2 + 4\, d\, m)$$

where d denotes the diameter of the end of the spindle.

Paraboloid, or Parabolic Conoid, is the solid generated by the rotation of a parabola about its axis, which remains fixed; the solidity of which may be found by the following rule;

diameter at the base $\times$ height $\times$ 0·3927.

Frustrum of a Paraboloid, is the lower solid formed by a plane passing parallel to the base of a paraboloid.

Parallel, in geometry, is applied to lines, figures, and bodies, which are every where equidistant from each other, or which, if ever so far produced, would never meet.—*Parallel Right Lines*, are those which, though infinitely produced, would never meet. To draw a line parallel to a given line through a given point. Draw a line meeting the given line in any point; and make at the given point an angle equal to the alternate angle made at the given line, then the line making this angle is the parallel.

Parallel Motion, the name given to a contrivance invented by Watt for converting a reciprocating circular motion into an alternating rectilinear motion. The chief use to which the parallel motion is applied, is to connect the pump rod and piston rod with the working beam in such a manner, that while the points of the beam to which these rods are attached move in arcs of circles, the rods are made to move alternately up and down, always keeping parallel to themselves.

In the following series of engravings we have shown different kinds of parallel motions, which will be understood by mere inspection, after the construction of the first has been explained.

The top of the piston rod and the top of the pump rod are connected by joints at B and C to the rods D B and E C, which rods are called straps or links. The links are connected by joints, B and C, to the working beam, and at their other extremities to a cross bar D E. The links are of the same length, and the bar D E being equal in length to the distance of the centres B and C, B C E D, will be a parallelogram, hence the bar D C, being parallel to the working beam, is called the parallel bar. Another bar, F E, is connected to the parallelogram by a joint at E, and is moveable round a fixed centre, F. This bar is called the radius bar. By the alternate motion of the beam, up and down, it is plain that the joint C will describe an arc of a circle whose centre is the centre A of the working beam; and the joint E will describe an arc whose centre is the other extremity F of the radius bar; the centres A and F being fixed. Now the centres E and C are connected by the link E C; and by the alternate motion of the beam the joint C will draw the upper end of the link towards the left hand side of the figure, and the other end E will advance towards the right, and the link will become inclined, but there will be some point, as C, in the link which is bent neither to the right nor to the left, and if to this point the top of the air pump rod be attached, it will rise and fall in a perpendicular direction, keeping always parallel to itself. The length of the rods are so adjusted that the centre D keeps parallel to the point C, and therefore the piston rod attached to this point will also have a parallel motion. A line drawn through the centres D G and A, is called the line of centre, and the apparatus should be so constructed that this line will move parallel to itself. It is impossible to make it do so exactly, and the longer the stroke is the greater will be the deviation. At the middle of the stroke the line of centres should be horizontal.

Fig. 1.

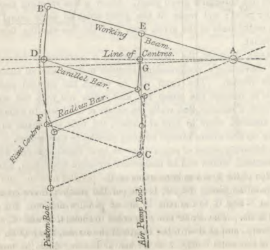


Fig. 2.

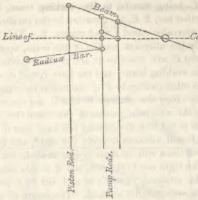
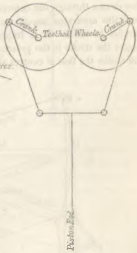


Fig. 3.

Fig. 4.



Figs. 1, 2, and 3, are modifications of the parallel motion, commonly used for fixed engines. Fig. 4, is the parallel motion, invented by Mr Cartwright. Fig. 5, is another form of parallel motion. Fig. 6, is drawn with the parts very far down in order to show, that when the beam is very short, compared with the length of the stroke, the motion of the rods is not parallel. Fig. 7, is a construction in which the motion of the air pump rod is not parallel. Fig. 8, is a parallel motion for a marine engine. Fig. 9, is another form of parallel motion.

Fig. 5.

Fig. 6.

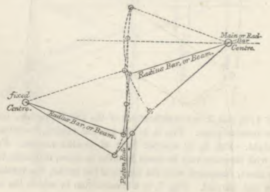


Fig. 7.

Fig. 8.

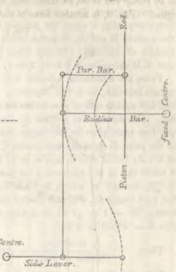
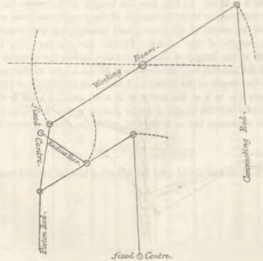


Fig. 9.



When the link, E C, is attached at a point, E, of the beam, which is half way between the centre, A, of the beam, and the centre B at the extremity, that is when the parallel bar C D is equal to the distance of the centres E and A, then the point G in the link E C will be in the middle of the link. If any other proportion between the lines A E and E B exists, as of 2 to 3, 3 to 4, 3 to 5, or in general of n to m.

From the number n subtract half the square root of four times its square less one, for a first number. Also from the number m subtract half the square root of four times its square less one, for a second number. Divide the first number by the first added to the second, and the quotient multiplied by the length of the link C E will give the distance of the point G from the top centre C of the link. Let A C be to E F as 2 : 3; hence n is 2, and m is 3; therefore, the square of 2 is 4, and 4 times this is 16, subtract 1 we have 15, the square root of which is 3·873, the half of which is 1·9365; hence $2 - 1·9365 = 0·0635 =$ the first number. For the second number we have $3 \times 3 \times 4 = 36$ then $\sqrt{36} - 1 = \sqrt{35} = 5·916$, the half of which is 2·958, wherefore $3 - 2·958 = 0·042$.

$$\text{Then} \qquad \frac{0·0635}{0·0635 + 0·042} = 0·602.$$

If the length of the link C E be 32 inches, then $32 \times 0·602 = 19·264 =$ the distance of the centre G from the centre C. The arc of vibration of the beam should never exceed 20°; and this is nearly the case when the length of the stroke is to the distance of the centres, B and A, as 2 is to 3. In this case the length of the radius bar may be found by subtracting twice the length of the parallel bar from one and a half times the length of the stroke, and multiplying the remainder by half the length of the stroke. Divide the number thus found by $0·343146 \times$ the length of the parallel bar, and to the quotient add the length of the parallel bar, the result will be the length of the radius bar. Thus, if the length of the stroke be 8 feet, and the length of parallel bar 3, we have $1·5 \times 8 = 12$, and $2 \times 3 = 6$, then $12 - 6 = 6$, which multiplied by half the length of stroke gives $6 \times 4 = 24$; next 0·343146 $\times$ length of parallel bar $= 1·029438$, gives the divisor; wherefore

$$\frac{24}{1·029438} = 23·313.$$

Messrs Hans and Dodd give the following table of parallel motions:—

Table of Parallel Motions, when the length of the stroke is not taken into consideration.

Radius of beam in inches.	Length of parallel bar in inches.	Length of radius rod in inches.	Radius of beam in inches.	Length of parallel bar in inches.	Length of radius rod in inches.	Radius of beam in inches.	Length of parallel bar in inches.	Length of radius rod in inches.
72	18	158·111	..	36	100	..	81	18·77
..	21	124	..	39	83·3	126	42	168
..	24	96	..	42	96·428	..	45	145·8
..	27	75	..	45	57·8	..	48	126·75
..	30	58·8	..	48	48	..	51	110·3
..	33	46	..	51	39·7	..	54	96
..	36	36	..	54	32·666	..	57	83·5
..	39	27·9	..	57	26·7	..	60	72·433
..	42	21·428	..	60	21·6	..	63	63
..	45	16·2	..	63	17·3	..	66	54·545
..	48	12	..	66	13·636	..	69	47
..	51	8·6	..	69	10·5	..	72	39·25
..	54	6	..	72	8	..	75	34·7
78	18	200	..	75	5·7	..	78	29·33
..	21	154·7	102	30	172·8	..	81	25
..	24	121·5	..	33	144·3	..	84	21
..	27	96·5	..	36	121	..	87	17·48
..	30	76·8	..	39	101·7	132	48	147
..	33	61·36	..	42	85·738	..	51	128·6
..	36	49·111	..	45	72·2	..	54	112·666
..	39	39	..	48	66·75	..	57	98·7
..	42	30·857	..	51	51	..	60	86·4
..	45	24·2	..	54	42·666	..	63	75·5
..	48	18·75	..	57	35·5	..	66	66
..	51	14·3	..	60	29·4	..	69	57·5
..	54	10·666	..	63	24·14	..	72	50
..	57	7·7	..	66	19·636	..	75	43·32
..	68	5·4	..	69	15·8	..	78	37·384
84	18	242.	..	72	12·5	..	81	32·111
..	21	189	108	36	144	..	84	27·428
..	24	150	..	39	122	..	87	23·27
..	27	120·3	..	42	103·716	..	90	19·6
..	30	97·2	..	45	88·2	..	93	16·35
..	33	79	..	48	75	138	48	168·75
..	36	64	..	51	63·7	..	51	148·4
..	39	52	..	54	54	..	54	130·666
..	42	42	..	57	45·6	..	57	115
..	45	33·8	..	60	38·4	..	60	101·4
..	48	27	..	63	32·14	..	63	89·3
..	51	21·35	..	66	26·727	..	66	78·545
..	54	16·666	..	69	22	..	69	69
..	57	12·8	..	72	18	..	72	60·5
..	60	9·6	..	75	14·52	..	75	52·9
..	63	7	114	42	123·428	..	78	46·153
..	66	4·9	..	45	105·8	..	81	40
90	18	288	..	48	90·75	..	84	34·643
..	21	226·7	..	51	77·8	..	87	30
..	24	181·5	..	54	66·666	..	90	25·6
..	27	147	..	57	57	..	93	21·7
..	30	120	..	60	48·6	144	48	192
..	33	98·4	..	63	41·3	..	51	169·6
..	36	81	..	66	34·9	..	54	150
..	39	66·7	..	69	29·3	..	57	132·7
..	42	54·857	..	72	24·5	..	60	117·6
..	45	45	..	75	20·3	..	63	104·14
..	48	36·75	120	42	146·761	..	66	92·181
..	51	30	..	45	125	..	69	89·3
..	54	24	..	48	108	..	72	72
..	57	19	..	51	93·35	..	75	63·5
..	60	15	..	54	80·666	..	78	55·846
..	63	11·5	..	57	69·6	..	81	49
..	66	8·727	..	60	60	..	84	42·857
..	69	6·4	..	63	51·5	..	87	37·35
..	72	4·5	..	66	44·181	..	90	32·4
96	24	2;6	..	69	37·7	..	93	28
..	27	176·3	..	72	32	..	96	24
..	30	145·2	..	75	27	..	99	20·4
..	33	120·3	..	78	22·564			

Parallel ruler, an instrument consisting of two wooden, brass, or steel rulers, equally broad throughout, and so joined together by the cross blades, as to open to different intervals, and accede and recede, yet still retain their parallelism. The use of this instrument is obvious; for one of the rulers being applied to a given line, another drawn along the extreme edge of the other will be parallel to it; and thus, having given only one line, and erected a perpendicular upon it, we may draw any number of parallel lines or perpendiculars to them; by only observing to set off the exact distance of every line with the point of the compasses.

But the best parallel rulers are those whose bars cross each other, and turn on a joint at their intersection; one of each bar moving on a centre, and the other ends sliding in grooves as the rulers recede.

Parallelepiped, or Parallelopiped, or Parallelopipedon, is a solid figure contained under six parallelograms, the opposite of which are equal and parallel; or it is a prism whose base is a parallelogram. See *Prism.*

Parallelogram, in geometry, is a quadrilateral right-lined figure, whose opposite sides are parallel.

A parallelogram has its opposite sides and angles equal to each other, and the diagonal divides it into two equal triangles. The two adjacent angles of any parallelogram are together equal to two right angles. Parallelograms having equal bases and altitude are equal; on equal bases they are to each other as their altitudes; and with equal altitudes they are to each other as their bases; and generally parallelograms are to each other in the compound ratio of their bases and altitudes. The sum of the squares of the diagonals of any parallelogram is equal to the sum of the squares of the four sides. The complements about the diagonals of any parallelogram are equal to each other.

Parallelogram of Forces, is a term used to denote the composition of forces, or the finding a single force that shall be equivalent to two or more given forces when acting in given directions, the principles of which may be thus illustrated.

The simultaneous action of two impulsive forces on a body which would impress upon it separately the velocities, in directions making an angle with each other, will cause that body to move uniformly over the diagonal of the parallelogram whose sides are in the direction of those forces.

Let the body be situated on a plane, the containing sides of which make any given angle with each other, and let the plane be moved parallel to one of its containing sides, and with an uniform velocity, so that it may arrive at the other extremity of that side, that is, that the plane may have moved its whole extent in any unit of time; it is obvious that, with regard to the plane, the body has remained at rest, but that with regard to space, it has passed over a line equal to the side of the plane. Suppose, again, that the body is acted upon at the same time by another force, which would carry it parallel to the other containing side of the plane, and make it arrive at the extremity of that side at the same instant that the motion of the plane brings it to the extremity of the other; then it is obvious, that the body will have arrived at the angle of a parallelogram, of which the lines of motion are the containing sides, opposite to that from which the body is supposed to set out; and that its path will have been along the diagonal of that parallelogram. At the half of the supposed unit of time, it will be at the middle of the parallelogram, or at the middle of the diagonal; and its situation at any other period may be easily found. If the angle made by the two forces, or motions which are the measures of those forces, be a right angle, the force produced, or the motion which is the measure of that force, will be equal to the square root of the sum of their squares; if less than a right angle, it will be greater than this; and, if greater than a right angle, it will be less. If the angle vanish by the forces and motion coinciding, the result will be their sum; and if it vanish by their opposing each other, it will be their difference. It could likewise be shown, that if a body be acted on by two similar variable forces, whose directions and magnitudes are expressed by the adjacent sides of a parallelogram meeting in the body, it will describe the diagonal of the parallelogram. Hence it appears, that in order to find a force that shall be equivalent to two forces, whose quantity and direction is given, we have only to find the diagonal of the parallelogram, by the sides of which the given forces are represented, and this will express the quantity and direction of the force which is equivalent to them both.

And in the same manner may be found the equivalent to three or more forces, by first reducing two of them to one single and equivalent force; then this and one of the other given forces; and so on till they are all reduced to one equivalent force.

Suppose, for example, it were required to compound three given forces; or to find the quantity and direction of one single force, which shall be equivalent to three given forces.

First reduce the two to one, by completing the parallelogram. Then reduce the result of these and the third to one, by completing a second parallelogram.

Hence conversely, any single direct force may be resolved into two or more oblique forces; which is done by merely describing any parallelogram, such that the line representing the given single force may be its diagonal; and as these may be an indefinite number of parallelograms having the same diagonal, so may any single force be resolved in an indefinite number of ways into two or more oblique forces, that shall produce the same effect as the single given force.

PARAMETER, a certain and constant right line in each of the three conic sections, and otherwise called the *Latus Rectum*, because it measures the conjugate axis by the same ratio, which has place between the axes themselves, being always a third proportional to them, viz. a third proportional to the transverse and conjugate axes in the ellipse and hyperbola, and, which is the same thing, a third proportional to any absciss and its corresponding ordinate in the parabola.

PARTICLE, the minute part of a body, or an assemblage of several atoms of which natural bodies are composed.

PATENT, in law, is the exclusive right of using and vending a certain composition or combination of matter, as a medicine or a machine. This right is not derived from the law of nature, as the whole field of inventions and improvements is open to all men, and one cannot monopolize a part of it by prior discoveries. By the common law of England, monopolies were declared to be generally void, and patents for new inventions, being a species of monopolies, would, according to this doctrine, be void by that law. But they seem to form an exception to this rule; for it was held that the king could confer on the inventor of any useful manufacture or art the power of using it for a reasonable time. But the law of patents, as it now stands in England, rests upon a statute of 21 Jac. I, c. iii, and in the United States of America, on statute Feb. 21, 1793, and April 17, 1800. In France, until 1790, inventors were generally obliged to keep their discoveries secret, in order to secure to themselves a small part of the benefit of them. In an early period of the French revolution, a law was passed in favour of new inventions, formed on the basis of the English statute. The French law of Jan. 7, 1810, declares that every discovery or new invention, in every species of useful industry, is the property of its author. In England, patents are now, as they were before the statute of James I, granted by the crown. Letters patent are made out by the secretary of state in the name of the United States of America, bearing *teste* of the president.

What is patentable? In general, any invention of a new and useful art, machine, manufacture, or composition of matter not known or used before, or any new and useful improvement in any art, machine, or manufacture, or composition of matter. The invention must be *new*. In England, a manufacture newly brought into the kingdom, from beyond sea, though not new there, is allowed by the statute of James; because that statute allows a patent for any new manufacture within this realm. By the patent law of the United States of America, if the thing patented was not originally discovered by the patentee, but had been in use, or had been described in some public work anterior to the supposed discovery by the patentee, or if he has surreptitiously obtained a patent for the discovery of another person, the patent is void. In France, by the law of Jan. 7, 1810, whoever introduces into that kingdom a foreign discovery shall enjoy the same advantages as if he were the inventor. In England, the publisher of an invention is entitled to a patent, whether he be the inventor or not. The subject of a patent must be vendible, in contradistinction to any thing that is learned by practice. The invention must be *material* and *useful*: thus the substitution of one material for another is insufficient to support a patent; as of brass hoops to a barrel instead of wooden ones. So there cannot be a patent for making in one piece what before was made in two. But if one elementary thing be substituted for another, as if that be done by a tube which was before done by a ring, a patent for the improvement would be good. It must not be hurtful to trade, nor generally inconvenient, nor mischievous, nor immoral, as an invention to poison people, or to promote debauchery. Patents for improvements are valid, as for an improved steam-engine; but if the improvements cannot be used without the engine which is protected by a patent, they must wait the expiration of the patent. But a new patent may be taken out for the improvement by itself. A combination of old materials, by which a new effect is produced, may be the subject of a patent. The effect may consist either in the production of a new article, or in making an old one in a better manner, in a shorter time, or at a cheaper rate. A patent may be obtained for a method or process by which something new or beneficial is done, when it is connected with corporeal substances, and is carried into effect by tangible means, as in the case of Watt's steam-engine, which was described to be a method of lessening the consumption of fuel in a steam-engine. So a chemical discovery, when it gives to the community some new, vendible, and beneficial substance, or compound article, is a subject of a patent, as medicines, &c. But a patent for a mere curiosity is void. If the manufacture in its new state merely answers as well as before, the alteration is not the subject of a patent: nor is a mere philosophical abstract principle, nor the application or practice of a principle, the subject of a patent. No patent can be obtained for the expansive operation of steam; but only for a new mode or application of machinery in employing it.

Right how lost. The inventor may lose his right to a patent by using, or allowing others to use, his invention publicly. It was considered that doctor Hall had not lost the right to a patent for his discovery of the object-glasses, because he had not made it known to others, though it was not immediately patented. If the secret of an invention is known only to a few persons, and one of them puts it in practice, then a patent afterwards obtained by any one of them is void. This happened to Mr Tennant, because a bleacher, who had not divulged the secret to any other person but his two servants, had used the same kind of bleaching-liquor for several years anterior to the date of Tennant's patent. Where a person who sought a patent for making spectacles incautiously told an acquaintance of the principle of the invention, by which means a person of the same trade made a similar pair, and the inventor, seeing them in a shop window, employed a friend to purchase them for him, and the patent was afterwards granted, it was said to be secure. The question does not, however, appear to have been brought before a court, and Mr Godson thinks that the patent was void. A patent for British imperial verdigris was declared to be void, because the inventor had, four months prior to the sealing of the grant, sold the article under a different name. Whether experiments made with a view to try the efficacy of an invention, or the extent of a discovery, are a *using*, and dedicating the invention to the public, within the statute of James, has not been decided; but it would be difficult to say how much a substance or machine might be used without running great risk of invalidating the right to a patent. In France, if the inventor do not, within two years, put his discovery into activity, or do not justify his inaction, the patent is annulled.

Duration of the Patent. In England and the United States of America, patents are granted for a term not exceeding fourteen years. The time in England may be prolonged by a private act, and, in the United States of America, by act of congress. In France, by the law already mentioned, patents are given for five, ten, or fifteen years, at the option of the inventor; but this last term is never to be prolonged without a particular decree of the legislature. The duration for imported discoveries is not to extend beyond the term fixed for the privilege of the original inventor in his own country. In France, if the inventor obtains a patent in a foreign country after having obtained one in France, the patent is annulled.—*Caveat.* In England, a *caveat* is an instrument by which notice is requested to be given to the person who enters it, whenever any application is made for a patent for a certain invention, which is therein described in general terms. It must be renewed annually. It is simply a request that, if any other person should apply for a patent for the same thing, the preference may be given to him who entered it. In the United States of America, in case of interfering applications for a patent, they are submitted to the arbitration of three persons, appointed one by each applicant, and one by the secretary of state.

Specification. The invention for which a patent is granted must be accurately ascertained and particularly described. The disclosure of the secret is the price of the monopoly. The specification must be such that mechanics may be able to make the machine by following the directions of the specification, without any new inventions of their own. The patent and specification are linked together by the title given to the invention in the patent, and the description of it in the specification. The specification must support the title of the patent: thus a patent taken out for a *tapering-brush* is not supported by the specification of a brush in which the bristles are of unequal lengths. It must point out what parts are new and what old. It must not cover too much: if it does so, it is not effectual, even to the extent to which the patentee would be otherwise entitled; as, if there be a patent for a machine and for an improvement upon it, which cannot be sustained for the machine, although the improvement is new and useful, yet the grant altogether is invalid, on account of its attempting to cover too much. A patent for a new method of drying and preparing malt is not sustained by a specification in which is described a method for heating, &c., ready-made malt: so a patent for an invention founded on a principle already known, for lifting fuel into the fire grate from below the grate, in the specification whereof was described a new apparatus, was held to be bad for not claiming the new instrument as the thing invented: so when a patent was "for a new method of completely lighting cities, towns, and villages," and the specification described improvements upon lamps, the patent was held to be void. The subject must be given to the public in the most improved state known to the inventor. A patent, in England, for steel trusses was held to be void, because the inventor omitted to mention that, in tempering the steel, he rubbed it with tallow, which was of some use in the operation. The specification must not contain a description of more than the improvement or addition. If there be several things specified that may be produced, and one of them is not new, the whole pateut is void. In England, if any considerable part of a manufacture be unnecessary to produce the desired effect, it will be presumed that it was inserted with a view to perplex and embarass the inquirer: thus, in 1 Term Reports, 602, in Turner's patent for producing a yellow colour, among other things, *minium* is directed to be used, which, it appeared, would not produce the desired effect, and, for this reason, the validity of the patent might be impeached. In the specification of Winter's patent, 1 Term Reports, 602, a great number of salts were mentioned, by which it appeared that either might be used to make the subject of the patent, but only one would, in fact, produce the effect; and, for this reason, the patent was held to be void. If the patentee makes the article of cheaper materials than those which he has enumerated in his specification, although the latter answer equally as well, the patent is void. In England, if the improved manner of using the invention be unintentionally left undescribed, still the patent is void. (1 *Mason's Reports*, 189.) In France, the general rules, in these respects, are similar.

Enrolment. In England, a patent is void unless it is enrolled. The time allowed for the enrolment is now generally confined to one month. Enrolment cannot be dispensed with, though it be to keep the specification secret. After a patent has passed, the time for enrolment cannot be enlarged without an act of parliament. In the United States of America, the patent, after the seal of the United States of America is affixed, is recorded in a book kept for the purpose.

Infringement. Whether any act is really an infringement of the patent, is a question for the jury. The using the least part of the manufacture is an infringement. In Manton *v.* Manton, the infringement consisted in making a perforation in the hammer of a gun in a direction a little different from that in the patent article. If the article manufactured be of a different form, or made with slight and immaterial alterations or additions, if the manufactures are really and substantially the same, the patentee is entitled to a remedy, as where the position of the different parts of a steam engine were reversed. Where several independent improvements are made in the same machine, and a patent is procured for them in the aggregate, the patentee is entitled to recover against any person who shall use any one of the improvements so patented, notwithstanding there shall have been no violation of the other improvements.—*Remedy for Infringement.* The remedies for infringement, in England, are by an action at law for the damages, or by proceedings in equity for an injunction and account. The remedy sought in equity is for instant relief, and it is often preferable to proceed in equity before a suit is commenced at law. In the United States of America, the circuit court has original cognizance, as well in equity as at law, in regard to patents, and may grant injunctions. The damages for a breach of the patent right, in the United States of America, are three times the actual damage sustained by the patentee: the jury are to find single damages, the court are to treble them. In France, the patentee, in case of infringement, shall recover the damage he may sustain, and a penalty for the benefit of the poor, not to exceed 3000 francs, and double in case of a second offence.—*Repeal.* If a patent be void, in England, the king may have a *scire facias* to repeal his own grant. All persons are injured by the existence of an illegal patent for an invention, and every one is therefore entitled to petition for a *scire facias* to have it cancelled. Patents are repealed, in the United States of America, by a process in the nature of a *scire facias.*—*Who may obtain a Patent.* Aliens who have resided two years in the United States of America are allowed to obtain patents under the act of 1800, on their making oath that the invention has not, to the best of their knowledge or belief, been used in any country before. The English law has no restrictions on this head, and it is every day's practice to grant patents for new inventions to Americans and other foreigners.

The foregoing portion of this article is modified from a very excellent article in the Popular Encyclopedia; and what follows we take the liberty of quoting from the Companion to the Almanac, for 1836.

An Act has been passed in a late Session of Parliament to do away with some of the defects with which our antiquated Patent Laws are encumbered; and although it does not pretend to an entire removal of the causes of complaint, yet considering the admitted difficulties of the case, and the very objectionable nature of some of the former propositions for amendment, we are not sorry that the work of improvement has been begun with caution; at the same time we wish to consider what has been done only as a beginning, and hope it will lead the way to a general amelioration.

One great grievance of the system, was the destruction of all right to a patent which resulted from an inadvertent claim put in to any part of an invention which might not actually be new, although that circumstance should be unknown to the inventor, and even although the part claimed should be a small and unessential portion of the whole invention. To make this matter clear, it must be stated that, in explaining the nature of an invention, such as a machine for instance, the patentee is compelled to describe the construction of his invention in the fullest detail, so as to enable an ordinary workman to construct a similar machine. As in every such new invention, certain parts must also necessarily be well known, certain wheels and levers will be like wheels and levers in other machines; and as to these wheels and levers the patentee can have no exclusive right, he is expected to declare in his specification what parts of the machine he claims as his own invention. To these alone he has exclusive right; all other parts are public property, and may be used by any one. Thus far all is right; if it were otherwise, a patentee might be allowed a right to what is not his own. The grievance complained of is, that if a patentee should inadvertently lay claim to any part of his new invention, which part might afterwards be found not original, he lost not only his right to an exclusive use of that one part, but to the entire invention, however new it might be. He was thus cooped up in a dilemma; if he did not claim the whole of his invention, from a fear of overclaiming, he of course lost his right to that which he did not claim; if, on the contrary, he claimed all which was his own, and it should be found that some part was not original, then he lost his whole patent. The motive to this severity seems to have been the wish to prevent by a penalty an unprincipled schemer from endeavouring to appropriate to himself more than his own. But while the schemer was punished, the honest inventor was often a sufferer. A new machine might have great merit, it might in principle and action be perfectly new; but some of its details might have been used in some other machine now in disuse, quite unknown to the inventor. This is discovered by some rival manufacturer, and the patentee loses his right. By the act now passed, this grievance is done away with; if a patentee should be in the situation supposed, if he should find that some portion of his invention has been anticipated, he may now, on a proper representation, obtain leave to enter and enrol a disclaimer of such portion, and remain in the situation he would have been in, had no such claim ever been put forward.

It has been objected to this alteration, that advantage may be taken of it by a dishonest schemer, who may take out a patent for an invention not his own, and then, as he finds himself discovered, enter a disclaimer, first to one part and then to another, as such parts are objected to, and in the mean time reap all the advantage of his patent, as though the invention were his own. This we imagine is an impossible occurrence; it must be remembered that the enrolment of the disclaimer is not a matter of right, that it may be refused by the Attorney-General, unless a sufficient cause is alleged for the alteration, and that in cause of fraud it would undoubtedly be refused. There is also another check, and a strong one, against such a practice: the disclaimer cannot be received in evidence, in case of an action brought before such disclaimer was enrolled. A patentee, therefore, who should make an overclaim, and against whom an action should be brought in consequence of that overclaim, will, as far as that action goes, stand precisely in the situation he would have stood in before the new act was passed. He will be liable to the same penalties, and be put to the same expense in the suit. The only difference is, that he will be enabled to protect himself from the loss of his whole patent in such a case, and will stand upon his own right in future. Now an honest patentee will, it is true, suffer in the immediate action the penalty of his inadvertence, but no more. The dishonest one will render himself liable to the same penalty, as often as he shall attempt to make use of any right given him by a fraudulent claim.

The second clause enacts, that if a patentee shall have reproduced some old invention, believing himself to be the inventor, it shall be in the power of the crown, upon a recommendation of the Judicial Committee of the Privy Council, to continue the patent to the patentee, wherever it shall appear that the invention has not been publicly and generally used. It is feared by some persons that all kinds of old inventions will be brought up again and promulgated as new, under favour of this clause, and that every body will be taking out patents for old and abandoned projects. This appears very absurd. To say nothing of the expense of taking out patents, and the almost certainty of their being useless to the patentee (for we may be well assured that in ninety-nine cases out of a hundred the inventions would not have been abandoned if they had not been useless), there are so many checks against the continuance of such patent by the crown to any but a *bonâ fide* re-inventor, that few persons will feel inclined to rake out old books for the purpose of picking up lost inventions. If any person should be lucky enough to re-produce an invention of value abandoned from any cause, and generally forgotten, we see no harm in his having the monopoly of its use for a few years as a recompense for his bringing to light a valuable idea, though we would rather he should be entitled to it without any misrepresentation.

The third clause contains a provision against the repeated vexatious actions by which a patentee might be put to enormous law expenses under the former act. Before the passing of the new law, although an action respecting the validity of a patent might be decided in favour of the holder of the patent, this verdict was no bar to a future action, nor to any number of future actions. Although nothing new could be alleged, although it was but going over the same ground again and again, the patentee might be compelled year after year to defend himself against fresh actions to his great injury, perhaps to his ruin. The clause enacts, that in any action respecting the validity of a patent, if a verdict pass in favour of a patentee, the certificate of the judge who tried the action may be adduced in evidence on any future action; and if the verdict in such subsequent action be given in favour of the patentee, he shall receive treble costs.

By the fourth clause, an extension of the term of a patent, not exceeding seven years, may be granted by his Majesty, on a recommendation of the Judicial Committee of the Privy Council, who may call and examine witnesses in the case of a petition for extension. This is decidedly an improvement: the term of fourteen years granted indiscriminately by every patent, is too short in some cases to render any profit to an inventor, and this chiefly in those inventions of great value which require time to introduce. We may instance Watt's improvements on the steam-engine, which from prejudice and other causes were hardly in general use when the term granted by his patent expired. By the old act, no extension could be obtained without an application to Parliament, which was attended with so many difficulties that it has been rarely resorted to.

The fifth and sixth clauses refer to the manner of conducting trials for infringement of patent rights, and regulate the costs in such actions. The last clause inflicts a penalty upon any person putting the name or mark of a patentee upon any article without his permission.

Here follows a more detailed abridgement of the act. *An Act to amend the Law touching Letters Patent for Inventions.* [5 and 6 Will. IV. c. 83.—10th September, 1835.]

1. Reciting that it is expedient to make certain additions to and alterations in the present law touching letters patent for inventions, as well for the better protecting of patentees in their rights, as for the more ample benefit of the public: enacts that any person having obtained letters patent for any invention may enter with the clerk of the patents of England, Scotland, or Ireland, respectively, as the case may be, having first obtained the leave of his Majesty's attorney-general or solicitor-general in case of an English patent, of the lord advocate or solicitor-general of Scotland in the case of a Scotch patent, or of his Majesty's attorney-general or solicitor-general for Ireland in the case of an Irish patent, certified by his fiat and signature, a disclaimer of any part of his specification, or a memorandum of any alteration therein, not being such as shall extend the exclusive right granted by the said letters patent; and which, when filed, shall be deemed part of such specification; but a caveat may be entered as heretofore; and such disclaimer shall not affect actions pending at the time; and the attorney-general may require the party to advertise his disclaimer.

2. Where a patentee is proved not to be the real inventor, though he believed himself to be so, he may petition his Majesty in council to confirm his letters patent or grant new ones; and the said petition shall be heard before the judicial committee of the privy council, who, on being satisfied that such patentee believed himself to be the first and original inventor, and that such invention had not been generally used before the date of such first letters patent, may report their opinion that the prayer of such petition ought to be complied with, whereupon his Majesty may, if he think fit, grant such prayer; but any person opposing such petition shall be entitled to be heard before the said judicial committee: and any person, party to any former suit touching such first letters patent, shall have notice of such petition.

3. If in any action or suit a verdict or decree shall pass for the patentee, the judge may grant a certificate, which being given in evidence in any other suit shall entitle the patentee, upon a verdict in his favour, to receive treble costs.

4. Allows a patentee, on advertising as therein mentioned, to apply to the privy council for a prolonged term. If the judicial committee report in his favour, his term may be prolonged for seven years; but such application must be made before the expiration of the original term.

5. In case of action, &c., notice of objections to be given with the pleadings.

6. Costs in actions for infringing letters patent, to be given as either

party has succeeded or failed in any part of his case, without regard to the general result of the trial.

7. Penalty for using, unauthorized, the name or device of a patentee, &c., £50, one half to his Majesty and the other to any informer.

Mr Farey, who has had much experience in superintending the taking of patents, states, that the average expence of a patent for England, may be estimated at £120; for Scotland, at £100; and for Ireland, £125.

PENDULUM. A simple pendulum consists of a particle of matter fastened to the end of a very fine inextensible string, the other end being fastened to a pin, about which it vibrates as a centre of motion. A compound pendulum consists of two or more bodies, or of one body from the figure and extent of which we are not permitted to abstract.

A pendulum which vibrates seconds in the latitude of London, is 39·1393 inches long; and $\sqrt{39 \cdot 1393} \times 60 = 375 \cdot 36$, serves as a constant number for other pendulums: thus, 375·36 divided by the square root of the pendulum's length, gives the number of vibrations per minute; and divided by the vibrations per minute, gives the square root of the length of pendulum. Thus, required the number of vibrations a pendulum of 25 inches long will make per minute.

$$\frac{375 \cdot 36}{\sqrt{25}} = 75 \cdot 072 \text{ vibrations per minute.}$$

Required the length of a pendulum to make 80 vibrations per minute,

$$\frac{375 \cdot 36}{80} = 4 \cdot 592^2 = 22 \cdot 014864 \text{ inches long.}$$

PENETRABILITY, the capability of being penetrated.

PENETRATION, is used principally to denote the forcible entry of one solid body within another by means of a projectile motion, communicated to the former, which enables it to displace those parts of the latter with which it comes in contact. Or, the penetration may be otherwise produced, by the action of some percussive force acting upon one of the bodies when in contact with the other; these two cases, however, differ rather in circumstances than in principle, and therefore in the slight sketch we shall give of this subject, we shall consider the penetrating body to be projected with a certain velocity, and impinging upon the fixed body in a direction perpendicular to its surface. This is a subject of considerable importance in military and naval gunnery, and has been accordingly treated of by different writers on these subjects; Dr Hutton, in particular, has made several experiments on different substances, and with different charges of powder, and different weight of shot, in order to procure data from which the penetration in other cases may be determined. The mean results of the most accurate of his experiments, as given in vol. iii. of his Tracts, are stated below.

Velocity in feet.	Substance.	Diam. of iron shot in inches.	Penetration.
1600	Elm	1·96	20 inch.
1200	Ditto	1·96	15
1500	Ditto	2·78	30
1060	Ditto	2·78	16
1200	Oak	5·04	34
1300	Earth	5·55	15 feet.

Pennyweight, the 20th part of an ounce Troy.

Pentagon, a figure of five angles, and five sides; when these are equal it is called a regular pentagon; but, otherwise, it is irregular. The angle at the centre of a pentagon is 72°, and the angle of its sides 144°. The area of a pentagon, whose side is one, is 1·7204774; consequently, when the side is s, the area $= s^2 \times 1{\cdot}7204774$.

Percussion, in Mechanics, the striking of one body against another, or the shock arising from the collision of two bodies. This is either direct or oblique.—*Direct Percussion*, is when the impulse takes place in a line perpendicular to the plane of impact.—*Oblique Percussion*, is that which takes place in any direction not perpendicular to the plane of impact.

The theory of percussion, is a subject which has much engaged the attention of philosophers, particularly with regard to the comparison of percussion and pressure, one party maintaining a perfect congruity between these two forces, while others assert their total incomparability, observing that the least quantity of percussion is greater than any pressure, however great; for, say they, the momentum of a body is measured by its mass into its velocity, if therefore the body A moves with a velocity v, while the body B is at rest, or has no velocity; the momentum of the former is $A \times v$, and of the latter $B \times 0$, and consequently the former is infinitely greater than the latter. However plausible this reasoning may appear at first sight, it is evidently erroneous as to the fact. Daily experience will convince us, that though the advantagos gained by bodies, moving swiftly, are very great over those which oppose merely a resistance of pressure, yet that they are by no means infinite. Numerous circumstances will suggest themselves to the mind, which prove, that, physically speaking, we may balance any percussive force by an equivalent one of mere pressure, or even we may make the latter greater, so as to overcome the former. The pile-engine offers a remarkable confirmation of this equality, or even preponderance on the side of pressure. It has, for instance, been found, that in driving piles in a uniform sandy soil of the same density to 47 feet, the piles could not be driven more than 15 feet by any percussive blow that could be communicated by the engine; that is, the friction and resistance of the soil, which may be considered as a pressive force, was greater than any percussive force that could be employed by the pile-engine, although the rammers made use of were extremely great. Hence, when we are computing the effect of a pile-engine, it will be necessary to estimate first the quantity of percussion that is equivalent to the resistance and friction opposed to the pile; as no momentum short of this, or even just equal to it, will produce any effect, and when the momentum is greater than this, it is only the difference between the two that is effective in producing motiou in the pile. And to this circumstance must be attributed the many erroneous solutions that appeared a few years back to the question, "What must be the height of a pile-engine to produce the greatest effect in a given time?" This question, at first sight, appears to be the same, with asking how high must the pile-engine be, to produce the greatest momentum in a given time; but by using this principle the solution always gave the height $= 0$; that is, the greatest effect will be produced when the rammer is left at rest on the top of the pile.

If, instead of proceeding thus, we first estimate, or find from experiment, the height to which the rammer must be drawn, in order that its momentum may be equivalent to the resistance of the pile, and then considering the difference between this and any greater momentum to be only the effective part, a very rational solution will be obtained.

But, before entering upon the solution of this problem, it will be proper to offer a few farther remarks with regard to the comparability of percussion and pressure, because the solution ultimately depends upon a proper comparison of those quantities, and a want of due attention to which seems to have been the cause of the erroneous results generally deduced in the solution of this problem.

Without, indeed, entering into a discussion concerning the congruity or incongruity of these forces, it is obvious, that they may be so employed as to produce the same or equal results. A nail, for example, may be driven to a certain depth into a block of wood by the blow of a hammer, or it may be sunk to the same depth by the pressure of a heavy body; whence, and from numerous other instances, it is obvious, that pressure and percussion, whether congrous or incongruous in their nature, are at least comparable in their effects. With regard to the above problem, the resistence and friction of the soil against the pile may, as above observed, be considered as a pressure, and the object of our inquiry is to establish a comparison between this resistance or pressure of the soil, and the momentum of the ram, or what part of the whole generated momentum of the latter is employed in overcoming the resistance of the former, in order to determine the effective part of the stroke, which ought alone to be considered in estimating the maximum effect; because any single momentum, less than that which is equivalent to the resistauce, would produce no effect whatever. It being admitted that pressure and momentum are at least comparable in their effects, it must also be granted that there is some determinate momentum of the ram, that is equivalent to the resistance of the pile, and the height necessary for producing this momentum must be the first object of our research, which it is obvious, from the various circumstances that may arise in the application of the pile-engine, can only be determined by experiment.

PERCUSSION, CENTRE OF. In striking any body with a bar or lever, it is always found that if the blow is given at or near the end of the bar, it will jar, or attempt to fly out of the hand; and if the blow is given by that part of the bar near the hand, it will also jar, and attempt to fly from it. Now there evidently must be a point between these two, where, if a stroke is given, the full effect of the blow will be sensible, and the bar will remain at rest, without jarring the hand. This point is called the centre of percussion, or the point in a striking body where, if it strike another, the effect will be most powerful; and as the centre of gravity of a body is a point on which, if suspended, the body would be in equilibrio, so the centre of percussion is a point in which the whole momentum of the moving body is placed to produce the greatest effect. The centre of *Percussion* is determined in the same way as the centre of *Oscillation*, which see.

PERIMETER, the boundary of any figure; being the sum of all the sides in right-lined figures, and means the same as circumference, or periphery, in circular ones.

PERIPHERY, the same as perimeter or circumference.

PERPENDICULAR, is formed by one line meeting another so as to make the angles on each side of it equal to each other.

PERPETUAL MOTION, is that which possesses within itself the principle of motion; and, consequently, since every body in nature, when in motion, would continue in that state, every motion once begun would be perpetual but for the operation of some external causes; such are those of friction, resistance, &c.: and since it is also a known principle in mechanics, that no absolute power can be gained by any combination of machinery, except there being at the same time an equal gain in an opposite direction; but that, on the contrary, there must necessarily be some lost from the above causes, it follows that a perpetual motion can never take place from any pure mechanical combination.

PERSPECTIVE, is the art of representing, upon a plane surface, the appearance of objects, however diversified, similar to that they assume upon a glass-pane interposed between them and the eye at a given distance. The representation of a solid object on a plane surface can show the original in no other point of view but that from which it is at the time beheld by the draughtsman; the least change in any of the parts requires a change in the whole; unless in fancy drawings where a fac-simile is not required. Nor can any deviation from the several lines, which will be hereafter explained, and on which the truth and correctness of representation depend, be allowed without changing the bearings, directions, and tendency of all the perspective lines which constitute the basis of that faithful and converging series which unite all the component parts in the most pleasing and harmonious concinnity.

The following definitions of the principal features in the science and application of perspective will prove useful to the student, viz. projection delineates objects in plano, by means of right lines called rays, supposed to be drawn from every angle of the object, to particular points. When the objects are angular, these rays necessarily form pyramids, having the plane or superfices, whence they proceed, for their basis; but when drawn from, or to, circular objects, they form a cone.

Ichnography, or ichnographic projection, is described by right lines parallel among themselves, and perpendicular to the horizon, from every angle of every object, on a plane parallel to the horizon. The points where the perpendicular lines or rays cut that plane being joined by right lines. The figure projected on the horizontal plane is likewise called the plan, or seat of that object on the ground plane. The points are the sites, or seats, of the angles of the object. The lines are the seats of the sides. By this we are to understand how the basis of figures represented as superstructures stand, or are supported; and we are further enabled to judge of, indeed to measure, their several parts, and their areas.

Orthography represents the vertical position and appearance of an object; hence orthographic projection is called the elevation. When we see the front of a house, we give it that term, but when the side is displayed, we call it the profile. If we suppose a house, or other object to be divided by a plane passing perpendicularly through it in a line at right angles with the point, we call it the lateral section; but if the plane pass in a direction parallel with the front, it is termed a longitudinal section. If the plane passes in neither of the former directions (not however deviating from the vertical) it is said to be an oblique section.

These give us the modes of laying down plans, of showing the parts, and the manner in which the interiors of edifices are arranged; consequently are indispensable to the architect, or surveyor, and indeed should be understood by every person in any way connected with building, or designing. Nor should the following be neglected, viz. scenography, which shows us how to direct the visual rays to every point, or part, of a picture; and stereography, which enables us to represent solids on a plane, from geometrical projection; whence their several dimensions, viz. length, breadth, and thickness may all be represented, and be correctly understood at sight. We suppose our readers to have some knowledge of geometry before they commence upon this, or any other of the abstract sciences which are founded thereon. Should such, however, not be the case, we beg leave to refer them to that head, where they will find sufficient instruction to enable them to prosecute their enquiries on the subject now before us.

An original object, is that which becomes the subject of the picture, and which is the parent of the design. Any plane figure may become an object, as may any of its parts, as a broken pillar, the ruins of a house, the stump or the branch of a tree; but we generally speak of objects as relating to entire figures represented as solids, or to as much rural or other scenery as may be embraced under an angle of 60 degrees formed by two lines meeting at the eye. This will explain why we are enabled to represent so great a number of distant objects, while the front, or foreground will contain, comparatively, but a very few: it being obvious that as the lines forming the angle become more distant, the more may be included between them.

Original planes, or lines, are the surfaces of the objects to be drawn; or they are any lines of those surfaces; or it means the surfaces on which these objects stand.

Perspective plane is the picture itself, which is supposed to be a transparent plane, through which we view the objects represented thereon.

Varnishing planes are those points which are marked upon the picture, by supposing lines to be drawn from the spectator's eye parallel to any original lines, and produced until they touch the picture.

Ground plane is the surface of the earth, or plane of the horizon, on which the picture is supposed to stand.

The ground line is that formed by the intersection of the picture in the ground plane.

The horizontal line is the vanishing point of the horizontal plane, and is produced in the same manner as any other vanishing line, viz. by passing a plane through the eye parallel to the horizontal plane.

The point of sight is the fixed point from which the spectator views the perspective plane.

Vanishing points are the points which are marked down in the picture, by supposing lines to be drawn from the spectator's eye, parallel to any original lines, and produced until they touch the picture.

The centre of a picture is that point on the perspective plane where a line drawn from the eye perpendicular to the picture, would cut it, consequently it is that part of the picture which is nearest to the eye of the spectator.

The distance of the picture is the distance from the eye to the centre of the picture. If what has been already said and repeated, regarding the angle of 60 degrees, is understood, the spectator will never bring the picture so near to himself as to occasion the eyes to expand, indeed to strain, so as to embrace more than that angle.

The distance of a vanishing point is the distance from the eye of the spectator to that point where the converging lines meet, and after gradually diminishing all the objects which come within their direction and proportion, are reduced so as in fact to terminate in nothing. All parallel lines have the same vanishing points; that is to say, all such as are in building, parallel to each other, when not represented exactly opposite to, and parallel with the eye, will appear to converge towards some remote point, i. e. their vanishing point. Circles, when retiring in such manner, are represented by ellipses, proportioned to their distances: their dimensions in perspective are ascertained by enclosing them, or the nearest of them, where a regular succession is to be portrayed, within a square, which being divided into any number of equal parts or chequers, will show all the proportions of those more remote. We trust it scarcely requires to be repeated that the further any object is from the eye or fore-ground of a picture, the less it will appear in nature, and the more it must be reduced in exhibiting its perspective.

A bird's-eye view is supposed to be taken from some elevated spot which commands such a prospect as nearly resembles the plane or ichnography of the places seen. Thus a view from a high tower, or from a mountain, whence the altitudes of the several objects on the plane below appear much diminished, gives nearly the same representation as is offered to a bird flying over them: whence the term. Some idea may be formed of this by standing on any height, and observing how low those objects, which are near thereto, will appear when compared with those more distant, taking, however, the perspective diminution of the latter into consideration.

The methods of perspective commonly practised and described in books are extremely complex and difficult to follow. We have pleasure in presenting to the reader an account of a method lately invented by Mr James Whitelaw, civil engineer, Glasgow, who has favoured us with the description and illustrations. The account will be found clear and complete, and when it is recollected that large volumes are necessary to explain perspective drawing on the old plan, the brevity of the following account is a sufficient proof of the superior simplicity of the method it describes.

1. If a person behind a transparent plane kept his eye exactly in the same position till he traced on the plane the objects on the other side of it by means of a pencil carried over the parts of the plane where the rays

of light reflected to the eye from all the lines in the objects cut the plane, the delineation would be a *perspective drawing* of the objects.

2. Fig. 1, is a ground plan of a number of objects, marked *a, b, c, d,* standing on a horizontal surface; the same letters in fig. 2, point out the same objects in the elevation; and fig. 3, is a perspective view of them. Before going farther, I may remark that when a *line* is spoken of in this paper it is a *straight line* that is meant, unless the contrary be mentioned.

3. In order to draw the perspective view, make first the ground plan and elevation as in figs. 1 and 2, then draw a line *f g*, in fig. 1, to represent the transparent plane which stands perpendicular to the surface on which the objects *a, b,* &c. stand, and after this fix upon the point *e*, in the same fig. for the position of the eye. But before making a full view it may be as well to illustrate the method by finding the perspective of a line, and as the line *h i*, in fig. 1, which stands perpendicular to the transparent plane is as good as any other, we shall commence with it. The point *h*, which marks the position of *h i*, in the elevation is on a level with the eye. From the ends of the line *h i*, draw the lines *h e* and *i e* to *e*, the *point of sight*, and the part *l h* of the transparent plane, or *picture sheet*, contained between the lines *h e* and *i e*, will be the perspective in the ground plan of the line *h i*, because the lines *h e* and *i e* represent the rays of light reflected to the eye from the ends of the line *h i*. From what is now said, it will be evident that *l n* shows the perspective in the ground plan of the part *i m*, of the line *h i*; and *n h* is the perspective in the same plan of *h m*, the other part of *h i*. If a line be drawn through *e*, parallel to *h i*, till it meets the picture sheet in *p*; *p h* will show, in fig. 1, the perspective of the line *h i*, if it is indefinitely extended beyond the point *i*. For, by inspecting the ground plan, it will be seen that the more distant from the picture sheet any point *i*, is taken, the line drawn from the point to the eye becomes more nearly parallel to *e p*; and in consequence of this, *p l* becomes smaller, the more distant the point is taken. And although we cannot name a distance from the picture sheet for the position of the point *i*, that will make *p* and *l* exactly coincide, yet we can place *i* so distant that the space betwixt *p* and *l* will be smaller than any quantity that we can form a notion of, and for this reason *p h* must be considered the perspective in the ground plan of the line *h i*, when it is indefinitely extended from the point *h*, in fig. 1, or from the point *h*, in the elevation which is on a level with *e*, the point of sight in the same view.

4. We now know how to represent on an edge view of the transparent plane, or picture sheet, the perspective of any line, or part of a line, running perpendicular to the transparent plane, and on the same level with the eye; but in order to make a picture, the perspectives of the

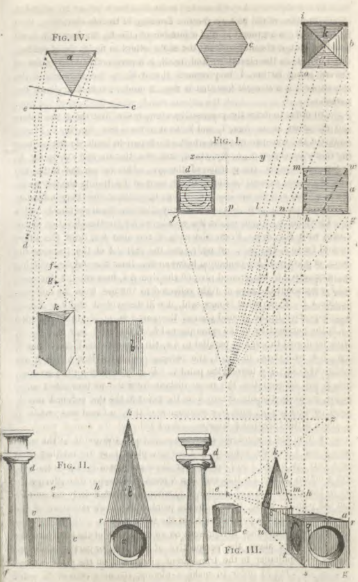


Fig. IV. Fig. I. Fig. II. Fig. III.

lines in the objects to be represented must be shown not on an edge but on an elevation of the picture sheet. Let fig. 3, be this elevation; then through the lowest points of the objects shown in fig. 2, draw the level line *f g*, in figs. 2 and 3. The part of *f g*, which is under the elevation, will represent a horizontal surface, passing through the lowest point of the objects to be shown in perspective, and if the bottom ends of the objects are on the same level as in figs. 1 and 2, this line shows the horizontal surface on which the objects stand, while the part of the line, *f g*, which passes under the perspective view, will represent the intersection of the transparent plane with this horizontal surface. I may remark just now, that the ground plan is drawn in such a position that the line *f g*, in figs. 2 and 3, is parallel to the line marked *f g*, in fig. 1; and I may further notice, that these lines are drawn parallel to the top or bottom edges of the drawing board, so that if a line is wanted to be drawn either parallel or perpendicular to these lines, the thing is done at once by applying a T square to the edge of the drawing board. If a line be drawn perpendicular to *f g*, in figs. 2 and 3, through *p*, or, which comes to the same thing, through *e*, in the ground plan, and if another line be drawn through *e*, which marks the place of the eye, as also the place of the point *p*, in fig. 2, parallel to the same line *f g*, and cutting the perpendicular line *e e*, in *e*; *e*, in the perspective view, is the position of the point *p*, shown in the ground plan. Now, if we let fall perpendicular lines from the points *h n* and *l*, in fig. 1, to the line *f g*, in figs. 2 and 3, and then produce the horizontal line *e e*, till it cuts the perpendicular lines *h q*, *n t*, and *l u*, in the points *h*, *m*, and *l*, in fig. 3, these points will be the perspectives of the points marked *h*, *m*, and *i*, respectively, in the ground plan. If the points *h* and *l*, in fig. 3, are joined, this line *h l*, will be the perspective of the line *h i*, the part *h m*, of this perspective line, is the perspective of the part marked *h m*, of the line *h i*, in the ground plan; and a line joining the points *h* and *e*, in fig. 3, is the perspective of the line *h i*, in the ground plan, when it is indefinitely extended in the direction *h i*.

5. Points in contact with the transparent plane must be at the same distance from, and in the same position with respect to, each other in the perspective view, as in the elevation; for the line drawn to the eye, which marks the perspective, can neither converge nor diverge in passing betwixt a point whose perspective is wanted and the picture sheet, as in this instance there is no distance betwixt the place of the point and the line *f g*, in fig. 1. From this it will be evident that any line or plane surface in contact with the transparent plane will have the same shape and dimension in the perspective view as in the elevation. And it will also be seen, that the principal reason why the point marked *e*, in fig. 3, is fixed upon as the place in the perspective view of the point

marked p, in fig. 1, is, that as this point e, is found in the place where a perpendicular let fall from the point p, to the line $f\,g$, in figs. 2 and 3, cuts a horizontal line running through the point e, in fig. 2, and the point e, in fig. 3, being the perspective of a point in contact with $f\,g$, in fig. 1, setting it off in this manner will allow the place of any other point of the objects to be shown in perspective which is in contact with the picture sheet, to be obtained by a similar process, which process is very easily gone through by means of a drawing square. As the part of the line $f\,g$, which is under fig. 2, represents a horizontal surface, which cuts the transparent plane, the intersection of the picture sheet and this horizontal plane being a line in contact with the picture sheet must be shown at the same distance below e, in the perspective view, that the part of $f\,g$, which is under fig. 2, is below the position of the eye, which is also the position in the elevation of the point marked p, in the ground plan. As we proceed it will become evident that the part of the line $f\,g$, which is under the perspective view, is of very great use to set up the height from it which any point in the elevation has above the line $f\,g$, in figs. 2 and 3, when the elevation cannot conveniently be drawn on the same board with the ground plan and the perspective view. The line $h\,e$, which shows, in fig. 3, the perspective of the line $h\,i$, when it runs to an indefinite distance from the picture sheet, must be a level line, as the point h, in fig. 2, at which the line commences, is in a level with the point e, the position of p, in the same fig., and these points being both in contact with $f\,g$, in the ground plan, must have the same position in the perspective view that they have in the elevation.

6. Suppose the line $h\,i$, which runs perpendicular to the picture sheet, and on a level with the eye, to have its commencement in fig. 1, at the point l, instead of the point h. By reasoning in the same way, as in paragraph 3, it will be found that $l\,p$ is the perspective in the ground plan of the line $h\,i$, when it is extended to an indefinite distance beyond the point l, in the ground plan. And it will further be found that the nearer to the point p, that any line, running perpendicular to the picture sheet, and on a level with the eye, is taken, the *indefinite perspective* (that is, the perspective of a line when it is indefinitely extended,) will always get shorter, so that if a line such as $h\,i$, has its commencement in the point p, its indefinite perspective will be shown in the ground plan by the point p itself. In the same way it may be shown that p is the *vanishing point* (that is, the point which terminates the perspective of a line when it is indefinitely extended,) of any line running perpendicular to the picture sheet and in a level with the point of sight, although the line commence at a point f, on the different side of the point p, from the line $h\,i$: and the reasoning employed in paragraph 3, will also show that the perspective of any point, in a line so situated, is

obtained in the same way in which the perspective of the point marked *m*, in fig. 1, or the point *i*, in the same fig., is found. Or, if a line running perpendicular from the picture sheet to an indefinite distance beyond it, have its commencement not, as in the above examples, at a part of the picture sheet on a level with the eye, but in a line passing through the point *p*, and running at right angles to the plane on which the objects *a*, *b*, &c., stand, the vanishing point of a line so situated will be the point *p* in the ground plan, and the point *e*, in fig. 3, in this case also: this may be demonstrated in the same way as the vanishing point of the line *h i*, or any of the other lines running parallel to, and on a level with it, was shown to be the points *p* and *e*, respectively, in figs. 1 and 3. In a similar manner it may be shown that if any line running perpendicular to the transparent plane, to an indefinite distance beyond it, has its commencement at any point *v*, in fig. 2, which is neither in a horizontal nor a perpendicular line, passing through the position of the eye in the same fig.; the vanishing point of a line so placed is, as in the above examples, the point *p*, in the ground plan; or the point *e*, in the elevation.

7. Let the line *h i*, fig. 1, have its commencement in the elevation at *r*, one of the corners of the cube *a*, its perspective view is found as follows. From the point *h*, in fig. 1, draw a line *h s*, perpendicular to the line *f g*, in figs. 2 and 3, and from *r*, draw a line *r q*, parallel to *f g*, and the point *q*, where the line *r q* cuts the line *h s*, is the commencement of the perspective of the line *h i*; join *q* with *e*, and this line will be the perspective of the line *h i*, when it is indefinitely extended. A line joining the points *s* and *e* is the perspective of the line *h i*, if it is indefinitely extended, when it has its position in the elevation at the corner which is under *r*, of the cube *a*. The point *s*, where the perspective line *s e* commences, is found in the very same way as the point *q* was found. As *q e* is the perspective of the line *h i*, which runs perpendicular to the picture sheet, when it is indefinitely extended, from *r*, in fig. 2, one of the top corners of the cube *a*; and as *s e* is the perspective of *h i*, when it is indefinitely extended, in a direction perpendicular to the picture sheet, from the corner under *r*, of the cube *a*, in fig. 2, the triangle *q e s* is the perspective of a parallel surface, standing perpendicular to the surface on which the objects *a*, *b*, &c. stand, and running at right angles to the picture sheet, to an indefinite distance from it. The side of the cube *a*, that is towards the centre of the picture, and the same side of the cube under the pyramid, form part of the perspective of this parallel surface. The point *t*, where the line *n t*, let fall from the point *n*, in the ground plan, perpendicular to the line *f g*, in figs. 2 and 3, cuts the line *s e*, is the perspective of the bottom corner at *m*, of the cube *a*; and the place where this same line, *n t*, cuts the perspective line *q e*, is the perspective of the top corner *m*, of the cube

marked *a*, in the ground plan. So now we have got the perspectives of the four corners of one of the sides of the cube, in front of the picture; and by joining these corners we get the surface *q t*, and this surface is the perspective of the side of this cnbe, which is towards the object *d*. A perpendicular, let fall upon the line *f g*, in the elevation and perspective view, from the point *l*, in fig. 1, will cut tho lines *q e*, and *s e*, so as to give the perspectives of the top and bottom corners at *i*, of the cube under the pyramid; and the other two corners of the side of this cube, which is next the object *c*, is obtained in a similar manner; and by joining these corners we get the surface *o u*, which shows, in perspective, the side of the base of the object *b*, marked *o i*, in the ground plan.

8. It may not be plain to every one how that the line, *m w*, in the ground plan, as well as every other line in the objects to be shown in perspective, which runs in a horizontal direction, and parallel to the picture sheet, should be shown by a level line in fig. 3. That this is the case, can very readily be proved, in a line, as above described, but in the position *x y*, in the ground plan, with the points *x* and *y*, which terminate the line, each at the same distance from the line, *e p*, produced. For whether the line *x y* be above, or below, or on the same level with, the eye, the rays of light, proceeding from the whole line *x y*, to the point of sight, form a plane of the shape of an isoceles triangle, having *x y* for its base; and a line joining the points *x* and *e*, will be the one side, while a line joining the points *y* and *e*, will form the other side. But this triangular plane is the surface which gives, by its intersectiou with the picture sheet, the perspective of the line *x y*; and as *x y* is a level line, and parallel to *f g*, in fig. 1, the line which forms the intersection of the triangular plane with the picture sheet, must be a horizontal line, which every person, at all acquainted with the properties of parallel lines and the intersection of planes, will see at once. Now, it will be evident that the perspective of any line in a position as *m w*, must be a level line, for *m w* forms a part of a line similarly situated to the line *x q*. Some people think that a line as *x y*, should appear in the perspective view, bent upwards or downward at the ends, from the point in it exactly under or above the point *e*, according as *x y* happens to be below or above the level of the point of sight in the elevation; but this is a mistake; for the perspective of every straight line must be a straight line, as it is formed by the intersection of two planes. By reasoning in the same way as in the former part of this paragraph, it will be seen that every line which stands in a perpendicular direction in the objects to be represented in perspective, will be shown by a perpendicular line in fig. 3. The upright corners of the cubes, and some other lines in the figs. illustrate this.

9. If what is written in the preceding paragraphs be well understood, it will be seen that the different figs. are placed in such a way, that when the perspective of a line, which stands perpendicular to the horizontal surface, passing through the lowest point of the objects to be shown in perspective, and of no particular length, is wanted, we have just to draw a line to the place of the eye, in the ground plan, from the point which marks the position of the perpendicular line in the same fig., and at the point in the picture sheet where the line, passing betwixt the place of the perpendicular line and the eye, cuts it, let fall a perpendicular line upon *f g*, in figs. 2 and 3, and this line will be the perspective of the line whose perspective is wanted. And when we want to find the perspective of a line running perpendicular to the picture sheet, from any point in it, we have first to let fall upon *f g*, in figs. 2 and 3, a perpendicular line from the point in the picture sheet, in fig. 1, where the line, whose perspective is wanted, commences, then we have to draw a horizontal line, to cut this perpendicular line, from the point which marks the place of the line to be shown in perspective, in fig. 2, and the place where this horizontal line cuts the perpendicular line, is the point in fig. 3, where the perspective of the line commences; and joining this point with the point *e*, in the same fig., will give the perspective of the line whose perspective is wanted, when it is indefinitely extended from the point where it commences in the picture sheet. The following *rule* to find the perspective of any point rests upon the principle, that a point to be shown in perspective, which does not happen to be in the intersection of two lines, the one running perpendicular to the picture sheet, and the other at right angles to the horizontal surface on which the objects to be drawn in perspective stand, may be supposed to be so situated, and then if the perspectives of these lines, cutting each other in the point whose perspective is wanted, be found, the point where they cross, in fig. 3, will give the perspective of the point.

RULE.—From the place of the point in the ground plan, draw a line to the point of sight, and from the point where this line cuts the picture sheet, let fall a perpendicular upon the line *f g*, in figs. 2 and 3. After this, from the place of the point in the ground plan, whose perspective is wanted, let fall another perpendicular upon the line *f g*, in figs. 2 and 3, on this perpendicular set up the height that the point stands at in the elevation above the line *f g*; measuring this height from part of *f g*, which is under the perspective view; then, from the height so set up, draw a line to the point *e*, in the perspective view, and the place where this line cuts the perpendicular let fall from the point in the picture sheet where the line drawn to the eye in the ground plan cuts it, is the perspective of the point wanted. Thus:—suppose that we want to find the perspective of the top point *k*, of the pyramid *q*. From *k*, in the ground plan, draw a line $k\ e$, to the eye, and from the point n, where this line cuts the picture sheet, let fall a line $n\ k$, perpendicular to $f\ g$, in figs. 2 and 3. Then from the point k, in fig. 1, let fall a line $k\ z$, perpendicular to $f\ g$, in figs. 2 and 3, on this line set up the point z, above the line $f\ g$, at a distance equal to the height that the top k, in the elevation of the pyramid, is above the part of $f\ g$, which is under fig. 2, and from the point z, draw a line to e, in the perspective view, and the point k, where the lines $z\ e$ and $n\ k$ intersect, is the perspective of the top point of the pyramid. As all the lines that run up the sides of the pyramid meet at the top, the perspective view of the pyramid is completed by finding the perspectives of the bottom ends of these lines, and joining as many of the perspective points as are not hid by surfaces in front of them, with the point k; and then join these perspective points, the one with the other. The method of drawing the cube in front of the picture, and also the cube on which the pyramid stands, is fully sketched out in the engraving. The six-sided prism c, is drawn in perspective, in the very same way as the pyramid, by finding the perspectives of the points at the ends of all the lines in it, and joining these perspective points.

To find the perspective of a circle or any other curve. Mark off, at random, a number of points in the ground plan of the curve, after this mark off the positions of the same point in the elevation, then find by the *rule* the perspective of each point, and when that is done, connect the perspective points by a line, and this line will be the perspective of the curve. The line which shows the perspective of a curve will be a straight line, when the curve to be shown in perspective is placed in a plane, which if it was produced, would pass through the point of sight. If a circle is placed in a plane, parallel to the picture sheet, its perspective is a circle. In any other position than the two now mentioned the perspective of a circle is an ellipse, and not two segments of a circle meeting at the ends, which is the way that persons who do not understand the subject draw a circle in perspective.

When the line drawn perpendicular to $f\ g$, in figs. 2 and 3, from the point in the ground plan, whose perspective is wanted, nearly coincides with the line drawn perpendicular to the same line $f\ g$, from the point in the picture sheet, where the line drawn to the eye, from the point in the ground plan cuts it, the height of the perspective of the point cannot be so exactly found by the *rule*, as the line drawn to the point e, in the perspective view, is, in this case, nearly a perpendicular line, and the place where this line cuts the line, let fall perpendicular to $f\ g$, in figs. 2 and 3, from the point in the picture sheet where the line drawn to the eye from the place of the point in the ground plan cuts it, is not so exactly marked as when these lines, which mark by their cutting the perspective of the point, cross each other in a direction nearer the perpendicular. When great exactness is wanted in a case of this kind, it will be the better way to find the perspective of a horizontal line, parallel to the picture sheet, passing through the point whose perspective is wanted, and the place where this perspective line cuts the line drawn perpendicular to the line $f\,g$, in figs. 2 and 3, from the point in the picture sheet, where the line drawn from the place of the point in the ground plan to the eye cuts it, is the perspective of the point.

The eye should not be nearer to the picture sheet than the greatest height or breadth of the picture, and it should be placed in the ground plan, so that a line let fall from it perpendicular to the picture sheet should bisect the angle $f\,e\,g$, formed by lines drawn to it from the points which mark out the greatest width of the picture. The line $e\,p$, in the ground plan, does not bisect the angle $f\,e\,g$; but this was done to save room, and to show some parts of the objects that could not have been so well represented if the position of the eye had been more nearly opposite to the centre of the picture. If the eye is very distant from the picture sheet a perpendicular let fall from it to the picture sheet need not fall exactly on the centre of the picture.

If, in the ground plan, or the elevation, one part keeps another out of sight, the part hid must be drawn before its perspective can be made. The dotted lines in the ground plan showing the small moulding on the top of the pillar, and the dotted lines in the same plan which show the round pannels in the cube that is close to the picture sheet, illustrate this remark.

When a figure in the objects to be represented is parallel to the transparent plane the perspective of the figure is similar to the original one, but less in magnitude, according to its distance.

If a picture is wanted in which the transparent plane does not stand perpendicular, the easiest way to make it is to consider the picture sheet perpendicular, and draw the figures corresponding to the ground plan and elevation as if the objects were put off the perpendicular by elevating one side of the horizontal surface passing through the lowest point in them.

Sometimes after the ground plan of any object or number of objects is drawn, it may be considered better not to have the picture sheet in this plan parallel to the top or bottom edges of the drawing board, but in a direction such as the line $h\,c$, in fig. 4, is drawn. When this happens draw, as in fig. 1, lines from all the points in the ground plan to d, the point of sight, then let fall perpendicular lines from the same points to the picture sheet, $h\,c$; after this draw from a point c, (which is beyond the lines drawn from the place of the points in the ground plan to the picture sheet,) the line $c\,e$, parallel to the top or bottom edge of the drawing board. Then from the point *c*, where the lines *h c* and *e c*, meet, with a pair of pencil bows draw circles to *e c*, from all points in *h c*, where the perpendicular lines, and the lines drawn to the eye from the points in the ground plan meet it, also the point where a perpendicular let fall from the point *d* to the picture sheet, meets it, must be transferred by means of the pencil bows to the line *e c*; and perpendicular to *e c*, from this last point transferred, mark off the point *f*, at the same distance from *e c*, that *d* is from *h c*. It will now be evident that transferring the points on *h c* to *e c*; and settling the point *f*, in the position mentioned above, produces the same effect as if *h c*, with all the points on it, together with *d*, the point of sight, moved with the same angular motion round the point *c*, as a centre, till *h c* came to the position *e c*. The point *d* would then coincide with *f*; and *e c* would be the picture sheet with all its points upon it brought into a position parallel to the bottom of the drawing board. When the operation is thus far gone through, the rest of the process is conducted as if the ground plan had been drawn to suit the picture sheet in the position *e c*. In order that fig. 4 may be fully understood, I need only add that *b* is an elevation of the object *a*, in the ground plan, and *k* is the perspective view of it; *g*, in the perspective view, being the vanishing point of the lines running perpendicular to the picture sheet. Rather than draw a perspectivo view with the position of the picture sheet in the ground plan inclined to the sides of the drawing board, as in fig. 4, it will be better to shift the blade of the drawing square so as to draw the ground plan of the objects at the required angle to the picture sheet, when it is in a position as in fig. 1.

Isometrical Perspective. This is a kind of perspective invented by professor Farish, of Cambridge. We extract, with some modifications, a portion of professor Farish's paper on the subject, which appeared in the first volume of the Transactions of the Cambridge Philosophical Society. The subject has been but little attended to by mechanical draughtsmen, but its importance is becoming daily better known.

After some general remarks on the inadequacy of the common methods of drawing machinery; he states that it is preferable to the common perspective on many accounts, for such purposes. It is much easier and simpler in its principles. It is also, by the help of a common drawing-table, and two rulers, incomparably more easy, and, consequently, more accurate in its application; insomuch, that there is no difficulty in giving an almost perfectly correct representation of any object adapted to this perspective, to which the artist has access, if he has a very simple knowledge of its principles, and a little practice.

It further represents the straight lines which lie in the three principal directions, all on the same scale. The right angles contained by such lines are always represented either by angles of 60 degrees, or the supplement of 60 degrees. And this, though it might look like an objection, will appear to be none on the first sight of a drawing on these principles, by any person who has ever looked at a picture. For, he cannot for a moment have a doubt, that the angle represented is a right angle, on inspection.

And we may observe further, that an angle of 60 degrees is the easiest to draw of any angle in nature. It may be instantly found by any person who has a pair of compasses, and understands the first proposition of Euclid. The representation, also, of circles and wheels, and of the manner in which they act on one another is very simple and intelligible. The principles of this perspective which, from the peculiar circumstance of its exhibiting the lines in the three principal dimensions on the same scale, I denominate "*Isometrical*," will be understood from the following detail:

Suppose a cube to be the object to be represented. The eye placed in the diagonal of the cube produced. The paper, on which the drawing is to be made to be perpendicular to that diagonal, between the eye and the object, at a due proportional distance from each, according to the scale required. Let the distance of the eye, and consequently that of the paper, be indefinitely increased, so that the size of the object may be inconsiderable in respect of it.

It is manifest, that all the lines drawn from any points of the object to the eye may be considered as perpendicular to the picture, which becomes, therefore, a species of orthographic projection. It is manifest, the projection will have for its outline an equiangular and equilateral hexagon, with two vertical sides, and an angle at the top and bottom. The other three lines will be radii drawn from the centre to the lowest angle, and to the two alternate angles; and all these lines and sides will be equal to each other both in the object and representation: and if any other lines parallel to any of the three radii should exist in the object, and be represented in the picture, their representations will bear to one another, and to the rest of the sides of the cube, the same proportion which the lines represented bear to one another in the object.

If any one of them, therefore, be so taken as to bear any required proportion to *its* object, e. g. 1 to 8, as in my representations of my models, the others also will bear the same proportion to *their* objects; that is, the lines parallel to the three radii will be reduced to a scale.

I omit the demonstration of this, and some other points, partly for the sake of brevity, and partly because a geometrician will find no difficulty in demonstrating them himself, from the nature of orthographic projection; and a person, who is not a geometrician, would have no interest in reading a demonstration.

For the same reason, it is unnecessary to show that the three angles at the centre are equal to one another, and each equal to 120 degrees, twice the angle of an equilateral triangle; and the angle contained between any radius and side is 60 degrees, the supplement of the above, and equal to the angle of an equilateral triangle.

In models, and machines, most of the lines are actually in the three directions parallel to the sides of a cube, properly placed on the object. And the eye of the artist should be supposed to be placed at an indefinite distance, as before explained, in a diagonal of the cube produced.

The last mentioned line may be called the *line of sight*.

Let a certain point be assumed in the object, as for example, C, fig. 2, and be represented in the picture, to be called, the *regulating point*. Through that point on the picture may be drawn a vertical line, C E, fig. 1, and two others, C B, C G, containing with it, and with one another, angles of 120°, to be called the *isometrical lines*, to be distinguished from one another by the names of the *vertical*, the *dexter*, and the *sinister* lines. And the two latter may be called by a common name—the *horizontal isometrical* lines. Any other lines, parallel to them, may be called respectively by the same names. The plane passing through the dexter, and vertical lines, may be called the *dexter isometrical plane*; that passing through the vertical, and sinister lines, the *sinister plane*; and that through the dexter and sinister lines, the *horizontal plane*.

Fig. 1.

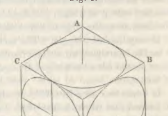
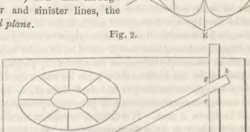


Fig. 2.



The drawing implements are thus described by the inventor. It is unnecessary to describe the drawing-table any further than by observing that it ought to be so contrived, as to keep the paper steady on which the drawing is to be made.

There should be a ruler in the form of the letter T to slide on one side of the drawing-table. The ruler should be kept, by small prominences on the under side, from being in immediate contact with the paper, to prevent its blotting the fresh drawn lines as it slides over them. And a second ruler, by means of a groove near one end on its under side, should be made to slide on the first. The groove should be wider than the breadth of the first ruler, and so fitted, that the second may at pleasure be put into either of the two positions represented in the plate, fig. 2, so as to contain with the former ruler, in either position, an angle of 60 degrees. The groove should be of such a size, that when its shoulders *a* and *d* are in contact with, and rest agaiust the edges of the first ruler, the edge of the second ruler should coincide with *d e*, the side of an equilateral triangle described on *d g*, a portion of the edge of the first ruler; and when the shoulders *b* and *c* rest against the edges of the first ruler, the edge of the second should lie along *g e*, the other side of the equilateral triangle. The second ruler should have a little foot at *k* for the same purpose as the prominences on the first ruler, and both of them should have their edges divided into inches, and tenths, or eighths of inches.

It would be convenient if the second ruler had also another groove *r s*, so formed that when the shoulders *r* and *s* are in contact with the edges of the first ruler, the second should be at right angles to it. For representing circles in their proper positions, the writer made use of the inner edges of rims cut out from cards, into isometrical ellipses as represented in the figure; of these he had a series of different sizes, corresponding to his wheels. Such a series might be cut by help of the concentric ellipses, but he thinks that it would be an easier way to make use of that set of concentric ellipses as they stand, by putting them in the proper place under the picture, if the paper on which the drawing is made, be thin enough for the lines to be traced through, as by the help of them the several concentric circles will go to the representation of one which might be drawn at once. It is difficult to execute them separately with sufficient accuracy to make them correspond. For this purpose a separate plate of ellipses should be had, and one edge of the paper on the drawing-table should be loose to admit of the concentric ellipses being slid under it to the proper place.

By the use of the simple apparatus described above, the representation of these lines iu the objects may be drawn on the picture, and measured to a scale, with the utmost facility, the point at the extremity being first found, or assumed. The position of any point in the picture may be easily found, by measuring its three distances, namely, first its perpendicular distance from the *regulating horizontal plane* (that is, the horizontal plane passing through the regulating point), secondly, the perpendicular distance of that point where the perpendicular meets the horizontal plane, from the regulating dexter line; and thirdly, of the point, where that perpendicular meets the dexter line from the regulating point; and then taking those distances reduced to the scale, first, along the dexter line, secondly, along the sinister line, and thirdly, along the vertical line, in the picture. These three may be called the *dexter distance* of the point, its *sinister distance*, and its *altitude*. And it is manifest they need not be taken in this order, but in any other that may be more convenient to the artist, there being six ways in which this operation may be varied.

If any point in the same isometrical plane, with the point required to be found, is already represented in the picture, that point may be assumed as a new regulating point, and the point required found by taking two distances; and if the new assumed regulating point is in the same isometrical line with the point, it is found by taking only one distance. And this last simple operation will be found in practice all that is necessary for the determination of most of the points required. Thus any parallelopiped, or any frame work, or other object with rafters, or lines lying in the isometrical directions, may be most easily and accurately exhibited on any scale required. But if it be necessary to represent lines in other directions, they will not be on the same scale, but may be exhibited, if straight lines, by finding the extremities as above, and drawing the line from one to the other; or sometimes more readily in practice by help of an ellipse, as hereafter described.

If a curved line be required, several points may be found sufficient to guide the artist to that degree of exactness which is required.

The method of exhibiting the representations of any machines, or objects, the lines of which lie, as they generally do, in the isometrical directions; that is, parallel to the three directions of the lines of the cube, is as has been already shown; and likewise the mode of representing any other straight lines, by finding their extremities; or curved lines, by finding a number of points.

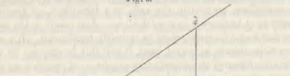
But in representing machines and models, there are not only isometrical lines, but also many wheels working into each other, to be represented. These, for the most part, lie in the isometrical planes. And it is fortunate that the picture of a circle in any one of these planes is always an ellipse of the same form, whether the plane be horizontal, dexter, or sinister; yet they are easily distinguished from each other by the position in which they are placed on their axle, which is an isometrical line, always coinciding with the minor axis of the ellipse.

This will be obvious from considering the picture of a cube with a circle inscribed in each of its planes, fig. 1, and considering these circles as wheels on an axle. The two other lines, or spokes of the wheel, in the ellipse, which are drawn respectively through the opposite points of contact of the circle with the circumscribing figure, are isometrical lines also; for the points of contact bisect the sides of the circumscribing parallelogram, and therefore the lines are parallel to the other sides. They give likewise the true diameter of the wheels, reduced to the scale required. It further appears from the nature of orthographic projection, that the major axis of the ellipse is to the minor axis, as the longer to the shorter diagonal of the circumscribing parallelogram, that is, since the shorter diagonal divides it into two equilateral triangles, as the square root of three to one; and since the sum of the squares of the conjugate diameters in an ellipse is always the same, if we put $\sqrt{1}$ for the minor axis, the $\sqrt{3}$ for the major, and i for the isometrical diameter, we shall have $2\,i^2 = 1 + 3, = 4$, and $i = \sqrt{2}$.

Therefore the minor axis, the isometrical diameter, and the major axis, may be represented respectively by $\sqrt{1}$, $\sqrt{2}$, $\sqrt{3}$, or nearly by 1, 1·4142, 1·7321; or more simply, though not so nearly, by 28, 40, 49.

These lines may be geometrically exhibited by the following construction:

Fig. 3.

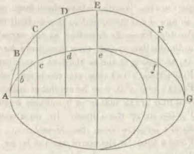


Let A B, fig. 3, be equal to B D, and the angle at B, a right angle. In B A produced, take B α = to A D draw α D, and produce both it, and α B. Then will B D, B α, and α D, be respectively to one another, as $\sqrt{1}$, $\sqrt{2}$, $\sqrt{3}$. Therefore if $\alpha\,\beta$ be taken equal to the isometrical diameter of the ellipse required, $\beta\,\delta$ drawn perpendicular to it will be the minor axis, and $\alpha\,\delta$ the major axis. The ellipse itself, therefore, may be drawn by an elliptic compass, as that instrument may be properly set, if the major and minor axes are known. If it is to represent a wheel on an axle, care must be taken to make the minor axis lie along that axle. In the absence of the instrument it may be drawn from the concentric ellipses, which may be placed under the paper, in the position above described, and seen through it; if the paper be not too thick, and in this method the smaller concentric circles of the wheel may be described at the same time, as they may be seen through the paper, or if they should not be exactly of the right size, it would be easy to describe them by hand between the two nearest concentric ellipses; and thus also the height of the cogs of a wheel in the different parts of it may be exhibited longer aud narrower towards the extremities of the minor axis. Their width may be determined from the divisions of the ellipse. In most cases this may be done with sufficient accuracy from the circumference of the ellipse being divided into eight equal divisions of the circle, by the two axes, and two isometrical diameters, each of which parts may be subdivided by the skill of the artist; and not only the face of the wheel in front may be thus exhibited, but the parts of the back circles also, which are in sight, may be exhibited by pushing back the system of concentric ellipses on the minor axis or axle through a distance representing the breadth of the wheel, and then tracing both the exterior and the interior circles of the wheel, and of the bush on which it is fixed, as far as they are visible. Care should be taken to represent the top of the teeth, or cogs, by isometrical lines, parallel to the axle, in a face-wheel, or tending to a proper point in the axle in a bevil-wheel. And nearly in the same way may the floats of a water-wheel be correctly represented. If a series of concentric ellipses be not at hand, it will still be easy for an artist to draw the ellipses with sufficient accuracy for most purposes, by drawing through the proper point in the axle, the major and minor axes, and the two isometrical diameters, thus making eight points in the circumference to guide him.

If in any case it should become necessary to represent a circle, which does not lie in an isometrical plane, we may observe that the major axis will be the same in whatever plane it lies: and it will be the picture of that diameter, which is the intersection of the circle with the plane parallel to the picture, passing through its centre. And the major axis will bear to the minor axis the proportion of radius to the sine of the inclination of the line of sight to the plane of the circle. We may observe further, that the diameters of the ellipse, which are to the major axis, as $\sqrt{2}$ to $\sqrt{3}$, when such exist, are isometrical lines.

And the representation of every other line parallel, and equal to any diameter of the circle, may be exhibited by drawing it equal and parallel to the corresponding diameter in the ellipse. If it should be desired to divide the circumference of an ellipse into degrees, or any number of parts representing given divisions of the circle, it may be done by the following method:—

Fig. 4.



Let an ellipse be drawn, fig. 4, and on its major axis, A G, a circle described, with its circumference divided into degrees or parts in any desired proportion, at B, C, D, E, F, &c. from which points draw perpendiculars to the major axis. They will cut the periphery of the ellipse in corresponding points. It would be difficult, however, in this way, to mark, with sufficient accuracy, the degrees, which lie near the extremities of the major axis. But the defect may be supplied by transferring those degrees in a similar way, from a graduated circle, described on the minor axis. In this manner an isometrical ellipse may be formed into an isometrical circular instrument, or an isometrical compass, which may show bearings or measure angles on the picture, in the same manner as a real compass or circular instrument would do in nature.

It may be often useful to have a scale to measure distances, not only in the isometrical directions, but in others also. And this may be done by a series of similar concentric ellipses, as in fig. 7, dividing the isometrical diameters into equal portions. The other diameters will be so divided as to serve for a scale for all lines parallel to them respectively.

Thus, in the isometrical squares, exhibited in fig. 1, distances measured on the longer diagonal, or its parallels, would be measured by the divisions on the major axis, those depending on the shorter diagonal by the divisions on the minor axis.

To describe a cylinder lying in an isometrical direction, the circles at its extremities should be represented by the proper isometrical ellipses, and two lines touching both should be drawn: and in a similar way, a cone, or frustum of a cone, may be described. A globe is represented by a circle, whose radius is the semi-major axis of the ellipse representing a great circle.

It would not be difficult to devise rules for the representation of many other forms which might occur in objects to be represented. But the above cases are sufficient to include almost every thing which occurs in the representation of models, of machines, of philosophical instruments, and, indeed, of almost any regular production of art.

PHYSICS, is a term denoting the same as experimental or natural philosophy; being the doctrine of natural bodies, their phenomena, causes, and effects, with their various affections, motions, and operations.—*Experimental Physics*, is that which enquires into the nature and reason of things by experiments, as in hydrostatics, pneumatics, optics, chemistry, &c.—*Mechanical Physics*, explains the appearances of nature from the matter, motion, structure, and figures of bodies, and their several parts, according to the established laws of nature.

PIERS, walls built to support arches, and from which as bases they spring.

PILES; large stakes or beams sharpened at the end, and shod with iron, driven into the ground for a foundation to build upon in marshy places.

PINION, in practical mechanics, is any small wheel working in the teeth of a larger wheel. See *Wheel*.

PIPE, a tube for the conveyance of water, steam, &c. Pipes receive particular names, according to the purposes to which they are applied, as *Steam Pipe*, *Eduction Pipe*, &c. We insert a table of the weight of cast iron pipes of the dimensions commonly in use.

Table of the Weight of Cast Iron Pipes.

Bore.	Thick.	Long.	Weight.	Bore.	Thick.	Long.	Weight.
inch.	inches.	ft. in.	cwt. qr. lbs.	inch.	inches	ft. in.	cwt. qr. lbs.
1	¼	3 6	0 0 12		¾	9 0	3 1 24
	⅜	3 6	0 0 20	5½	⅜	9 0	1 3 10
1½	¼	4 6	0 0 21		½	9 0	2 2 0
	⅜	4 6	0 1 4		⅝	9 0	3 0 18
2	¼	6 0	0 1 8		¾	9 0	3 3 7
	⅜	6 0	0 2 0		1	9 0	5 0 12
2½	¼	6 0	0 1 16	6	⅜	9 0	2 0 0
	⅜	6 0	0 2 10		½	9 0	2 2 21
	½	6 0	0 3 10		⅝	9 0	3 1 17
3	¼	9 0	0 2 20		¾	9 0	4 0 16
	⅜	9 0	1 0 6		1	9 0	5 2 20
	½	9 0	1 1 12	6½	⅜	9 0	2 0 16
	⅝	9 0	1 3 6		½	9 0	2 3 20
	¾	9 0	2 1 0		⅝	9 0	3 2 21
3½	¼	9 0	0 3 0		¾	9 0	4 1 20
	⅜	9 0	1 0 21		1	9 0	6 0 14
	½	9 0	1 2 14	7	⅜	9 0	2 1 7
	⅝	9 0	2 0 8		½	9 0	3 0 7
	¾	9 0	2 2 0		⅝	9 0	3 3 20
4	⅜	9 0	1 1 10		¾	9 0	4 3 5
	½	9 0	1 3 12		1	9 0	6 2 4
	⅝	9 0	2 1 12	7½	⅜	9 0	2 2 4
	¾	9 0	2 3 21		½	9 0	3 1 6
4½	⅜	9 0	1 2 2		⅝	9 0	4 0 22
	½	9 0	2 0 4		¾	9 0	5 0 10
	⅝	9 0	2 2 14		1	9 0	7 0 0
	¾	9 0	3 0 20	8	½	9 0	3 2 4
5	⅜	9 0	1 2 22		⅝	9 0	4 1 25
	½	9 0	2 1 10		¾	9 0	5 1 18
	⅝	9 0	2 3 17		1	9 0	7 1 16

Table of the weight of Cast Iron Pipes, continued.

Bore.	Thick.	Length.		Weight.			Bore.	Thick.	Length.		Weight.		
inch.	inches.	ft.	in.	cwt.	qr.	lbs.	inch.	inches.	ft.	in.	cwt.	qr.	lbs.
8½	½	9	0	3	3	2	12½	1	9	0	11	0	21
	⅝	9	0	4	2	26	13	½	9	0	5	2	20
	¾	9	0	5	2	22		⅝	9	0	7	0	14
	1	9	0	7	3	8		¾	9	0	8	2	7
9	½	9	0	4	0	0		1	9	0	11	2	12
	⅝	9	0	5	0	4	13½	½	9	0	5	3	7
	¾	9	0	6	0	2		⅝	9	0	7	1	12
	1	9	0	8	0	26		¾	9	0	8	3	16
9½	½	9	0	4	0	18		1	9	0	11	3	24
	⅝	9	0	5	1	0	14	½	9	0	6	0	4
	¾	9	0	6	1	6		⅝	9	0	7	2	16
	1	9	0	8	2	20		¾	9	0	9	1	0
10	½	9	0	4	1	10		1	9	0	12	1	14
	⅝	9	0	5	1	26	14½	½	9	0	6	0	24
	¾	9	0	6	2	14		⅝	9	0	7	3	14
	1	9	0	9	0	8		¾	9	0	9	2	2
10½	½	9	0	4	2	14		1	9	0	12	3	6
	⅝	9	0	5	3	7	15	½	9	0	6	1	21
	¾	9	0	7	0	0		⅝	9	0	8	0	14
	1	9	0	9	2	0		¾	9	0	9	3	7
11	½	9	0	4	3	14		1	9	0	13	0	26
	⅝	9	0	6	0	11		1¼	9	0	16	3	5
	¾	9	0	7	1	7	15½	½	9	0	6	2	14
	1	9	0	9	3	20		⅝	9	0	8	1	14
11½	½	9	0	5	0	7		¾	9	0	10	0	10
	⅝	9	0	6	1	12		1	9	0	13	2	17
	¾	9	0	7	2	8		1¼	9	0	17	1	6
	1	9	0	10	1	2	16	½	9	0	7	0	22
12	½	9	0	5	0	24		⅝	9	0	8	3	7
	⅝	9	0	6	2	8		¾	9	0	10	1	20
	¾	9	0	7	3	20		1	9	0	14	0	8
	1	9	0	10	3	0		1¼	9	0	17	3	14
12½	½	9	0	5	1	16		1½	9	0	21	3	4
	⅝	9	0	6	3	9		2	9	0	29	3	21
	¾	9	0	8	1	0							

Piston, a thin solid cylinder fitted to move in a hollow cylinder, so as to prevent the escape of air between the surfaces. Pistons, for steam engine cylinders, or pumps, have been made of wood and metal. The common piston is formed by joining the frustra of two cones at their smaller sections. The two cones have two bands of leather bound round them and fastened with nails. The joints of the leather are closed as accurately as possible, but not seamed, nor put opposite one another. When no wood is employed, a brass cylinder is made so as to fit the bore of the cylinder, and be capable of moving easily up and down. On the bottom and top of the brass cylinder pieces of leather are fixed, being confined within plates of metal, and cut in a bevelled manner round the edges, the angle of bevel being about 45°. The piston of the atmospheric engine is formed of a cast-iron plate, about one inch and a quarter thick, and in diameter one-eighth of an inch less than the diameter of the cylinder, and furnished with a rim about four inches from the edge; on the top of this rim a plate similar to the former is fitted, the two being fastened by bolts. The exterior of the rim is wound round with soft hemp, or gasket, saturated with oil, which packing is kept in its place by the pressure of the two plates. A quantity of water is kept on the upper side of the piston to make it more tight. Smeaton improved this kind of piston by adding a bottom of elm or beech planks, the interstices of which were packed with tarred flannel so as to render the piston air-tight.

The piston now commonly employed in steam engines is the hemp packed piston, a section of which is represented in figure 1. The bottom part is a circular plate of metal, of a diameter such that it shall easily move up and down in the cylinder; immediately above this plate is the portion round which the packing is coiled, being smaller in diameter by one or two inches than the diameter of the cylinder, in order to allow sufficient space to be occupied by the hemp or soft rope (*gasket*). On the top is a plate similar to the plate at the bottom, and called the piston cover. The packing is kept tight by means of the two plates being pressed together by means of screws. When the plates are screwed the packing is pressed outwards and made to fit the interior of the cylinder. As the packing wears, the screws are tightened, until, through course of time, the packing is so much worn as not to be tightened in this way, the top plate is then taken off and new packing substituted. With a view to save the trouble of taking off the cylinder cover when the packing has to be tightened, Mr Wolf fixed a small toothed wheel to the head of each screw. Each of these wheels act in the teeth of a central wheel which turns upon the piston rod as an axis. One of the small wheels has a square projecting piece on its axis, which rises through the cylinder cover when the piston is at the top, the opening through which it rises is furnished with a cap which may be taken off at pleasure. When the screws are to be tightened, the cap is taken off and a key applied to the projecting axis of the wheel, which being turned gives motion to the central wheel which gives motion to the other small wheels, and thus the screws are tightened. Little trouble is required to replace the cap air-tight upon the cylinder cover.

Metallic packed pistons are daily coming into more general use. The first was invented by the Rev. Mr Cartwright, patented in 1797. He packed his piston by using two rows of segments of rings, the outer row being formed to an arc of the same diameter as the cylinder. The inner row was formed so as to press out the outer row, they being themselves pressed outward by means of springs formed like the letter V. In order to prevent the steam from escaping by the joints of the segments, the joints of the outer row were placed against the middle of the inner segments. This piston did not answer so well as was wished. A better form of metallic packed piston was that invented by Barton, and exhibited in the cut, fig. 2, below, which is a plan with the top plate removed.

Fig. 1.

Fig. 2.

a a a a are the four metal segments; *b b b b* four right-angled wedges interposed between the segments, their points forming a portion of the periphery of the circle; *c c c c* is a thin steel spring, formed into a single broad hoop, and pressed into the undulated form represented, by which it is found to act with uniform energy upon the wedges, until they and the segments become so much worn in the course of time, that the steel spring recovers itself into its original circular figure; *d* is the framework, cast in one piece, with the lower plate of the piston; *e* is the piston rod; the dark spaces shown on the plan within the circular frame *d*, are cavities to lessen the weight of metal; the other dark spaces are cavities to allow of the free action of the circular spring. To prevent the segments from falling out of their places whilst the piston is being taken out, or put into the cylinder, the periphery of it is grooved near to its upper and lower edge, in which are sunk two slight spring hoops, cleft across into forked joints, which close together simply by their elasticity. To lubricate the piston, there is a third groove, made midway between the two former, for the reception of oil; these parts are not introduced into the figures. The action is as follows:—as the piston and cylinder wear away by the friction, the circular spring *c*, presses out the wedges *b*, and these project the segments against the cylinder; by degrees they are reduced in thickness.

It is certainly easily demonstrated that the wedges move faster than the segments, and that, consequently, the pressure upon the wedges is greater than that on the segments; in a right-angled wedge this difference is as 2 to 1, but the wearing is in no such proportion, nor is there in practice any perceptible difference at all; which arises, we conjecture, from the following cause. The cylinder being of cast-iron, and the piston of a much softer and easier abraded metal (an alloy of copper), the only effect of the superior pressure of the wedges, is to wear them away quicker than the segments, while the wearing of the cylinder, from its superior hardness, is scarcely perceptible. In consequence of this arrangement, the brass piston will always conform itself to the circular figure of the cylinder, until worn out.

Another kind of metallic packing is that invented by Jessop: it consists of an elastic spiral spring substituted instead of the hemp packing.

Mr Tredgold states that in double-acting engines the friction of a hempen packed piston is 0·1222 of the power, and a metallic packed piston, 0·069. The thickness should be to the diameter as the friction is to the pressure of the rubbing surface.

PISTON ROD; the rod connecting the piston with the end of the working beam in the steam engine. The piston rod is attached by a joint to the parallel motion, and to the piston by being passed up through a conical hole in the bottom, into which its end is exactly fitted and secured, by a screw nut or wedge, between the top and bottom. To find the diameter of a piston rod: take the product of the square root of twice the pressure of the steam per circular inch $\times$ the diameter of the piston, divide by 45 for malleable, and 42 for cast iron, and the quotient will be the diameter of the piston rod of a double acting engine.

Thus, if the pressure be 11 lbs. to the circular inch, and the diameter of the piston 36 inches, then,

$$\frac{36 \times \sqrt{(2 \times 11)}}{45} = \frac{36 \times 4{\cdot}69}{45} = 3{\cdot}75 \text{ inches}$$

= the diameter of the malleable iron piston rod: the cast iron one will be = 3·93 inches.

PLANE, or PLAIN, denotes a surface or superficial extension, lying evenly between its bounding lines; being such, that if a right line touch it in two points, it will touch through its whole extent. See *Inclined Plane*.

PLATONIC BODIES, the same as regular bodies.

PLUMBLINE, a line having a plummet or weight attached to it, in order to find a perpendicular.

PLUNGER, the solid brass cylinder used as a forcer in forcing pumps.

PNEUMATICS, is that branch of natural philosophy which treats of the weight, pressure, elasticity, &c. of elastic fluids, but more particularly of the air, the history and principles of which will be found under the articles, *Air*, *Atmosphere*, *Barometer*, &c.

POINT, in Geometry, according to Euclid's definition, is that which has no parts or dimensions, neither length, breadth, nor depth; and therefore marks position only.—A *Physical Point*, is the smallest or least sensible object of sight, and is thus distinguished from a geometrical point, which has only position, being of no magnitude or dimension.

POLYGON, in Geometry, a multilateral figure, or a figure whose perimeter consists of more than four sides, and consequently having more than four angles. If the angles be all equal among themselves, the polygon is said to be a regular one; otherwise it is irregular. Polygons also take particular names according to the number of their sides; thus a polygon of

3 sides is called a trigon,
4 sides is called a tetragon,
5 sides is called a pentagon,
6 sides is called a hexagon, &c.

and a circle may be considered as a polygon of an infinite number of small sides, or as the limit of the polygons. Polygons have various properties, as below:—Every polygon may be divided into as many triangles as it has sides. The angles of any polygon taken together, make twice as many right angles, wanting 4, as the figure hath sides; which property, as well as the former, belongs to both regular and irregular polygons. Every regular polygon may be either inscribed in a circle, or described about it; which is not necessarily the case if the polygons be irregular. An equilateral figure inscribed in a circle is always equiangular; though an equiangular figure inscribed in a circle is not always equilateral, but only when the number of sides is odd. For if the sides be of an even number, then they may either be all equal, or else half of them may be equal, and the other half equal to each other, but different from the former half, the equals being placed alternately. Every polygon, circumscribed about a circle, is equal to a right angled triangle, of which one leg is the radius of the circle, and the other the perimeter or sum of all the sides of the polygon. Or the polygon is equal to half the rectangle under its perimeter and the radius of its inscribed circle, or the perpendicular from its centre upon one side of the polygon. The area of a circle being less than that of its circumscribing polygon, and greater than that of its inscribed polygon, the circle is the limit of the inscribed and circumscribed polygons: in like manner, the circumference of the circle is the limit between the perimeters of the said polygons. See *Circle*.

The following table exhibits the angles and areas of all the polygons, up to the dodecagon, viz. the angle at the centre, the angle of the polygon, and the area of the polygon when each side is 1.

No. of sides.	Name of polygon.	Angle F at cent.	Ang. C of Polygon.	Area.
3	Trigon	120o	60	0·4330127
4	Tetragon	90	90	1·0000000
5	Pentagon	72	108	1·7204774
6	Hexagon	60	120	2·5980762
7	Heptagon	$51\frac{3}{7}$	$128\frac{4}{7}$	3·6339124
8	Octagon	45	135	4·8284271
9	Nonagon	40	140	6·1818242
10	Decagon	36	144	7·6942088
11	Undecagon	$32\frac{8}{11}$	$147\frac{3}{11}$	9·3656399
12	Dodecagon	30	150	11·1961524

To find the area of any regular polygon, not exceeding 12 sides, square the side, and multiply that square by the corresponding tabular number in the preceding table.

To inscribe a polygon within, or to circumscribe a polygon about a given circle:—Bisect two of the angles of the given polygon, and by the right lines; and from the point where they meet, with the radius equal to either of them, describe a circle which will circumscribe the polygon. Next to circumscribe a polygon, divide 360 by the number of sides required, which will give the angle at the centre; draw a radii, including this angle; they will cut off one side, and this applied round the circle will give the polygon. 2. On a given line to describe any given regular polygon. Find the angle of the polygon in the table, and at each extremity of the given line make an angle equal to half that angle, produce the lines till they meet at the centre, then describe the circle, and the construction becomes the same as before.

Otherwise. To inscribe a polygon in a circle.—Draw a diameter, and divide it into as many equal parts as the figure has sides. From the extremities of the diameter as centres, with the radius = the diameter, describe arcs crossing each other. From the point of section, through the second division of the diameter, draw a line. Join the points, and the distance between the point where it cuts the circle, and the nearest extremity of the diameter will give the side of the polygon.

Another method, something more accurate, is by erecting a perpendicular from the centre, of such a length that the part without the circle shall be equal to $\frac{3}{4}$ of that within, and drawing a line from its extremity through the second division as before.

Polygons of less than 100 sides, admitting of geometrical construction.

No. of sides.	No. of sides.
$3 = 3$	$10 = 2 \cdot 5$
$4 = 2^2$	$12 = 2^2 \cdot 15$
$5 = 2^2+1$	$15 = 3 \cdot 5$
$6 = 2 \cdot 3$	$16 = 2^4$
$8 = 2^3$	$17 = 2^4+1$

No. of sides.	No. of sides.
$20 = 2^2 \cdot 5$	$51 = 3 \cdot 17$
$24 = 2^3 \cdot 3$	$60 = 2^2 \cdot 15$
$30 = 2 \cdot 15$	$64 = 2^6$
$32 = 2^5$	$68 = 2^2 \cdot 17$
$34 = 2 \cdot 17$	$80 = 2^4 \cdot 5$
$40 = 2^2 \cdot 5$	$85 = 5 \cdot 17$
$48 = 2^4 \cdot 3$	$96 = 2^5 \cdot 3$

POLYHEDRON, a body or solid contained by many rectilinear planes or sides. When the sides of the polyhedron are regular polygons, all similar and equal, then the polyhedron becomes a regular body, and may be inscribed in a sphere. There are but five of these regular bodies, viz. the tetrahedron, the hexahedron or cube, the octahedron, the dodecahedron, and the icosahedron.—*Gnomical Polyhedron*, is a stone with several faces, on which are projected various kinds of dials.

PORES, are the small interstices between the solid particles of bodies.

POSTULATE, in Geometry, a demand or petition, or a supposition so easy and self-evidently true, as needs no explanation or illustration; differing from an axiom only in the manner in which it is put, viz. as a request instead of an assertion.

POUND, an English weight of different denominations, as Avoirdupois, Troy, Apothecaries, &c. The pound avoirdupois is sixteen ounces of the same weight, but the other pounds are each equal to twelve ounces. The pound avoirdupois is to the pound troy as 5760 to $6999\frac{1}{2}$, or nearly as 576 to 700.

POWER, in Mechanics, denotes some force which, being applied to a machine, tends to produce motion; whether it does actually produce it or not. In the former case, it is called a moving power; in the latter, a sustaining power. Power is also used in mechanics, for any of the six simple machines, viz. the lever, the balance, the screw, the wheel and axle, the wedge, and the pulley, which see.

PRESSURE, properly the action of a body which makes a continual effort or endeavour to move another body on which it rests; such as the action of a heavy body supported by a horizontal table, and is thus distinguished from percussion or momentary force of action. Since action and re-action are equal and contrary, it is obvious that pressure equally relates to both bodies, viz. the one which presses and that which receives the pressure. See *Percussion*.

PRESSURE OF FLUIDS, is of two kinds, viz. of elastic and non-elastic fluids.

Pressure of Non-elastic Fluids. The upper surface of a homogeneous heavy fluid in any vessel, or any system of communicating vessels, is horizontal.

This is usually explained by saying, that since the parts of a fluid are easily moveable in any direction, the higher particles will descend by reason of their superior gravity, and raise the lower parts till the whole comes to rest in a horizontal plane. Now, what is called the horizontal plane is, in fact, a portion of a spherical surface, whose centre is the centre of the earth: hence it will follow, that if a fluid gravitate towards any centre, it will dispose itself into a spherical figure, the centre of which is the centre of force.

If a fluid, considered without weight, is contained in any vessel whatever, and an orifice being made in the vessel, any pressure whatever be applied thereto, that pressure will be distributed equally in all directions. Hence:—Not only is the pressure transmitted equally in all directions, but it acts perpendicularly upon every point of the surface of the vessel which contains the fluid. For, if the pressure which acts upon the surface were not exerted perpendicularly, it is easy to see that it could not be entirely annihilated by the re-action of that surface; the surplus of force would, therefore, occasion fresh action upon the particles of the fluid, which must of consequence be transmitted in all directions, and thus necessarily occasion a motion in the fluid; that is, the fluid could not be at rest in the vessel, which is contrary to experience. If the parts of a fluid contained in any vessel, open towards any part, are solicited by any forces whatever, and remain notwithstanding in equilibrio, these forces must be perpendicular to the open surface. For the equilibrium would obtain, in like manner, if a cover or a piston of the same figure as the open surface were applied to it; and it is manifest that, in this latter case, the forces which act at the surface, or their resultant, must be perpendicular to that surface. If, therefore, the forces which act upon the particles of the fluid are those of gravity, we shall see that the direction of gravity is necessarily perpendicular to the surface of a tranquil fluid; consequently, the surface of a heavy fluid must be horizontal to be in equilibrio, whatever may be the figure of the vessel in which it is contained. If a vessel, closed throughout except a small orifice, is full of a fluid without weight; then, if any pressure be applied at that orifice, the resulting pressure on the plane surface, or bottom, will neither depend upon the quantity of fluid in the vessel, nor on its shape; but, since the pressure applied at the orifice, is transmitted equally in all directions, the actual pressure upon the bottom will be to the pressure at the orifice, as the area of the bottom is to that of the orifice. In the same manner will the pressure applied at the orifice, be exerted in raising the top of the vessel; so that if the top be a plane, of which the orifice forms a part, the vertical pressure tending to force the top upwards will be to the force applied at the surface, as the surface of the top to the area of the orifice. The hydraulic press is founded upon this principle. The pressure of a fluid on the horizontal base of a vessel in which it is contained, is as the base and perpendicular altitude, whatever be the figure of the vessel that contains it; the upper surface of the fluid being supposed horizontal.

PRISM, in Geometry, is a body, or solid, whose two ends are any plane figures which are parallel, equal, and similar; and its sides connecting those ends are parallelograms. Prisms receive particular names, according to the figure of their bases; as a triangular prism, a square prism, a pentagonal prism, a hexagonal prism, and so on. The axis of a prism, is the line conceived to be drawn lengthwise through the middle of it, connecting the centre of one end with that of the other end. Prisms, again, are either right or oblique. A right prism is that whose sides and its axis are perpendicular to its ends, like an upright tower. An oblique prism, is when the axis and sides are oblique to the ends; so that, when set upon one end, it inclines on one hand more than on the other.

The chief properties of prisms are, That all prisms are to one another in the ratio compounded of their bases and heights. Similar prisms are to one another in the triplicate ratio of their like sides. A prism is triple of a pyramid of equal base and height; and the solid content of a prism is found by multiplying the base by the perpendicular height. The upright surface of a right prism is equal to a rectangle of the same height, and its breadth equal to the perimeter of the base, or end. And, therefore, such upright surface of a right prism, is found by multiplying the perimeter of the base by the perpendicular height. Also the upright surface of an oblique prism is found by computing those of all its parallelogram sides separately, and adding them together.

If to the upright surface be added the areas of the two ends, the sum will be the whole surface of the prism.

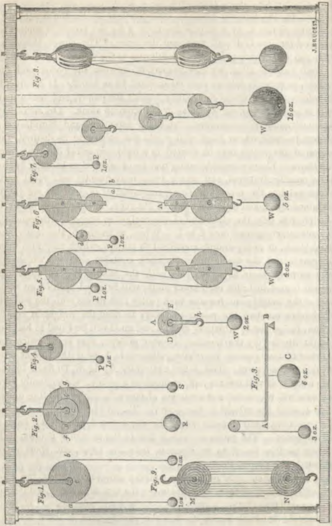
PRISMOID, a figure resembling a prism.

PROBLEM, a proposition wherein some operation or construction is required; as to divide a line or angle, erect or let fall perpendiculars.

PROJECTILES, is that branch of mechanics, which relates to the motion, velocity, range, &c. of a heavy body projected into void space by any external force, and then left to the free action of gravity, by which it descends to the earth.

PULLEY, one of the six mechanical powers. The pulley is a small wheel turning on an axis, with a rope passing over it. The circumference of the pulley is generally grooved to receive the rope, which is attached on the one end to the moving power, and on the other to the resisting force. The pulley is sometimes called a sheave, and is so fixed in a frame or block, as to be moveable on a pin passing through its centre. When pulleys are made of wood, a ring of iron or brass is generally let into the middle of them, to work upon the pin, as they would otherwise wear unequally, and their motion would then be impeded by an increased degree of friction. A fixed pulley is one which has no motion except upon its axis : a moveable pulley is one which rises and falls with the weight.

The *gorge* or *groove* of a pulley, is the hollow part of the circumference which receives the rope or cord; it is frequently hollowed out angularly, so that the rope is, by the pressure, so wedged in the angle, that it cannot glide or slip in its motion. A pair of blocks, with the rope fastened round it, is commonly called a *tackle*. Two equal weights attached to the ends of a rope going over a fixed pulley, as fig. 1, in the accompanying engraving, will balance each other, for they stretch the rope equally, and if either of them be pulled down through any given space, the other will rise through an equal space in the same time, and consequently as their velocities are equal, they must balance each other. This kind of pulley, therefore, gives no mechanical advantage, but the use of it is a source of great convenience. It serves to change the direction of draught; it gives a man an opportunity of applying his weight instead of his muscular strength, but not of lifting more than his weight; it also enables a man to raise a weight to any point, without moving from the place he is in, whereas he would otherwise have been obliged to ascend with the weight; and, lastly, by it several men may apply their strength to the weight by means of the rope, with as much facility, under the same circumstances, as one person only. If the lever of the second order, A B, fig. 3, have its fulcrum at B, the weight in the middle at C, and the power at A, half the weight being supported by the fulcrum, a power equal to the other half will keep it in equilibrium. This will apply to the illustration of the action of pulleys, which, when the weight is appended to the circumference, may be considered as levers of the first kind, and when the weight is appended to the centre, they may be considered as levers of the second kind: hence the ropes *a b*, fig. 1, hanging at equal distances from the centre, *c*, (which must be regarded as the fulcrum,) equal weights must be in equilibrium, exactly as they would be if placed in the scales of a common balance. But if one weight be further from the centre or fulcrum than the other, they will balance each other only as they would in a steel-yard, and, therefore, though still a lever of the first kind, a less weight will suspend a greater. Thus, if the pulley, as in fig. 2, have different gorges, and the weight R of six ounces, be hung at the distance of one inch from the fulcrum, *c*, and the weight S of three ounces be hung at the distance of two inches from the same centre; the two weights R and S, though in the proportion of 2 to 1, will balance each other. If the weight S were only two ounces, it would produce the same effect upon R, pro-



vided its distance from the fulcrum were proportioned to the diminution of its weight; that is, if it were three times as far from the centre *c*, as R. We have now to show that the moveable pulley acts like a lever of the second order. Let the moveable pulley A, fig. 4, be fixed to the weight W, with which it rises and falls. In comparing it with the lever alluded to, the fulcrum must be considered as at F; the weight acts upon the centre *c*, by means of the neck *c h*; the power is applied at D; and the line D F will represent the lever. The power, therefore, as in fig. 3, is twice as far from the fulcrum as the weight, and the effect in both cases is alike, viz. the proportion between the power and the weight, in order to balance each other, must be as 1 to 2. It is evident, therefore, that the use of this pulley doubles the power, and that a man may raise twice as much by it, as by his strength alone. Or, as variety in illustration will sometimes catch the attention, and familiarize a subject to some whose ideas of it would not otherwise be distinct, the action of this pulley may be viewed in a light somewhat different from the above. Every moveable pulley may be considered as hanging by two ropes equally stretched, and which must consequently bear equal parts of the weight; the rope F G being made fast at G, half the weight is sustained by it, and the other part of the rope, to which the power is applied, has only the other half of the weight to support; consequently the advantage gained is as 2 to 1. When, as in fig. 5, the upper and fixed block, or pulley-frame, contains two pulleys, which only turn upon their axis, and the lower moveable block contains also two, which not only turn on their axis, but rise with the weight W, the advantage gained is as 4 to 1; for each lower pulley will be acted upon by an equal part of the weight; and because each pulley that moves with the weight, diminishes one-half the power necessary to keep the weight in equilibrium, the power by which W may be sustained will be equal to half the weight divided by the number of lower pulleys; that is, as twice the number of the lower or moveable pulleys is to 1, so is the weight suspended to the power. But if the extremity A, fig. 6, be fixed to the lower block, it will sustain half as much as a pulley; consequently here the rule will be, as twice the number of moveable pulleys, adding unity, is to 1, so is the weight to the power. To prevent the ropes *a* and *b* from rubbing against each other, the upper fixed pulley may have a double gorge. The pulley *d* belongs not to the system of pulleys, it is merely used in the plate, to separate from the ropes, and show more distinctly the power, P.

If instead of one rope going round all the moveable pulleys, the rope belonging to each of them be made fast at the top, as in fig. 7, a different proportion between the power and the weight will take place. Here it is evident, that each pulley doubles the power; thus, if there are two pulleys, the power will sustain four times its own force or weight; if three pulleys, eight times its own weight; if four pulleys, sixteen times its own weight, as in the figure, where the weight W, of sixteen ounces, is supported by the power P, of only one ounce. This arrangement of pulleys takes up much room, raises the weight very slowly, and is not convenient to fit up. It is therefore seldom used, notwithstanding the great power gained.

These rules are applicable, whatever may be the number of pulleys employed.

The large space occupied by pulleys, when arranged under each other, as in figs. 5 and 6, is an inconvenience that would often render them useless, and such an arrangement would increase the liability to entanglement, particularly on shipboard; it is therefore common to place all the pulleys in each block on the same pin, by the side of each other, as in fig. 8. The advantage, and the rule for the power, are the same here as in fig. 5. In this kind of tackle, the ropes are not exactly parallel, a direction which should be preserved as much as possible; but the defect is not very considerable.

The reason of the parallel direction of the ropes being better than an oblique one, is that less power is required to sustain the same weight; and in proportion to the obliquity of the ropes must be the increase of the power. When there are many pulleys in the same block, and the end of the rope to which the power is applied terminates over one of the outside pulleys, that pulley always endeavours to get into a line with the centre of suspension or middle of the moveable pulleys, from which the weight hangs. In consequence of this, the friction of the pulleys against the sides of the block is so great as sometimes to equal the power. Hence the multiplication of pulleys thus used, soon ceases to be advantageous; they are seldom effective, if their number exceeds three or four. Smeaton, the eminent engineer, was the first who disencumbered himself of the difficulty here stated, by making the rope terminate over the middle pulley or sheave in the fixed block, which is thereby kept perpendicularly under the other, and the friction of the sheaves is on their centres of motion only. The number of sheaves must always be uneven, or this improvement cannot be adopted. To avoid as much as possible the friction and shaking motion of a combination of pulleys, James White, a very able mechanic, invented and obtained a patent for the concentric pulley, fig. 9. M and N are two of these pulleys, one of them being fixed, the other moveable. They are usually made of brass, and answer the purposes of as many distinct pulleys as there are grooves. In this case, as in fig. 5, the weight being divided among the number of ropes, a power of 1 will support a weight of 12. In speaking simply of a system of pulleys, the common arrangement of them is meant, viz. that where the number of ropes is just twice the number of the moveable pulleys. Figs. 4, 5, and 8, are all systems of this kind. The ropes are spoken of as if they were in different lengths, but it can hardly require an observation, that the expression is used merely because it is convenient, and that there is in fact but one rope, the parts of which are alluded to as if they were separate.

It has been shown, in illustrating fig. 2, that by means of a pulley of several grooves, the actions of two unequal powers may be made to balance each other. In like manner, a constant equilibrium or relation may be preserved between two powers, the relative forces of which continually change. Watchmakers derive great advantage from the application of this principle to their work. The spring of a watch always acts with the greatest power immediately after it has been wound up, and its power is continually but gradually diminishing, till the watch stops. If this inequality of the maintaining power operated upon the wheels, the watch would not go two successive hours at the same rate; but the effects of it are completely avoided by the peculiar conformation of the pulley off which the spring draws the chain. Instead of many concentric gorges upon the fusee, they make only one, but that one is in a spiral form upon a truncated cone.—*Smith's Panorama.*

Pump, in a general sense, is a machine consisting of a peculiar arrangement of a piston, cylinder, and valves, employed for extracting air or raising water. See *Air Pump*, and *Water Works*. In the steam engine several pumps are employed; as the air pump for exhausting the condenser; the cold water pump for supplying the cistern; and the hot water pump for supplying the boiler. See *Boiler*, *Condenser*, and *Steam Engine*.

Pumping of Water. When a steam engine is employed in raising water the pumps are either sucking or forcing. The action of pumping, it would appear, expells a portion of air from the water, and on this account, as well as on account of the defect of pressure on the water that follows the piston and the escape by the piston or bucket, the stroke should not exceed eight feet, and the velocity of the piston in feet per minute ought to be $= \sqrt{\text{the length of the stroke}} \times 98$. The quantity of water that a pump in good order will deliver in cubic feet per minute may be found by taking the product of half the velocity of the piston $\times$ the diameter ^{2} of the pump $\times$ the constant number 0·00518. To find the amount of power necessary to raise a given quantity of water, find the height of the point of discharge above the surface of the well in feet, and add 1·5 for each lift, and 1-20th of the height, and call this H, call p the pressure on the steam piston per circular inch, D the diameter of the steam piston, d that of the pump barrel, and W the quantity of water discharged per minute, the velocity of the piston being 180 feet per minute, we have,

$$\sqrt{\left(\frac{H \times W \times 0{\cdot}7332}{p}\right)} = D.$$

$$\text{and } \sqrt{(2{\cdot}15 \times W)} = d.$$

Let it be required to lift 60 cubic feet of water per minute from a depth of 100 fathoms, there being 5 lifts, and the mean pressure on the steam piston being 11 lbs. per circular inch. 100 fathoms = 600 feet, add 5 × 1·5 and $\frac{600}{20}$, we have 600 + 7·5 + 30 = 637·5 = H, and W = 60, p = 11, wherefore,

$$\sqrt{\left(\frac{637{\cdot}5 \times 60 \times 0{\cdot}7332}{11}\right)} = \sqrt{\frac{28044{\cdot}9}{11}} = \sqrt{2549{\cdot}5} = 50{\cdot}48$$

or $50\frac{1}{2}$ inches nearly = the diameter of the steam cylinder in inches. By the second formula we have $\sqrt{(3{\cdot}15 \times 60)} = \sqrt{189} = 13{\cdot}747$, or nearly 14 inches for the diameter of the pump barrel.

Pyramid, is a solid having any plane figure for its base, and triangles for its sides, all terminating in one common point or vertex. If the base of the pyramid be a regular figure, the solid is called a regular pyramid, which then takes particular names according to the number of its sides, as triangular, square, pentagonal, &c. the same as the prism. If the perpendicular demitted from its vertex falls on the centre of the base, the solid is called a *right* pyramid; but if not, it is *oblique*.

The principal properties of the pyramid may be stated as follows:— Every pyramid is one-third of a prism of equal base and altitude. Pyramids of equal bases and altitudes are equal to each other, whether the figure of their bases be similar or dissimilar. Any section of a pyramid parallel to its base will be similar to the base, and these areas will be to each other as the squares of their distances from the vertex. Pyramids, when their bases are equal, are to each other as their altitudes, and when their altitudes are equal they are to each other as their bases; and when neither are equal, they are to each other in the compound ratio of their bases and altitudes.

To find the solidity of a pyramid. Multiply the area of the base by its perpendicular altitude, and one-third of the product will be the solidity.

To find the surface of a pyramid. Multiply the perimeter of the base by the slant altitude of one of its faces, and half the product will be the surface. Or, find the area of one of its triangular faces, and multiply by the number of them, which is the same thing.

Q

Quadrangle, a figure having four angles and four sides; it is otherwise called a quadrilateral.

Quadrant, the fourth part of a circle, being bounded by two radii perpendicular to each other, and a quarter of the circumference, or 90°.

Quadrature, in Geometry, is the finding a square equal in area to another figure, or in other words, finding the areas of plane surfaces.

Quadrilateral, a figure of four sides and angles. All quadrilaterals have the following properties. The sum of their four angles is equal to two right angles; and if the sum of each pair of opposite angles be equal to two right angles, the figure may be inscribed in a circle, otherwise it cannot; and in all such quadrilaterals the sum of the rectangles of the opposite sides is equal to the rectangle of the two diagonals.

Quantity, any thing capable of estimation or mensuration; or which, being compared with another thing of the same kind, may be said to be greater or less than it, equal or unequal to it.

R

Radiant Point, any point from which rays proceed.

Radii, the plural of radius.

Radius, in Geometry, the semi-diameter of a circle, or a right line drawn from the centre to the circumference.

Railway; lines of wood or iron for the purpose of diminishing the resistance to the wheels of carriages moving upon them, are called railways. The first railways, formed on the plan of making a distinct surface and track for the wheels, seem to have been constructed near Newcastle on Tyne. In Roger North's life of lord keeper North, he says, that at this place (in 1676) the coals were conveyed from the mines to the banks of the river, "by laying rails of timber exactly straight and parallel; and bulky carts were made with four rollers fitting those rails, whereby the carriage was made so easy that one horse would draw four or five chaldrons of coal." One hundred years afterwards, viz. about 1776, Mr Curr constructed an iron railroad at the Sheffield colliery. The rails were supported by wooden sleepers, to which they were nailed. In 1797, Mr Barns adopted stone supports in a railroad leading from the Lawson main colliery to the Tyne, near to Newcastle; and, in 1800, Mr Outram made use of them in a railroad at Little Eaton, in Derbyshire. Twenty-five years afterwards, this species of road was successfully adopted on a public thoroughfare for the transportation of merchandise and passengers, viz. the Stockton and Darlington railroad, which was completed in 1825, and was the first on which this experiment was made with success. From that time, accordingly, a new era commenced in the history of inland transportation.

The first inquiry presenting itself in respect to a railroad between two points, relates to the choice of a route, where the nature of the territory permits of any such choice. In making this election, the comparative distances, the amount of intermediate transportation to be accommodated, the character of the soil as to affording a good foundation, the excavations and embankments necessary to be made in order to bring the road within a certain scale of inclination, and the difficulty or facility of obtaining suitable materials for the construction of the road, are all to be taken into consideration. These investigations and comparisons cannot be too rigidly and minutely made; and it has been suggested by experienced engineers, that, in some of the roads of this description constructed in the United States of America, great mistakes will be found to have been made in this respect, in consequence of too great precipitancy in fixing on a route.

The scale of inclination to which the road is to be reduced, is necessarily taken into consideration in fixing upon a general route; but still a choice often presents itself in parts of such route, between the expense in reducing the rate of inclination by excavations and embankments, and the saving of expense by taking a more circuitous route. Another question also presents itself, namely, whether to reduce an acclivity, or to surmount it; and the manner of overcoming it is a subject of inquiry at the same time; for, the surface of the ground having been examined and the route determined, on a general scale of inclination, within which the ordinary power used for transportation is to be applied, the whole line is either to be brought within this scale, or, if an inclination exceeding it is admitted, it is to be overcome by the use of an extra power. In such case, if the extraordinary expense of reducing the inclination is not so great that the interest upon this part of the original outlay would exceed the additional expense of the use of an extra power to overcome an inclined plane, it will be a decisive reason in favour of reducing the inclination. The amount of transportation to be accommodated will determine, in a great degree, the expense of the extra power requisite to overcome a given inclined plane. Another circumstance to be considered is, whether the extra power to be used is that of horses, or steam, or water; for the two former are comparatively more expensive for a small than for a large amount of transportation, owing to the cost of maintaining them; but the difference is not so great where a water power can be used. In some cases, it may be better to make deflections in the road, than to reduce inclinations, or to use extra power. This will depend on the kind of transportation and the importance of celerity; for if the object is mainly the transportation of increased weight by the same power, without regard to the time, any deviation from a direct course is less objectionable. But upon lines of public travel, despatch is of great importance.

In the recently constructed railroads in England, the iron rails are in general supported by iron chairs or props, at a distance of about three feet from each other; in most of those hitherto constructed in the United States of America, the rail is supported by a continued line of wood or stone. Where the rails rest on a line of wood, the track must be comparatively imperfect, since the wood will yield to the weight of the load transported, and be slightly compressed as the wheels pass, thus offering a continual resistance. Where successive parts of the track are formed by laying iron rails upon pine, oak, and stone, the difference of power necessary to move the same load on the different parts, will be evident in the different degrees of exertion made by the horse, where this power is used. Accordingly, if a soft species of wood is used to support the iron rail, it is a great advantage to interpose a line of oak or other hard wood. A rail continuously supported by a line of stone will not yield to the weight of the load; and where the rail is supported at successive points by chairs, it is always intended to be of such strength, that it will not be sensibly bent by the weight. The plan of supporting by chairs has been very thoroughly tried in England, and so much improved, that a very perfect track may be now (1832) formed in this way. Continued lines of granite or other durable stone, are now in use on a number of railroads in the United States of America, but cannot, as yet, be considered to be so thoroughly tested, though the results of the experiments are thus far very favourable. It was apprehended, at first, that the action of the wheel would draw or flatten the iron plate; but it has been found by experience, that this effect is not produced. The principal difficulty in the use of this kind of track, was in the fastening of the rail to the stone, the nails used for this purpose being liable to be loosened or cut off by the expansion and contraction of the iron rail. This defect has, however, been partially remedied by making oval holes in the rails for the fastenings, thus allowing a little longitudinal motion of the rail without injury to the fastenings. A question was heretofore made, whether cast iron or malleable was the best material for the rail. Cast iron rails do not so easily bend, and the same weight of iron is also much cheaper. But they are more subject to be broken by sudden jars and blows, and a much greater weight must be used in order to obtain the requisite strength. It was at one time supposed, that the action of the wheels on rails of malleable iron would cause them to exfoliate in thin laminæ, and that thus they might be subject to greater waste than those of cast iron. But this has proved to be a mistake. It has also been further proved, that if a bar of iron be cut into two equal pieces, and one of them be laid on a railroad, and used for a track, and the other laid by the side of the road, and exposed to the action of the atmosphere, and not used at all, the latter will waste and lose weight much more rapidly than the former. The loss of malleable iron rails by use, is less than that of cast iron ones. Mr Wood states the following comparison of the two: Malleable iron rails, 15 feet long, were used on the Stockton and Darlington railway; over which locomotive engines passed, weighing from 8 to 11 tons, and wagons with their loads weighing four tons: 86,000 tons passed over the rails in one year, exclusive of the weight of the engines and wagons. A rail 15 feet in length, weighing $136\frac{1}{2}$ pounds, lost in the year eight ounces, or 1-272 part of its weight; and the loss was the same in a similar rail over which only empty wagons passed. A cast iron rail four feet long, weighing 63 pounds, over which wagons passed, weighing four tons each when loaded, and on which the same number of tons, besides the wagons, was transported in a year, lost eight ounces, being 1-126th part of the whole weight of the rail, or more than twice as great a proportion as the former. The inclination of opinion is, accordingly, from these circumstances, very strong in favour of the use of malleable iron rails. Plate rails were first used, which presented a flat surface to the wheel; but what are denominated *edge rails* have since come into use, and, according to Mr Wood, are preferable, on account of their presenting less resistance to the wheel, and being less subject to injury and destruction by use. The upper surface of the edge rail has a slight transverse curve, so as to be highest in the central line of the track, and to fall off by degrees towards each side of the rail, thus presenting no angle. Where the iron rail is supported by chairs at distances of three, or three and a half feet from each other, the rail will evidently require to be of greater strength in the centre between the supports, if it be proposed to form the rail so that it shall be able to bear the same weight in every part; and it would evidently be a waste of material to form it upon any other plan. The rail ought, also, to be stronger at the same point, in order to resist any lateral pressure, as the cars, in moving over the road, will necessarily be sometimes propelled against one or the other side of the road; which makes it necessary to strengthen the central part of the rail laterally, to prevent its being broken or bent by such lateral pressure. The rails are accordingly formed upon this principle, the size and weight of iron increasing from each support towards the centre. In the tram railways, plate rails are used, with a perpendicular plate, or rim, at the outside edge of the rail, of two or three inches in height, to confine the wheels upon the railroad. But this mode of keeping the carriage upon the road is not necessary; for, whether the rail be of the plate or of the edge form, the wheels of the carriages may be confined to the road equally well by a flange, or projection at the periphery of the wheel, on the side next the centre of the road. In the mode of joining the rails, very important improvements have been made since the introduction of railroads into more general use. The rails were, at first, only about three or three and a half feet in length, and fastened in the chairs by a pin running horizontally through each end of the rail, there being two holes in each chair for the admission of two pins for this purpose, one for the end of each rail, so that the fastenings were distinct. The consequence was, that if the chair did not stand upon a perfectly firm foundation, but upon one that yielded on one side, so that the chair leaned in the line of the road, one of the pins, and consequently the end of the rail fastened by it, would be depressed below the other, thus making a sudden break in the surface of the track, which would cause a jolt as the wheel passed over it, to the injury of both the road and the carriages, and the inconvenience of passengers. Mr Wood says this defect was very frequent on railroads constructed upon this plan. It has been remedied by making the rails join by lapping with what is called the *half-lap*, and fastening the ends of both rails by one pin; so that, although a chair should lean in the line of the road, or be a little depressed below the others, still the two rails would present a smooth surface at their junction. The injury and inconvenience occasioned by the imperfections of the junctions of the rails were still further remedied by making the rails twelve or fifteen feet in length, supported at short distances as before, the form and dimensions of each part of the rail between any two supports being constructed as already described; by which means the number of junctions was reduced to one-fourth or fifth of their former number. This was a very great step in the improvement of this species of road. An improvement, of great utility, has also been made in the mode of fastening the rails, by dispensing with the use of pins, which were liable to work loose. There are various forms of constructing the rails and chairs for this purpose, but they all agree in principle. One mode is by making a depression in the chair on one side of the rail, into which a projection from its lower side precisely fits. If the rail is held close upon that side, it is thereby fixed to the chair, and can be moved only with the chair itself; and it is so held by driving a key or wedge along the opposite side of the rail, between the rail and the side of the chair projecting upon the side of the rail.

In describing the rails, the supports or chairs have been partly described. They are of iron, with a broad, flat base, supported upon blocks of stone, into which holes are drilled, and filled with wooden plugs. The chairs are fastened to the stone blocks by nails driven into these plugs. This stone block should rest firmly upon its base, and not be liable to change of position by frost or any other cause; and, accordingly, great care has been taken to make these supports firm.

If all the wagons upon a railroad, whether for the transportation of passengers or merchandise, were to travel at the same time, and at the same speed, two sets of tracks would be sufficient to accommodate the whole, as there would be no necessity of their turning out to pass each other. But in the transportation of passengers, greater speed is desirable than in the transportation of merchandise; for the transportation of merchandise, whether by horse power or steam power, can be done more economically, and with less injury to the road, at a low than a very high rate of speed. It is, therefore, a very considerable object, in railroads upon lines of public travel, to allow wagons to pass others travelling in the same direction. Provision must be made, accordingly, for turning out. This provision is particularly necessary in case of a road with a single set of tracks, on which the carriages must meet. These turn-outs are made by means of a movable or switch rail at the angle where the turn-out track branches from the main one. This rail is two or three feet, more or less, in length, and one end may be moved over that angle, and laid so as to form a part of the main track, or the turn-out track. The switch rail is usually moved by the hand, so as to form a part of that track on which the wagon is to move.

The bodies of the wagons will, obviously, require to be constructed with reference to the kind of transportation. The principal consideration, in regard to the construction of the carriages, relates to their bearings on the axle and the rim of the wheel. The rule given by Mr Wood, as to the bearing on the axle, is, that in order to produce the least friction, the breadth of the bearing should be equal to the diameter of the axle at the place of bearing. This diameter must be determined by the weight to be carried; and the breadth of the bearing will accordingly vary with it. The objection to the plate rail, as already stated, is, that the breadth of the bearing of the rim of the wheel upon such a rail, causes an unnecessary additional friction; and the resistance to the wheel is increased in consequence of the greater liability of such a rail to collect dust and other impediments upon its surface. The edge rail is preferable, in these respects; but, at first, these rails were liable to one difficulty, in consequence of their wearing grooves in the rim of the wheel, so that the friction was continually increasing, and the wheel soon became unfit for use. To remedy this defect, the rims were case-hardened, or chilled, by rolling them, when hot, against a cold iron cylinder. Wheels so case-hardened are found to be subject to very little wear. It was, at first, objected to the use of iron wheels, that they would not take sufficiently strong hold of the rails to draw any considerable load after them, and that therefore they would not answer for the use of locomotive engines. Where horses are the motive power, it is evident that if the horse draws the car to which he is attached, the others fastened to it must follow, it being no objection that either the wheels of the carriage to which the horse is harnessed, or of those of the train following, do not take hold of the rails, but, on the contrary, the less hold they take, the more easy it will be to move the train. But where one carriage is impelled forward by the action of the engine in turning the wheels, and the following train of wagons is drawn by the engine car, if the resistance by gravity and friction is greater than the force with which the wheels adhere to the rails, the engine will only revolve the wheels to which it is geared, which would turn upon the rails, and the car and whole train remain stationary. To prevent this, different contrivances were heretofore resorted to, one of which was to let teeth project from the sides of the wheels to interlock with rack-work on the side of the rail. It has, however, been found, in practice, that, for the ordinary inclinations of rail-roads, to the extent of about thirty feet per mile, the wheels may be so constructed as to move a train of wagons by their mere adhesion to the rails. The inclination which can be so overcome must evidently depend on the kind of surfaces of the rim of the wheel and the rail, the weight bearing upon the wheels, the weight to be moved, and the resistance from the friction of the train of wagons; so that no precise rule can be given that shall be applicable to roads and wheels of different materials and construction. One of the first expedients for increasing the adhesion of the wheels to the rails, without incurring any considerable loss by additional weight or friction, was to gear the four wheels of the engine car together, so as to have the advantage of the friction of all of them upon the rails; for, if the piston of the engine is connected by gearing only with the wheels of one axle, a resistance in the other wheels of the engine, and by the whole train, only equal to the friction of these two wheels, can be overcome. By gearing the piston of the engine with the four wheels, by means of an endless chain passing round the two axles upon two cog-wheels, or by otherwise gearing the four wheels together or to the piston, the hold of the wheels on the rails is doubled. For the same purpose, an additional set of wheels, making six in the whole, for the engine car, is sometimes added; but such an addition to the number of sets of wheels is evidently attended with disadvantages on the score of expense, complication of structure, weight to be moved, and friction of parts to be overcome. The advantage proposed by adding another set of wheels is, that a greater weight may be carried by the engine car, thus making a greater adhesion to the rails by the wheels geared together, without throwing so great a weight upon any of the wheels as to injure the road. But resort is rarely had to this expedient. An improvement, having the same object, and attended by no loss from addition of weight or friction, is a contrivance for securing the adhesion of all the wheels to the rails; for it will be obvious that, if the two axles of the two sets of wheels are fastened to a strong unyielding car frame, the car will rest upon three wheels, whenever the surface of the road does not precisely correspond in relative altitude to the lower points in the rims of the wheels; that is, if the surfaces of the rails are precisely in the same plane, and the bearing surfaces of the rims of the wheels are also precisely in the same plane, all the wheels will rest upon and take hold of the rails, whether the axles are fastened to an unyielding frame or not. But no road or carriage can be so perfectly constructed, that the surfaces of the rails and bearings of the wheels can always exactly correspond. Mr Knight, the chief engineer of the Baltimore and Ohio railroad, says, in his report of October, 1831, that the whole weight of a wagon, with an unyielding frame, will frequently be supported on two only of the four wheels, thus making a load bear twice as much upon one part of the rail, as it would do if its weight were equally supported by the four wheels. To remedy this difficulty, the whole weight carried upon the axle is supported by springs, or some interposed elastic power, that of the condensed steam being taken advantage of for the purpose in some cars, whereby each wheel is pressed upon the rail, though the relative surfaces on which the wheels may bear, on different places in the road, may vary. Mr Knight, in the same report, makes a suggestion worthy of consideration in the construction of wagons, as well as engine cars. He proposes that in all cases the weight should be supported on springs, not only for the purpose of distributing the weight equally, but also to prevent shocks and jars, whereby both the road and carriages are injured. Another expedient to secure a sufficient adhesion of the wheels to the surfaces of the rails, is to use wheels for the engine car that are not case-hardened.

The experiments stated by Mr Tredgold and Mr Wood show a very great advantage in the use of large wheels. Mr Wood states that the motive power required to overcome the same friction of rubbing parts of the car and engine, in case of wheels four feet in diameter, is less by one fourth than in case of those three feet in diameter. But there is some limit to the extent of this advantage; for an increase of the diameter of the wheel adds to the weight, and the expense of construction, so that wheels of not more than four or five feet in diameter are ordinarily used, and a great part of those in use are not above two and a half feet. Some of the locomotives used on the Liverpool and Manchester railroad have sets of wheels of different sizes, the diameter of one being nearly double that of the other. The state of the rail will have some effect upon the adhesion of the wheels, which is least when the rails are slightly wet. The experiments of Mr Booth, on the Liverpool and Manchester railroad, prove that in the most unfavourable state of the rails, the adhesion of wheels of malleable iron upon rails of the same material, is equal to one-twentieth of the weight upon them. The locomotives vary in weight, from three or four to ten or eleven tons. A locomotive, with its apparatus and appendages weighing four and a half tons, will adhere to the rails with sufficient force to draw thirty tons weight on a level road, at the rate of fifteen miles per hour, and seven tons up an ascent of one in ninety-six, or fifty-five feet in a mile; at a slower rate, it will draw a greater weight. The slower the rate of travelling is, the greater is the weight that may be supported by the same wheel, without injury to the road from shocks, though the weight must of course be limited by the size and strength of the rails, whether the rate of motion be quick or slow.

The curvatures of the railroad present some obstructions, since, the axles of the car and wagons being usually fixed firmly to the frames, every bend of the tracks must evidently cause some lateral rubbing, or pressure of the wheels upon the rails, which will occasion an increased friction. If the wheels are fixed to the axles, so that both must revolve together, according to the mode of construction hitherto most usually adopted, in passing a curve, the wheel that moves on the outside or longest rail must be slided over whatever distance it exceeds the length of the other rail, in case both wheels roll on rims of the same diameter. This is an obstruction presented by almost every railroad, since it is rarely practicable to make such a road straight. The curvatures of some roads are of a radius of only 300, and even of 250 feet. The consequence was that the carriages heretofore in use were obstructed, not only by the rubbing of the surfaces of the wheels upon the rails, already mentioned, but also by the friction of the flange of the wheel against the side of the rail. This difficulty has, however, been in a great measure remedied by an improvement made in the form of the rim of the wheel. The part on which this rim ordinarily rolls on the rail, is made cylindrical, this being the form of bearing evidently the least injurious to the road, as the weight resting perpendicularly upon the rails has no tendency to displace them or their supports. But between this ordinary bearing and the flange, a distance of about one inch in a wheel of thirty inches diameter, is the rim made conical, rising towards the flange one-sixth of an inch, and thus gradually increasing in diameter. Wherever the road bends, the wheel, rolling on the exterior, and, in such case, longer track, will, in consequence of the tendency of the carriage to move in a right line, be carried up a little on the rail, so as to bear upon the conical part of the rim, which gives a bearing circumference of the wheel on that side, greater than that of the wheel at the opposite end of the same axle. The tendency, accordingly, is to keep the car in the centre of the tracks, by producing a curvilinear motion in the wagon, exactly corresponding to the curve of the road. A car, with wheels such as those already described, was run upon a part of the Baltimore and Ohio railroad, where the greatest curvatures were of a radius of 400 feet, at the rate of fifteen miles per hour, and the additional friction on such a curve, above that on a straight road, is 1 in 1418, equal to 3·72 feet in a mile, with Winans's car, and 1 in 356, equal to 14·83 feet in a mile, with another car. If the diameter of the wheel is increased, that of the conical part of the rim should be increased also, making the rise of the conical part between the flange and the cylindrical part one-fifth of an inch in a wheel of three feet diameter, and one-fourth of an inch in a wheel of four feet diameter.

Gravity, horse power, and steam power, have been used on railroads. Where the road is sufficiently and uniformly descending in one direction, gravity may be relied upon as a motive power in that direction; but on railroads generally, some other power must be resorted to in each direction. At the time of the construction of the Liverpool and Manchester railway, much discussion took place as to the expediency of using stationary or locomotive steam-engines. The result of the deliberations was, that if locomotives could be constructed within certain conditions as to weight and speed, they would be preferable. The directors accordingly offered a premium for the construction of such a locomotive, as should perform according to the conditions prescribed. At the celebrated trial on that road in October, 1829, of which Mr Wood gives a particular account in the edition of 1831 of his work on railroads, the locomotive, called the *Rocket*, constructed upon the plan of Mr Robert Stevenson, was found to come within the proposed conditions, and accordingly the decision, in respect to that road, was in favour of locomotives. The opinion in favour of this kind of power on roads of which the inclination does not exceed about thirty feet in a mile, has become pretty fully established. Stationary power can be used to advantage only on lines of very great transportation, as the expense is necessarily very great, and almost the same, whether the transportation be greater or less. Another objection to the use of stationary power is, that its interruption, in any part, breaks up the line for the time, which is not necessarily the case with a locomotive. The alternative, accordingly, is between the use of locomotive steam engines or horses, and the choice must be determined by the particular circumstances of the line of transportation. The advantages of this species of road are illustrated by the action of a horse upon it, compared with his performance upon the best turnpike, being, as Mr Wood assumes in one of his estimates, in the proportion of 7·5 to 1; thus enabling us to dispense with thirteen out of fifteen horses required for transportation on the best common roads. The horse's power of draught is much the greatest at a low rate of speed, since the more rapid the velocity, the greater proportion of his muscular exertion is required to transport his own weight. But it is ascertained, on the Baltimore and Ohio railroad, that a speed of ten miles an hour may be kept up by horses travelling stages of six miles each, which would perform the whole distance between Baltimore and the Ohio river in thirty-six hours. The whole expense of transportation by horse power, including cars, drivers, and every expense except repairs of the roads, on the same railroad, from January to September, 1831, amounted to about one-third of the gross tolls received; and this expense, it was calculated, might be very materially reduced. The average consumption of coke by a locomotive engine, on a passage from Liverpool to Manchester, thirty-two miles, is stated by Mr Wood to be 800 pounds, and the water evaporated 225 gallons per hour, and 450 gallons on the passage. Mr Wood computes that one of those locomotives will perform the work of 240 horses travelling at the rate of ten miles per hour upon a turnpike road, the velocity of the locomotive being fifteen miles per hour. The fact is well established, that where the transportation is sufficient for supplying adequate loads for locomotive engines, and where the load is so constructed that they can be advantageously used, and where fuel is not exceedingly expensive, they afford much the most economical motive power. Mr Robert Stevenson, in a communication to the agent of the Boston and Lowell railroad, estimates that the most advantageous speed is that of fifteen miles per hour for passenger trains, and seven miles for those transporting merchandise. A reason for adopting a lower speed for the latter, is, to prevent injury to the road by the heavily loaded wheels.

Speculators in railroads ought not to be sanguine as to profits derivable from the transport of goods, as they can be carried by canals at a lower rate of charge than by railways, and as great rapidity of transport, in which the railway is chiefly preferable to the canal, is in general of little consequence in manufacturing, mining, or agricultural produce.

Rapidity of transport is mainly advantageous to travellers, and therefore the chief source of emolument derivable from a railroad will arise from the transport of passengers. The speed of conveyance on the Manchester and Liverpool railway may be estimated on an average at 20 miles per hour; the average rate of transport of goods on a canal may be estimated at 4 miles per hour; the railway conveyance being thus preferable to the canal in the proportion of 5 to 1, or 1 to 0·2, so far as economy of time is concerned.

Formerly on all canals, and on some canals still, the rate of conveyance of passengers was the same, or perhaps about 5 miles per hour. But about 1830, a species of light boats, made of sheet iron, were introduced on the canal between Glasgow and Johnston, and called *Swift* boats, the average of which may be estimated at 9½ miles per hour. These boats are adapted exclusively to the conveyance of passengers, and have, since their invention in Scotland, been introduced on the principal canals in Great Britain, and at this date, July, 1836, one is constructing at Paisley for the French government. So far then as these swift boats and railway carriages are to be compared in respect to speed, the latter has the advantage over the former in the proportion of 20 to $9\frac{1}{4}$, or as 1 is to 0·462. The average fares charged upon the Manchester and Liverpool railway is 1·084d. per mile; the average upon the Kendal and Preston railway is 1d. per mile. The average speed of the swift boats on the Glasgow and Johnstone canal is 9·75 miles per hour; and that of the carriages on the Glasgow and Garnkirk railway 18 miles an hour; the charge for passengers on the former is to that on the latter as 1·111 to 1. Since the superiority of a railroad over a canal consists chiefly in the transport of passengers, no rail road can be undertaken with prudence where there is not likely to be a sufficient number of passengers to clear at least a small percentage of profit. As rapidity of conveyance increases the inducement for travelling, a greater number of travellers may be expected on a line of railroad than on the same line of common road or canal. Dr Lardner thinks that the probable number of passengers on a line where a railway is to be constructed may be estimated by doubling the average number on the same line by a common road, for the last three years. This is a prudent estimate; for we find that on the Manchester and Liverpool line the number of passengers has been increased three times instead of twice.

From what has been stated before, it is easy to see that a long railroad can be wrought with a proportionally less expense than a short one, other things being the same. It will also be manifest that the fewer the ascents and descents the better, as also the deviations from a right line. Gradients, according to Dr Lardner, are accompanied with a loss of power when they exceed 17 feet in a mile, and when the acclivities exceed 30 feet per mile assistant engines will be required; and when the gradients amount to 50 feet per mile, the assistant engine must be stationary, and the train brought up by ropes. Steep gradients are not objectionable when they descend from the commencement of the line, and are not very long. The resistance on the level is doubled when the ascent is 17 feet in the mile; and the resistance is proportionally greater or less as the ascent is greater or less than this. The curves on a rail road should never be placed at the foot of a descent; nor should the diameter of the arc of curvature be less than two miles. Tunnels should, if possible, be avoided, and when necessary not of less height than 30 feet, and ventilated by upright shafts. The greater the capacity and the shorter the better.

While comparing railway and canal transport it may be interesting to the reader to learn the distinguishing features of the new system of canal navigation. T. Grahame, Esq., civil engineer, gives the following particulars. Two horses on the Paisley canal boats, drag, with ease, a passage boat, with her complement of seventy-five or ninety passengers, at the rate of ten miles an hour, along the canal.

The facts now stated, though more decidedly exhibited in the Paisley canal, from its narrowness, have been proved and exhibited on various other canals, and must, though in different degrees, affect motion along all bodies of water.

I have been dragged, by one horse, in a common gig boat, with five or six other persons, for two miles, along a canal, at the rate of fifteen miles per hour; and this speed was not limited by the labour of the draught, but by the power of speed of the horse. A high degree of speed is safer both for the light boat and the canal works, than a speed of five miles an hour with a common heavy boat; as the light boat carries little way, or momentum, and might be dragged at the above high velocity to the very entry of a lock, and would have her speed reduced before she was fully into it, so that there is no danger to the gates.

I have also performed a voyage of 56 miles, along two canals, including the descent of four, and the ascent of eleven locks, the passage of eighteen draw-bridges where the line was thrown off, and sixty common bridges, and a tunnel half a mile long, in six hours, thirty-eight minutes. The boat was of a twin shape, 69 feet long and 9 feet broad, and was drawn in stages by two horses each stage, and carried thirty-three passengers with their luggage and attendants.

A speed of ten miles an hour has for the last two years been maintained, in the carriage of passengers, on one of the narrowest, shallowest, and most curved canals in Scotland, where the vessel carried upwards of 100 passengers, or as many as are carried in a train of coaches on the Liverpool and Manchester railway.

The expenses or cost of obtaining this speed are so trifling, that the fares per mile are in these quick boats just one-half and one-third of the fares in the Liverpool railway coaches, while at these low fares the profits are such as have induced the boat proprietors to quadruple the number of boats on the canal.

The ordinary speed for the conveyance of passengers on the Ardrossan canal has, for nearly two years, been from nine to ten miles an hour, and although there are fourteen journeyings along the canal per day at this rapid speed, the banks of the canal have sustained no injury. The boats are formed 70 feet in length, about 5 feet 6 inches broad; and, but for the extreme narrowness of the canal, might be made broader. They carry easily from seventy to eighty passengers, and when required, can, and have carried, upwards of 110 passengers. The entire cost of a boat and fittings up, is about £125. The hulls are formed of light iron plates (16 gauge), and iron ribs, and the covering is of wood and light oiled cloth. They are more airy, light, and comfortable than any coach;

they permit the passengers to move about from the outer to the inner cabin; and the fares per mile are one penny in the first, and three farthings in the second cabin. The passengers are all carried under one cover, having the privilege also of an uncovered space. These boats are drawn by two horses (the prices of which may be from £50 to £60 per pair), in stages of four miles in length, which are done in from 22 to 25 minutes, including stoppages to let out and take in passengers; each set of horses doing three or four stages alternately each day!

The entire amount of the whole expenses of attendants and horses, and of running one of these boats four trips of 12 miles each (the length of the canal), or 48 miles daily, including interest on the capital, and twenty per cent. laid aside annually for replacement of the boats, or loss on the capital therein invested, and a considerable sum laid aside for accidents and replacement of the horses, is £700, some odd shillings; or taking the number of working days to be 312 annually, something under £2 4*s*. 3*d*. per day, or about 11*d*. per mile. The actual cost of carrying from 80 to 100 persons a distance of 30 miles (the length of the Liverpool railway), at a velocity of nearly 10 miles an hour, on the Paisley canal, is therefore just £1 7*s*. 6*d*. sterling. Whilst the daily expense of the railway is much more than three times as great!

Mr M'Neill made several experiments on the subject of resistance, in which he was assisted by Mr Gordon, who says, "there was no reason to doubt the accuracy of the law, that the resistance increased as the squares of the velocity when the transverse section immersed remained the same. But in a range of velocities from 1 to 12·396 miles per hour with an iron passage-boat, such as is used on the Scotch canals; and in a range of velocities from 1 to 14 miles per hour with various shaped models; the resistance was *not* found to be as the squares of the velocities when the boat was hauled at and above 6 miles per hour.

At the velocity 10·383 miles per hour, the iron passage boat, containing 15 persons, and weighing in all 3·5 tons, was hauled by two horses, whose exertion, registered by Mr M'Neill's dynamometer, was 285·15 lbs.; whereas if the old law of the resistance being as the squares had been correct, 429·5 lbs. would have been necessary. We afterwards measured the boat's emergence from the water, and although it could not be stated with mathematical accuracy, there was no room left for doubting, that the emergence of the boat caused the difference."

We have now to investigate the quantity of power necessary to move a train of carriages over a given line of rail. The mean tractive power on a horizontal rail has been variously estimated. It is commonly supposed that the tractive power is, at a mean, 9 lbs. per ton; or the power is to the weight as 9 is to 2240, or as 1 is to 250, in round numbers. It would seem, however, that in favourable circumstances, and on a well

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Fig. 1.

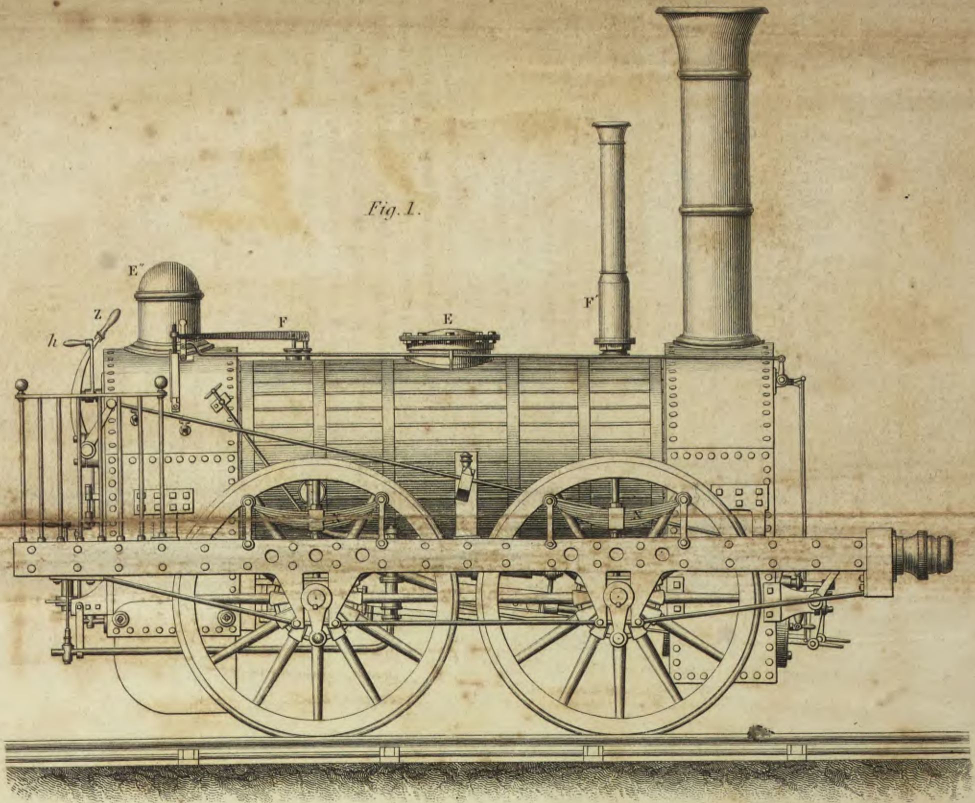


Fig. 4.

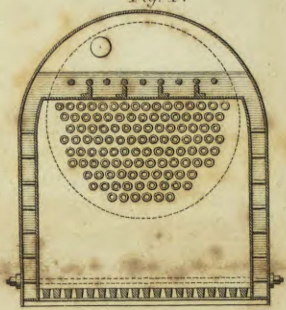


Fig. 2.

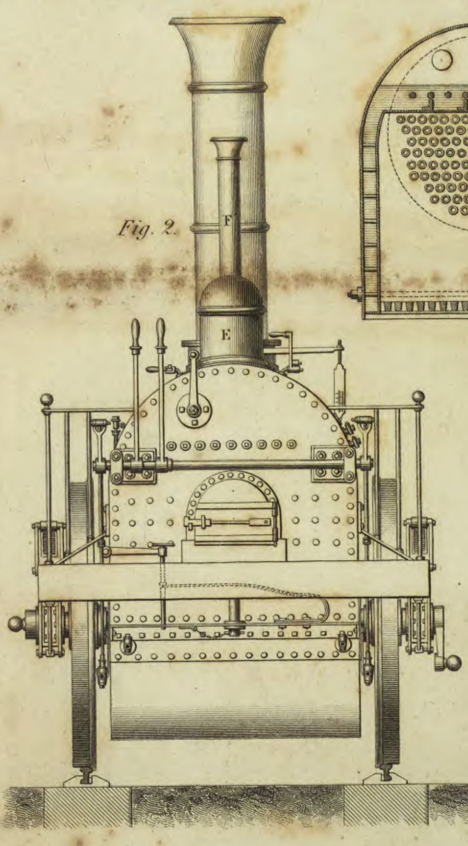
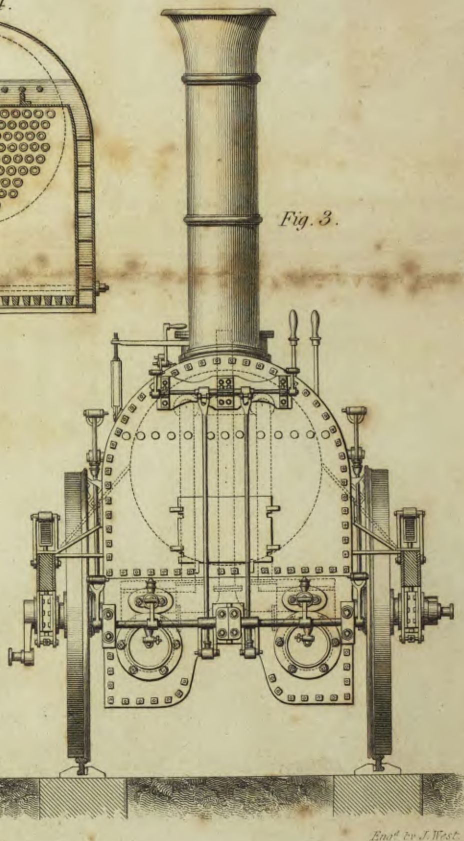


Fig. 3.



Engd by J. West.

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constructed rail, this estimate is too much; and from the improvements daily making, we may take the power of traction as 1-200th part of the load. If we suppose that the same locomotive engine drags the same train over the whole length of rail, and there are not descending slopes of more than 1 in 200, the power required to tract the load L from the station A to the station B, B being the higher point; by the quantity h, then we have the formulæ.

(1) power $\times \left(\frac{\text{length of A B}}{200} + h\right)$ when the train moves from A to B, ascending.

(2) power $\times \left(\frac{\text{length of A B}}{200} - h\right)$, when the train moves from B to A, descending.

These formulæ are true, supposing that the train starts from a state of rest and terminates the journey when the velocity is reduced to zero, the power expended in moving the train being only regarded. It is necessary, however, to determine the amount of power of the engine used in dragging the train, and also that expended in friction and other unavoidable resistances. If we make n represent the force in atmospheres of the steam, then $n - 1$ will be the effect on the piston, and $\frac{0\cdot5\, n-1}{n-1}$ will be the part of the power used, and $\frac{0\cdot5\, n}{n-1}$, the part lost in friction, &c.

Now, the pressure commonly employed in locomotive engines (which are noncondensing,) is 4 atmospheres, and therefore $\frac{0\cdot5 \times 4 - 1}{4 - 1} = \frac{1}{3}$ for the effective part of the engine's power, and $\frac{0\cdot5 \times 4}{4 - 1} = \frac{2}{3}$, that lost by friction, &c. This is M. Navier's formula; according to Mr Stevenson's estimate the number 0·6 should be substituted for 0·5, which would make the effective power equal to half the power of the steam in the boiler, a result too great, at least, for ordinary pressure. Mr Wood, on the other hand, estimates the effective pressure at $\frac{3}{10}$, which would make the number 0·3 instead of 0·5, an estimate decidedly too low, if the management and construction of the carriage be at all judicious.

In order to determine the total quantity of power expended by the locomotive engine, we must recollect that when the train passes up a slope, or gradient, to a certain height, and then passes down another gradient of the same height, the descent restores the power that had been expended in raising the weight of the train, but not that which was consumed by the friction, and therefore there is a loss of power whenever there is a useless ascent, that is, when the train is made to rise and then fall through the same height, and vice versa. Thus, let A be one extremity of the rail, and B the other, and the train moving in the direction A B, the point B being the higher of the two, then will there be a useless waste of power every time there is a descent; and in returning from B to A there will be a waste of power every time there is an ascent; wherefore it is preferable to have one long gradient than undulations. The useless gradients may easily be found by inspecting a section. Take the greater rises and falls in the line, i. e. the highest and lowest points: let h represent the sum of the useless rises, and L the power lost in friction or otherwise, and not used to drag the train, also let L represent the length of the rail, and H the height of B above A, then we have,

$$0{\cdot}005 \times L \pm H + f\,h,$$

an expression which gives us the power necessary to effect the transit in terms of the height to which it could elevate the whole weight of the train, or, in other words, the power employed in transit would raise the weight of the train to $\frac{1}{200}$dth part of the length of the rail, increased or diminished by the difference of the heights of the two extremities of the rail, to which is to be added the sum of the useless rises, multiplied by that fraction of the whole power which is expended in friction, &c. This is applicable only when the inclination of the gradient is not more than 1 in 200. Whenever the descending slope is greater than this expression, where i is the inclination, and s the difference of the height of the two ends of the slope,

$$\frac{-\,0{\cdot}005}{i} \times s.$$

When there is an ascent so steep as to require an additional engine, let a be the length of the incline, n the height, and e the fraction that the weight of the additional engine forms of the whole weight, then must we add to the expression,

$$0{\cdot}005 \times L \pm H + f\,h, \text{ the quantity } e \times (0{\cdot}005 \times a + n).$$

Stations.	Length of rail.	Height above 1st station.	Height from the preceding station.	Ascents and descents.
A	—	—	—	—
a	4000	8	8	ascending.
b	5000	50	42	ascending.
c	6000	57	7	ascending.
d	10000	51	6	descending
e	11000	58	7	ascending.
f	8000	62	4	ascending.
g	32000	23	39	descending.
B	35000	32	9	ascending.

We will now proceed to show the application of these principles; supposing the reader to draw the section of a railway, as directed in the above table, of a section of a line of rail.

Now the length of rail, being the sum of the lengths of the rails of all the stations, will be found, by adding the 2d column of the above table, to be 101000 yards; wherefore from what was stated formerly, $\frac{101000}{200}$ = 505 yards the height to which the power would raise the weight of the train, supposing the rail to be horizontal, but the station B is 32 yards higher than A, and therefore if the train move in the direction A B, this must be taken into accouut, wherefore the power necessary to move the train on the rail would be the same as that required to raise the weight of the train to a height equal to $505 + 32 = 537$ yards, that is, if there were no descending slopes in the line of rail or useless ascents. On looking over the table, however, we find the rail continues to ascend to the station *c*, but the next station *d* is lower by six yards; it ascends again to the station *f*, and then falls at *g* 39 yards; the total of descents being 45 yards. Now, since two-thirds of the power of the engine are lost in overcoming friction, and other resistances, and, as before observed, all this is expended in effecting useless rises, it follows that two-thirds of this 45 must be added to the former result in order to account for the whole power expended in dragging the train, including the useless descents or ascents. Two-thirds of 45 being 30, we have $337 + 30 = 367$ yards to which height the power would be capable of raising the weight of the train.

Suppose the train moves back from B to A, we have a descent of 32 metres, which taken off the result for the horizontal rail, as first found, gives $505 - 32 = 473$ yards, but the amount of the useless ascents is in this case the same as before, therefore we must add 30, and we obtain 503.

In general we may state that if the height to which the train is to be raised in the gradients be called *q*, and the length of the rail, as before, L, the weight of the train P, then the mean tractive power will be expressed by the formulæ $\frac{q}{L} \times P$.

There are two circumstances which chiefly limit the effective traction of a locomotive engine, i. e. a sufficient quantity of steam, and the slipping of the wheels upon the rails. It is to be observed that the space passed through by the piston is equal to the volume of steam generated in a given time, and the pressure of the steam must be such as to produce the mean tractive power at the circumference of the wheels To determine the first condition, let F represent the pressure of steam in the boiler, then multiply F by the decimal 0·0000484, and add

0·1985 to the product; for a divisor and for a divident take the product of the pressure of the steam in lbs. × 60·027, the quotient is the cubic inches of steam generated in a second of time.

The effective force exerted by the engine being of the high pressure kind, is $0·6\ n - 1$, where n is the pressure of the steam in the boiler. M. Navier gives the following formulæ.

$$F = 94·57 \times J \times P + 20660.$$

$$P = \frac{1}{J} \times \left(\frac{4132}{U} - 238\right)$$

$$U = \frac{4132}{J\,P + 238}$$

$$\Pi = 0·09 + 0·0000484 \times F$$

$$\gamma = \frac{\Pi}{w} = \frac{c}{\varpi\, r} \times \Omega\, U$$

$$J = \frac{c}{\varpi\, r} \times \frac{(0·5\ F - 10330) \times \Omega}{P}$$

$$P = \frac{c}{\varpi\, r} \times \frac{(0·5\ F - 10330) \times \Omega}{J}$$

$$P = \frac{1}{J}\left(\frac{10330 \times \Pi}{U} - 11260 \times \frac{c\,\Omega}{\varpi\, r}\right)$$

$$U = -\frac{10330 \times \Pi}{P\,J + 1260 \times \frac{c\,\Omega}{\varpi\, r}}$$

In which P is the weight of the train, J the ratio of the height of the plane to the length, Ω the area of the pistons, c the length of the stroke, r the radius of the wheels, F the force of the steam, Π the weight of steam produced in a second, U the velocity of the train in a second, ϖ the number 3·1416. All the measures are taken in metres, and the weights in killogrammes, and in the three first formulæ the formulæ are applied to a particular case, i. e. that of the Planet on the Liverpool and Manchester railway, when

$$\Omega = 12315\, m$$

$$c = \cdot 41\ m$$

$$r = \cdot 76\ m$$

$$\frac{c\,\Omega}{\varpi\ r} = 0·21148 \text{ kil.}$$

$$\Pi = 0·4 \text{ kil.}$$

In a discussion at the late meeting of the British Association at Bristol, Professor Mosely drew the attention of the meeting to the resistance of railway carriages. The friction of the machinery itself he considered to be of two kinds, which was composed of two elements, one was that which would oppose itself to a force applied to the wheels of the carriage, if it were lifted off the rail; this friction amounted to from 120 to 180 lbs. in the Liverpool and Manchester railway carriages. The other element was the friction of the machinery dependent on, and proportional to, the load. The traction resulting from friction has been variously estimated at from 8 to 11 lbs. per ton. The first of these resistances is constant; and the second varies with the load, the velocity of the train, and inclination of the rail. Much advantage, it would seem, arises from watering the rails immediately before the carriages have passed over them.

A tolerable estimate may be formed of the performance of a locomotive engine, from the following statement of an experiment made on the Manchester and Liverpool railway, with the Victory, on the 5th of May, 1831. This engine made the trip of 30 miles in 1 hour 34 minutes 45 seconds, exclusive of ten minutes spent at the middle of the journey for taking in water; 929 lbs. of coke were consumed, the train consisting of 20 wagons carrying merchandise, and weighing 92 tons 19 cwt. 1 qr., exclusive of the weight of engine and tender. The train was retarded, from two to three minutes, by the slipping of the wheels at Chat moss. On the level the speed was 18 miles an hour, on a descent of 4 feet in a mile the speed was $21\frac{1}{2}$ miles an hour, on a fall of 6 feet per mile $25\frac{1}{2}$ miles an hour; on a rise of 8 feet per mile the speed was 17 miles an hour, and on an incline, rising 1 in 96, the train was assisted by an additional engine, making the ascent of $1\frac{1}{2}$ miles in 9 minutes. There was a moderate wind direct a-head; but when the train was on a level sheltered from the wind the speed was 20 miles an hour. The attendance required is that of an engine man who receives 1*s.* 6*d.* per trip, and fire boy who receives 1*s.*

We will terminate what farther we have to state regarding railways by giving a few useful tables from which the reader will collect more information than he could from any general formulæ. For the purpose of saving space we present these tables together, reserving the short explanation which they require to page 483.

TABLE A.

Number of Experiments.	Description of metal.	Weight of each rail.	Weight which produced fracture.	Average weight of each kind of rails.	Average strength of each kind of rails.	Relative strength of mixed and unmixed metal, specific gravity considered.
		lbs. oz.	cwts. qr. lbs.	lbs. oz.	cwts. qr. lbs.	
1	No. 1, metal A......	56 6	126 3 0	55 9	114 1 14	146 122
2	—— ditto..........	56 0	99 3 0			
3	—— ditto..........	55 8	108 3 0			
4	—— ditto..........	54 7	122 1 0			
5	No. 1, A, same kind as preceding mixed with old metal....	58 14	148 2 0	59 10	146 0 14	
6		58 9	144 0 0			
7	No. 1, metal B.......	55 10	113 1 0	56 6	106 2 0	156 108
8	—— ditto	57 1	99 3 0			
9	No. 1, B, mixed with old metal	57 13	162 3 0	57 10	156 0 0	
10		57 7	149 1 0			
11	No. 1, metal C........	55 8	150 3 0	55 4	140 2 14	173 128
12	—— ditto	55 0	130 2 0			
13	No. 1, C, mixed	56 4	184 2 0	56 10	173 3 0	
14	—— ditto...... ..	57 0	162 0 0			
15	No. 1, metal D	56 3	113 1 0	56 2	115 2 6	194 119
16	—— ditto.........	56 1	117 3 0			
17	No. 1, D, mixed with old metal	59 9	207 3 0	58 4	194 1 0	
18		56 14	180 3 0			
19	No. 2, ditto D..........	56 13	95 1 0	56 5	97 2 0	
20	—— ditto............	55 12	99 3 0			
21	No. 3, ditto D	57 13	104 1 0	57 5	108 3 0	
22	—— ditto............	56 14	113 1 0			
23	No. 1, metal E....... ..	56 6	128 1 0	56 12	131 2 14	137 144
24	—— ditto............	57 2	135 0 0			
25	No. 1, E, mixed with old metal	55 6	148 2 0	55 8	137 2 0	
26		55 10	126 0 0			
27	Rail cast-iron different kinds of metal, close fracture......	55 8	135 3 0			
28	Do. open fracture......	57 1	99 3 0			
29	Rail 4 feet long	58 0	120 0 14			
30	—— 3 feet long, No. 2 metal	33 0	98 2 14			
31	—— 3 ft. Welsh metal	33 0	100 3 14			
32	—— 3 ft. No. 1 metal	33 0	107 2 14			

TABLE B.

Weight in cwts.	Deflexion in inches.	REMARKS.
28	·06	
56	·11	On the weight being removed it immediately resumed its original form; and to ascertain if any injury had taken place, the following experiments were made.
84	·2	
112	·35	
126	·47	
28	·11	When the weights were taken off, the bar again returned to its original form; the weights were then replaced, and the successive deflexions corresponded with the respective weights as in the former experiment.
126	·47	
131·5	·57	When unloaded it came back to its original form.
56	·115	The weights were again applied and the respective deflections found as described; the weights were allowed to remain on for some time, and, on being removed, a permanent deflexion had taken place of ·0035 inches.
126	·48	
140	·63	
154	·92	On the weights being again added, the deflexions were nearly similar to those previously observed. When loaded with 154 cwt. the deflexion was found as stated; the weights were then removed, and it was found that the bar had acquired a permanent bend of ·24 inches. The rail did not appear otherwise injured.

TABLE C.

ENGINES.	RAILROADS.	IN SUMMER.												IN WINTER.											
		At Five miles per hour.				At Eight miles per hour.				At Ten miles per hour.				At Five miles per hour.				At Eight miles per hour.				At Ten miles per hour.			
		Goods.	Carriages.	Engine and Tender.	Gross Weight.	Goods.	Carriages.	Engine and Tender.	Gross Weight.	Goods.	Carriages.	Engine and Tender.	Gross Weight.	Goods.	Carriages.	Engine and Tender.	Gross Weight.	Goods.	Carriages.	Engine and Tender.	Gross Weight.	Goods.	Carriages.	Engine and Tender.	Gross Weight.
		tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.
Engine on six 4 feet wheels, Hackworth	Stockton and Darlington . . .	47¾	23¾	15	86½	26	18	15	54	18¾	9½	15	43¼	40¾	20¼	15	76	21¾	10¾	15	47½	15¼	7¾	15	38
Engine on four 4 feet wheels . .	Stockton and Darlington . . .	34	17⅓	12	64	18⅔	9⅛	12	40	13½	6⅔ [?]	12	32	23¾	14½	12	55¼	15	7½	12	34½	$10\frac{1}{10}$	$5\frac{3}{10}$	12	$27\frac{6}{10}$
Engine on four 4 feet 2 inch wheels .	Killingworth Colliery	38	19	10½	67½	21	10½	10½	42	15¼	7¾	10½	33¾	31¼	15¾	10½	57½	17	8½	10½	36	12	6½	10½	28¾
Engine on four 3 feet wheels . .	Hetton Colliery .	24¾	12	10½	46¾	12½	6¼	10½	29¼	8⅔	4⅓	10½	23½	19¾	9¾	10½	40	9¾	4¾	10½	25	6¼	3¼	10½	20
Engine on 4 wheels, rack rail . .	Middleton Colliery, near Leeds .	22¾	11	6¼	39½	12¾	6¼	6½	24¾	9	4½	6¼	19¾	19¼	9½	6¼	35	10¼	5¼	6¼	21¾	7½	3¼	6¼	17½

TABLE D.

Inclination of railway from a level to 1 to 25.	Weight of locomotive engine exclusive of the tender, &c.	Power of engine in pounds by adhesion in the worst state of weather.	Power of engine in pounds by adhesion in the best state of weather.	Gravity per ton at the different inclinations of the railway.	Power per ton to overcome the friction of the carriages and load in the worst state of weather for the adhesion of the engine wheels.	Power per ton to overcome the friction of the carriages and load in the best state of weather for the adhesion of the engine wheels.	Load of engine at a speed of 4 miles per hour worst weather.	Load of engine at a speed of 4 miles per hour best weather.	Load of engine at a speed of 8 miles per hour worst weather	Load of engine at a speed of 8 miles per hour best weather.	Load of engine at a speed of 16 miles per hour worst weather.	Load of engine at a speed of 16 miles per hour best weather.	Load of engine at a speed of 20 miles per hour worst weather.	Load of engine at a speed of 20 miles per hour best weather.	REMARKS. * Signifies a weight less than that of the engine itself.
	tons	pounds.	pounds.		pounds.	pounds.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	
Level	7½ or 16,80 lbs.	672	1810	·00	8	10·8	84·	167·75	42·	83·7	21·	41·9	16·8	33·5	The gravity of a ton (or any other given weight) is found by multiplying the weight of the body by the height of the plane and dividing the sum by its length. The friction of the carriages is taken at one two hundredth part of their weight; and is a constant quantity so long as the speed remains the same, but increases as the square of the velocity.
1 in 800				2·8			62·2	133·	35·7	74·1	19·3	39·3	15·7	31·8	
1 in 400				5·6			49·4	110·	31·1	66·5	17·8	37·	14·7	30·3	
1 in 200				11·2			35·	82·2	24·6	55·1	15·5	33·2	13·1	27·7	
1 in 100				22·4			22·1	54·5	17·5	41 1	12·3	27·5	10·7	23·6	
1 in 96				23·3			21·4	53·	17·	40·3	12·1	27·2	10·6	23·4	
1 in 50				44·8			12·7	32·5	11·	27·2	8·7	20·5	7·9	18·3	
1 in 25				89·6			6·8	18·	6·3*	16·2	5·5*	12·6	5·1*	12·5	
1 in 96	engine weighing 5 tons, or 11,200 lbs.	448	1206	23·3	8	10·8	56·9	111·8	28·	55·8	14·	27·9	11·2	22·3	
1 in 96	engine weighing 6 tons, or 13440	537·6	1448	23·3	8	10·8	67·2	134·2	33·6	66·9	16·8	33·5	13·4	26·8	

TABLE E.

	£	s.	d.
Advertising account, - - - - - - -	332	1	4
Brickmaking account, - - - - - -	9,724	4	4
Bridge account - - - - - - -	99,065	11	9
The number of bridges is 63, of which one is of 9, a second of 4, and a third and fourth of 2 arches. The rest are of one arch each.			
Charge for direction - - - - - -	1,911	0	0
Charge for fencing - - - - - - -	10,202	16	5
Cart establishment - - - - - - -	461	6	3
Chat Moss account - - - - - - -	27,719	11	10
The embankments included under this head consist of about 277,000 cubic yards of raw moss earth, in the formation of which about 677,000 cubic yards of raw moss earth have been used; the difference of measurement being occasioned by the squeezing out of the superabundant water and consequent consolidation of the moss. The expenditure on this part of the line has been less than the average expenditure.			
Cutting and embankments - - - - - -	199,763	8	0
Under this head is comprised the earth-work on the whole line, exclusive of the Chat Moss district. The cutting somewhat exceeds the embankments; the surplus is principally deposited along the border of the Great Kenyon cutting. The excavations consist of about 722,000 cubic yards of rock and shale, and about 2,006,000 cubic yards of marl, earth, and sand. This aggregate moss has been removed to various distances, from a few furlongs to between three or four miles; and no inconsiderable portion of it has been hoisted up by machinery, from a depth of from 30 to 60 feet, to be deposited on the surface above, either to remain in permanent spoil banks, or to be afterwards carried to the next embankment.			
Carrying department, comprising account expended in land and building for stations and depots, warehouses, offices, &c. at the Liverpool end - - - £35,538 0 0			
Expended at the Manchester station - - 6,159 0 0			
Side tunnel - - - - - - - 2,485 0 0			
Gas light account, including cost of pipes, gasometer, &c. - - - - - - - 1,046 0 0			
Engines, coaches, machines, &c. - - 10,991 11 4			
	56,219	11	4
Formation of the road - - - - -	20,568	15	5
By this is understood what is termed ballasting the road, that is, depositing a layer of broken rock and sand about two feet thick; viz. one foot below the blocks and one foot distributed *between* them, serving to keep them firm in their places. Spiking down the iron chains to the blocks or sleepers, fastening the rails to the chains with iron keys, and adjusting the Railway to the exact width, and curve, and level, come under this head of expenditure.			
Rail account - - - - - - - -	69,912	0	2
This expenditure comprises the following items:—			
Rails for a double way from Liverpool to Manchester, with additional lines of communication, and additional side lines at the different depots, being about 35 miles of double way = 3847 tons, at prices averaging something less than £12 10s. per ton - - - - - - - - £48,000 0			
Cast iron chains, 1428 tons, at an average of £10 10s. - - - - - - - - 15,000 0			
Spikes and keys to fasten the chains to the blocks and the rails to the chains - - - - 3,830 0			
Carry forward	£495,880	6	10

			£	s.	d.
Brought forward			£444,000	0	0
Oak plugs for blocks	615	0			
Sundry freights, cartages, &c.	467	0			
Interest account (balance)			3,629	16	7
Land account			95,305	8	8
Office establishment			4,929	8	5
Parliamentary and law expenditure			28,465	6	11
Stone blocks and sleepers			20,520	14	5
Out of the 31 miles about 18 are laid with stone blocks, and 13 with wooden sleepers, oak or larch; the latter being laid principally across the embankment and across the two districts of moss.					
Surveying account			19,829	8	7
Travelling account			1,423	1	5
Tunnel account			34,791	4	9
Tunnel compensation account			9,997	5	7
Wagons used in the progress of the work			22,185	5	7
Sundry payments for timber, iron, petty disbursements, &c.			2,227	17	3
			£739,185	5	0

1st of January to 1st of July, 1831.

	Tons.
Merchandise carried between Liverpool and Manchester	35,865
Between Liverpool and the Bolton Junction............	6,827
	42,692
Coals from Collieries near Liverpool	2,889

Passengers booked at Company's Office, 188,726, exclusive of passengers taken up on the road.

The gross receipts of this traffic were as follows:—

	£	s.	d.
Passengers	43,600	7	5
Merchandise	21,875	0	1
Coals	218	6	2
	£65,693	13	8

amounting to 4*s.* 7¼*d.* per passenger booked, and 10*s.* 3*d.* per ton for merchandise.

The disbursements on the same traffic were as follows:—

	£	s.	d.
Coaching department for passengers ..	19,099	16	5
Merchandise, &c.	16,279	7	5
Total ..	35,379	3	10
Profit..................................	30,314	9	10
	£65,693	13	8

1st July to 31st December, 1831.

	Tons.
Merchandise between Liverpool and Manchester ..	52,224
Traffic on the road	2,347
	54,571
Between Liverpool and the Bolton Junction........	10,917
Coal from the adjacent Collieries	8,396

Passengers booked, exclusive of those taken up on the road, 256,321.

Receipts.

	£	s.	d.
Coach department............	58,348	10	0
Merchandise	30,764	17	8
Coal	695	14	4
	£89,809	2	0

Expenses.

	£	s.	d.
Passengers' department	25,930	1	1
Merchandise	21,841	4	10
Coal department	505	16	3
Bolton Junction..............	748	16	3
	49,025	18	5
Net profit....................	40,783	3	7
	£89,809	2	0

The profits from the opening to December 31, 1831, were as follows:—

	£	s.	d.
From September 16th to December 31st, 1830......	14,432	19	5
From January 1st to June 30th, 1831	30,314	9	10
From July 1st to December 31st, 1831	40,783	3	7
Total........	£85,530	12	10

Table A exhibits the results of various experiments made with a view to determine the strength of cast iron rails of various forms and sizes, and under various circumstances. Table B exhibits similar results obtained from experiments made on malleable iron rails. From the great importance of this subject to the practical engineer it is to be hoped that these investigations will ere long be carried to a greater extent, more especially as since the introduction of the hot blast in smelting there seems to be reason to believe that there is a difference in the quality of the iron employed since Mr Wood made these experiments. Tables C and D exhibit the results of experiments with different engines on several rails, which furnish valuable data for calculation; another table of the same kind will be found in Mr M'Neill's translation of Naver's work on Locomotion. Table E exhibits an account of the cost and profits of the Liverpool and Manchester Railway, which will assist considerably in forming estimates for new lines.

Horses are still extensively employed in mining districts for the traction of coals, iron stone, &c. upon railways. The wagons are made of wood, bound with iron, being about 80 inches long, 45 broad, and 30 inches deep, the weight varying from 12 to 15 cwts. They run upon four wheels, each about 3 feet diameter containing about 32 cwt. of coal, and costing about £14. On a railway the ease of draught is about 6 times greater than on a common road; and it has been found that an ordinary horse will draw 4 tons upon a tram rail, and 7 tons upon an edge rail, at the average rate of 3 miles an hour, when the line is level.

Rarefaction, in Physics, is the making a body to expand or occupy more room or space without the accession of new matter.

Rarity, lightness, thinness, the reverse of density.

Ratio, is the relation of two quantities of the same kind with respect to quantity, and is by some authors divided into arithmetical and geometrical ratio: viz. arithmetical when the term is used with respect to the difference of the two quantities, and geometrical when it relates to the number of times in which the one of those quantities is contained in the other.

Reciprocally, the property of being reciprocal; thus we say, that in bodies of the same weight, the density is reciprocally as the magnitude; viz. the greater the magnitude the less is the density; and the less the magnitude, the greater the density. So again, the space being given, the velocity is reciprocally as the time.

Rectangle, in Geometry, is a figure having all its angles right angles, being a particular species of parallelogram, and consequently possessing all the properties belonging to the latter figure; besides which, it has the following ones peculiar to itself, viz. If from any point in the plane of a rectangle, lines be drawn from any point either within or without, or in any of its sides to the four angles of the figure, the sum of the squares of two of those lines going to the opposite angles of the figure, is equal to the sum of the squares of the lines joining the other opposite angles. To find the area of a rectangle, multiply its length by its breadth, and the product will be the area.

Rectangular Figures and Solids, are those which have one or more right-angles.

Rectification, in Geometry, is the finding of a right-line equal to a proposed curve.

Rectilineal, or Rectilinear, consisting of, or being bounded by, right lines.

Reflection, is the return or regressive motion of a moveable body, arising from the reaction of some other body on which it impinges. The reflection of bodies after impact, is attributable to their elasticity, and the more perfectly they possess this property the greater will be their reflection, all other things being the same. In case of perfect elasticity they would be reflected back again with the same velocity, and at an equal angle with which they met the plane; that is, the angle of incidence would be equal to the angle of reflection, and the velocity both before and after impact would be the same, at equal distance from the body on which they impinge. See *Incidence* and *Percussion*.

Refraction, is the deviation of a body in motion from its direct course, in consequence of the variable density of the mediums in which it moves. This, however, except in speaking of the rays of light, is more commonly called *deflection*.

REGULAR FIGURE, in Geometry, is one that has all its sides and all its angles equal. If these are not both equal, the figure is irregular. Regular bodies, are those which have all their sides, angles, and faces, similar and equal. Of these there are only 5, viz.

The *Tetraedon*, contained by 4 equilateral triangles;

The *Hexaedron* or *cube*, by 6 squares;

The *Octaedron*, by 8 triangles;

The *Dodecaedron*, by 12 pentagons; and

The *Icosaedron*, by 20 triangles.

REPULSION, that property in bodies, whereby, if they are placed just beyond the spheres of each other's attraction of cohesion, they mutually recede and fly off.

RESISTANCE, any power which acts in opposition to another, so as to destroy or diminish its effect. Resistances are of various kinds, arising from the nature and properties of the resisting bodies, the circumstance in which they are placed, and the laws by which they are governed. These may be divided into the following cases: 1. The resistance between the surfaces of contiguous solid bodies, generally denominated friction. 2. The resistance between the contiguous particles of the same body, whether fluid or solid. 3. The resistance that solid bodies oppose to penetration. 4. The resistance of elastic and non-elastic fluids to the motion of bodies moving in them. The resistance that a body experiences from the fluid medium through which it is impelled, depends on the velocity, form, and magnitude of the body, and on the inertia and tenacity of the fluid. For fluids resist the motion of bodies through them. 1. By the inertia of their particles. 2. By their tenacity, or the adhesion of their particles. 3. By the friction of the body against the particles of the fluid. In perfect fluids the latter causes of resistance are very inconsiderable, and therefore are not commonly considered; but the first is always very considerable, and obtains equally in the most perfect, and in the most imperfect fluids. In what follows, and in all cases of a similar description, it will be necessary to distinguish between *resistance* and *retardation;* the former being the quantity of *motion*, and the latter the quantity of *velocity*, which is lost; therefore the retardations are as the resistances applied to the quantity of matter, and in the same body they have always the same constant ratio to each other. In fluids of uniform tenacity, the resistance from the cohesion of its particles is as the velocity with which the body moves. For, since the cohesion of the particles is constantly the same, in the same space, whatever may be the velocity, the resistance from this cohesion will be as the space described in a given time; that is, as the velocity. In a fluid whose parts yield easily without disturbing each other's motions, and which flows in behind as fast as a plane body moves forward, the resistance will be as the density of the fluid; for in this case the pressure on every part of the body is the same as if the body were at rest. And on the same hypothesis, the resistance from inertia will be as the square of the velocity. For the resistance must vary as the number of particles which strikes the plane in a given time, multiplied into the force of each against the plane, and both these quantities varying as the velocity, the resistance which is measured by this product must vary as the square of the velocity. We here suppose the plane of the body to be perpendicular to its direction; but if, instead of being so, it is inclined to it in any given angle, then the resistance of the plane in the direction of the motion will be diminished in the ratio of 1, to the sine cubed of the angle of inclination.

Rest, the continuance of a body in the same place, either absolutely or relatively. The support for a tool in Turning.

Retardation, any force tending to diminish the velocity of moving bodies; it may arise either from the effect of resistance, or from the action of gravity.

Revolution, the motion of a body or line about a centre, which remains fixed.

River, a stream or current of fresh water flowing in a bed or channel from its source or spring into the sea.

Water running in open canals or rivers is accelerated in consequence of its depth, and of the declivity on which it runs, till the resistance increasing with the velocity, becomes equal to the acceleration, when the motion of the stream becomes uniform. But this resistance, it is obvious, can only be determined by experiment, and hence several philosophers have undertaken different courses of experiments for this purpose, amongst whom Buat seems to have met with the most complete success. Let V represent the velocity of the stream per second in inches; R the quotient arising from the division of the section of the stream by its perimeter, *minus* the superficial breadth, all in inches; and S the cotangent of the inclination of the slope. Then the section and velocity being both supposed uniform,

$$V = \sqrt{\left(\cdot R - \frac{1}{10}\right)} \times \left\{ \frac{307}{S^{\frac{1}{2}} - \frac{1}{2}\,h.\,l.\,(S + 1.6)} - \frac{3}{10} \right\}$$

which, when R is very great, and *s* small may be reduced to

$$V = R^{\frac{1}{2}} \times \left\{ \frac{307}{S^{\frac{1}{2}} - \frac{1}{2}\,h.\,l.\,S} - \frac{3}{10} \right\}$$

From which it appears that when the slope remains the same, the velocity varies as $\sqrt{(R - \frac{1}{10})}$, or as $\sqrt{R}$, when R is very great. Hence the velocity of two great rivers of the same declivity are as the square root of $\frac{b\,d}{b + 2\,d}$, where b and d represent the breadth and depth of a transverse section in inches. It follows also, from what is said above, that if $R = \frac{1}{10}$, or is less than that, the velocity is zero, which agrees with the theory of capillary attraction; also the slope may be so small that the other factor may become zero, or

$$\frac{307}{S^{\frac{1}{2}} - \frac{1}{2}\,h.\,l.\,(S + \frac{16}{10})} - \frac{3}{10} = 0,$$

in which case likewise there will be no motion; this, however, can never happen, if the declivity be not less than $\frac{1}{10}$th of an inch in an English mile, as this will produce a sensible motion in the water. In a river the greatest velocity is at the surface, and in the midle of the stream, from which it diminishes towards the bottom and sides, where it is least; and it has been found by experiment, that if $v =$ the velocity of the stream in the middle, in inches, then $v - 2\sqrt{v} + 1$, is the velocity at the bottom.

The mean velocity, or that with which (were the whole stream to move) the discharge would be the same as the real discharge, is equal to half the sum of the greatest and least velocities, as computed by the above formulæ. Suppose that a river, having a rectangular bed, is increased by the junction of another river equal to itself, the declivity remaining the same; required the increase of depth and velocity. Let the breadth of the river equal b, the depth before the junction d, and after it x; the velocity before v, and after it v'; then the quantity denoted by R, in the preceding formula, is $R = \frac{b\,d}{b + 2\,d}$ before the junction, and $R' = \frac{b\,x}{b + 2\,x}$ after the junction.

When the water in the river receives a permanent increase, the depth and velocity, as in the example above, are the first quantities that are augmented, the increase in the velocity increases the action on the sides and bottom; in consequence of which the width is augmented, and sometlmes, though rarely, the depth also. The velocity is thus diminished till the tenacity of the soil, or the hardness of the rock, affords a sufficient resistance to the force of the water. The bed of the river then changes only by insensible degrees, and is said to be permanent; though, in strictness, this is not applicable to the course of any river. When the sections of a river vary, the quantity of water remaining the same, the mean velocities are inversely as the areas of the sections; this being necessary to preserve a uniform discharge. *Playfair's Outlines of Natural Philosophy.*

Rivets, short bolts of metal inserted in a hole at the juncture of two plates, and after insertion hammered broad at the ends, so as to keep the plates together: it is in fact a sort of double headed nail.

Rod, or Pole, a long measure of $16\frac{1}{2}$ linear feet, or a square measure of $272\frac{1}{4}$ square feet.

Roller, a solid cylinder of metal or wood; used for various purposes. A roller placed under a heavy body will enable it to move with less friction than a wheel, that is, so long as the roller's path does not deviate from a straight line.

Rope. The weight in lbs. of a hempen rope may be found by multiplying the square of the circumference in inches by 0·045 for the one foot in length, but for cables use the number 0·027. The load in lbs. that a rope will bear with safety may be found by multiplying the square of the circumference in inches by 200, and for cables use the number 120.

Table showing what weight a good hemp rope will bear with safety

Diameter.	Circumference.	Pounds.	Diameter.	Circumference.	Pounds.
·315	1	200	1·510	4·75	4512·5
·397	1·25	312·5	1·590	5	5000
·477	1·50	450	1·670	5·25	5512·50
·557	1·75	612·5	1·750	5·50	6050
·636	2	800	1·830	5·75	6612·50
·715	2·25	1012·5	1·910	6	7200
·795	2·50	1250	1·990	6·25	7812·50
·874	2·75	1512·5	2·070	6·50	8450
·945	3	1800	2·150	6·75	9112·50
1·030	3·25	2112·5	2·230	7	9800
1·110	3·50	2450	2·310	7·25	10512·50
1·190	3·75	2812·5	2·390	7·50	11250
1·270	4	3200	2·470	7·75	12012·50
1·350	4·25	3612·5	2·540	8	12800
1·430	4·50	4050			

Table showing what weight a good hemp Cable will bear with safety.

Circumf.	Pounds.	Circumf.	Pounds.	Circumf.	Pounds.	Circumf.	Pounds.
6	4320	9·25	10267·5	12·50	18750	15·50	28830
6·25	4687·5	9·50	10830	12·75	19507·5	15·75	29767·5
6·50	5070	9·75	11407·5	13	20280	16	30720
6·75	5467·5	10	12000	13·25	21067·5	16·25	31687·5
7	5880	10·25	12607·5	13·50	21870	16·50	32670
7·25	6307·5	10·50	13230	13·75	52687·5	16·75	33667·5
7·50	6750	10·75	13867·5	14	23520	17	34680
7·75	7207·5	11	14520	14·25	24367·5	17·25	35707·5
8	7680	11·25	15187·5	14·50	25230	17·50	36750
8·25	8167·5	11·50	15870	14·75	26107·5	17·75	37807·5
8·50	8670	11·75	16567·5	15	27000	18	38880
8·75	9187·5	12	17280	15·25	27907·5	18·25	39967·5
9	9720	12·25	18007·5				

Table showing the Proportion of Chain when substituted for Ropes, with the proof strain of each size.

Lbs. per fathom.	Inch diameter of iron.		Circumf. of rope.	Proof in tons.	Supposed tonnage.
5½	$\frac{5}{16}$	Substituted for a rope.	3 inch.	1	
8	$\frac{3}{8}$		4	2	
10½	$\frac{7}{16}$		4¾	3	
13½	½		5¼	4	20
17	$\frac{9}{16}$		6	5	35
24	$\frac{5}{8}$		6½	6	50
27	$\frac{11}{16}$		7	8	70
30	¾		7½	9¾	90
36	$\frac{13}{16}$		8	11¼	110
42	$\frac{7}{8}$		9	13	130
50	$\frac{15}{16}$		9½	15	150
56	1		10½	18	170
60	1$\frac{1}{16}$		11	21½	200
70	1⅛		12	24	240
78	1$\frac{3}{16}$		12½	27	280
86	1¼		13¼	38½	320
96	1$\frac{5}{16}$		14	33	350
108	1⅜		14½	36	400
115	1$\frac{7}{16}$		15½	39½	450
125	1½		16	43	500
	1⅝		17½	50½	700
	1¾		18½	59½	900
	1⅞		20	67½	1009
	2		22 to 24	77	1200

ROTATION, the motion of the different parts of a solid body about an axis, called the *axis of rotation*, being thus distinguished from the progressive motion of a body about some distant point or centre; thus the diurnal motion of the earth is a motion of rotation, but its annual motion one of revolution.

S

SAFETY VALVE. Papin was the first who proposed loaded valves in order to ensure vessels in which steam was formed against bursting by the vapour becoming too elastic. The invention was applied to the boilers of steam engines by captain Savary. Safety valves are of two kinds, external and internal; the first of which opens outwards, and is intended to admit of the escape of steam when it attains an elastic force which may endanger the bursting of the boiler; and the second opens inwards, in order to admit of the ingress of atmospheric air, when by any means a vacuum has been formed in consequence of the condensation of the steam in the boiler. The external safety valve is usually of the conical kind, resting in a seat made in the top of the boiler. It is loaded so as to oppose a certain resistance for each square inch of its surface to the escape of the steam, which load consists of weights laid on its upper surface, and held from sliding off by means of an upright spindle, or the valve is pressed into its seat by means of a lever, drawn down by a weight, and the pressure regulated by placiug the weight at the proper distance from the fulcrum. In case the engine keeper should overload the valve, it is sometimes inclosed in a locked box, the key of which is kept by the proprietor. The escape steam passes through a pipe, led from this box into the furnace chimney. Corrosion causes the valve to stick in its seat, in order to separate it a small rod is attached to its upper surface by which it may be lifted. For enclosed valves Mr Tredgold proposes that the seat should be flat, and the surface of contact small. It has been proposed to make the valve hemispherical instead of conical, and to form the seat so that it may exactly fit the curved surface; the weight is to be hung below. This kind of valve seems peculiarly applicable to marine engine boilers, as the valve would roll without being unseated by the rolling of the vessel. Another safety valve has been employed, which is very certain in its action. It consists of a column of water, of a certain height, contained within a tube rising from the surface of the water in the boiler. The bottom of the tube is bent upwards, and opeus a little below the water line, but above the top of the flues. It rises to the proper height, and a pipe is led from its top to a side pipe, down which the hot water flows that has been expelled up the tube by the force of the steam, and the steam escapes by the top of the side pipo which opens into the atmosphere. Plugs of fusable metal have been proposed. A hole is to be made in the boiler, and filled up with some alloy that will melt before the steam has reached a temperature such that its force would endanger the boiler. 5 parts of bismuth, 3 of tin, and 1 of lead, form an alloy that melts at the boiling point, i. e. 212°; a valve formed of this alloy can therefore be of no use. If 4 parts of tin be used, instead of 3, the alloy will not melt under 246°, a temperature at which steam has an elastic force of 54·68 inches of mercury. Equal parts of bismuth and tin form an alloy which melts at 286°, the elasticity of the steam = 95·48 inches of mercury. With double the quantity of tin the alloy will melt at 336°, when the elastic force = 225 inches. A mixture of 2 parts of lead and 3 of tin forms an alloy that melts at about 334°. These metals alone melt at higher temperatures, i. e. tin, 442°, bismuth, 472°, lead, 612°, zinc, 648°, within which limits the elasticity of the steam ranges between 30 and 60 atmospheres. To find the size of the safety valve, i. e. the diameter of the narrowest part of its seat, supposing the orifice to be circular. Let A be the area in square feet of the bottom surface of the boiler, D = the density of the steam, and S = the diameter of the lowest part of the safety valve, then,

$$\sqrt{\frac{A}{(D-1) \times D \times 7\cdot5}} = S;$$

or for low pressure boilers a very simple rule is, $\sqrt{(A \times 0\cdot22)} = S$. Thus, if a boiler be 20 feet long, and 5 wide, then $20 \times 5 = 100 = A$, and $\sqrt{(100 \times 0\cdot22)} = \sqrt{22} = 4\cdot69$, rather more than four inches, for safety it may be made 5. When the pressure is high the following multipliers should be used instead of 0·22.

Pressure in inches of mercury.	Atmosphere.	Temperature.	Multiplier.
60	2	250	0·0666
90	3	275	0·0344
120	4	293	0·0222
150	5	308	0·0166

Thus, as is the case in locomotive high pressure engines, a force of 4 atmospheres above the atmospheric pressure is used, then 0·0166 for a multiplier. Suppose there be 65 feet of fire surface, then,

$$\sqrt{(65 \times 0\cdot0166)} = 0\cdot739 \text{ nearly.}$$

There ought to be two safety valves, or, if not, one larger than the rule given.

Scalene, or **Scalenous**, is a term used to distinguish any figure or solid, when the line drawn from the vertex to the centre of the base is not perpendicular to the base.

Scholium, a note, annotation, or remark, occasionally made on some passage, proposition, or the like.

Screw, one of the mechanical powers, or rather a combination of two of them, the inclined plane and the lever, principally used in pressing bodies together, or in lifting great weights, which may be conceived to be generated as follows:—Let a solid and a hollow cylinder of equal diameters be taken, and let there be a right-angled plane triangle, whose base is equal to the circumference of the solid cylinder, and applied to the latter in such a manner, that the base may coincide with the circumference of the base of the cylinder, and the hypothenuse will form a spiral thread on its surface. By applying to the cylinder triangles in succession similar and equal to this, in such a manner that their bases may be parallel to its base, the spiral thread may be continued; and supposing the threads to have thickness, or the cylinder to be protuberant where it falls, the external screw will be formed, in which the distances between two contiguous threads, measured in a direction parallel to the axis of the cylinder, is the perpendicular of the triangle. Again, let the triangles be applied in the same manner, to the concave surface of the hollow cylinder, and where the thread falls let a groove be made, and the internal screw will be formed. The two screws being thus exactly adapted to each other, the solid or hollow cylinder, as the case requires, may be moved about the common axis by a lever, or in such other manner as the nature of the case may require. The external screw is sometimes called the *male* screw, and the internal the *female* screw.

When there is an equilibrium upon the screw, then the power is to the weight, as the distance between two contiguous threads, measured in a direction parallel to the axis, is to the circumference of the circle described by the power.

That is, if P represents the power, W the weight to be lifted, or the resistance to be overcome, also d the distance of two contiguous threads, and l the length of the lever; then $P : W = d : 6{\cdot}2832' . l$. calling 6·2832 the circumference of a circle to radius 1.

This results immediately, if we admit the equality in the momenta of the power and weight, for the velocity of the power is to the velocity of the weight, as the circumference of the circle described by the power is to the distance of the threads; but this principle has been justly objected to by some modern writers, and other demonstrations adopted in its stead. The result, however, is the same in all cases; and so far as relates to the theory it is perfectly correct; but in practice, not only the weight, or resistance, but also the friction of the screw, is to be overcome, which in this machine is very great, in some cases equal to the weight itself, being frequently sufficient to sustain this after the power is removed.

Table of the best Proportions between the diameters and pitches of Screws with square threads.

Diameter of screw in inches.	Pitch in inches.	Diameter of screw in inches.	Pitch in inches.	Diameter of screw in inches.	Pitch in inches.
1/4	·062	3	·750	7 1/4	1·812
3/8	·093	3 1/4	·812	7 1/2	1·875
1/2	·125	3 1/2	·875	7 3/4	1·937
5/8	·156	3 3/4	·937	8	2·000
3/4	·187	4	1·000	8 1/4	2·062
7/8	·218	4 1/4	1·062	8 1/2	2·125
1	·250	4 1/2	1·125	8 3/4	2·187
1 1/8	·281	4 3/4	1·187	9	2·250
1 1/4	·312	5	1·250	9 1/4	2·312
1 3/8	·343	5 1/4	1·312	9 1/2	2·375
1 1/2	·375	5 1/2	1·375	9 3/4	2·437
1 5/8	·406	5 3/4	1·437	10	2·500
1 3/4	·437	6	1·500	10 1/4	2·562
1 7/8	·468	6 1/4	1·562	10 1/2	2·625
2	·500	6 1/2	1·625	11	2·750
2 1/4	·562	6 3/4	1·687	11 1/2	2·875
2 1/2	·625	7	1·750	12	3·000
2 3/4	·687				

RULE :—Divide the diameter by 4.

Table of the best proportions between the diameters and pitches of screws, with round top and bottom or V threads.

Diameter in inches.	Pitch in inches.	Diameter in inches.	Pitch in inches.	Diameter in inches.	Pitch in inches.
$\frac{1}{4}$	·030	$1\frac{1}{2}$	·187	$3\frac{1}{2}$	·437
$\frac{3}{8}$	·046	$1\frac{5}{8}$	·203	$3\frac{3}{4}$	·468
$\frac{1}{2}$	·062	$1\frac{3}{4}$	·218	4	·500
$\frac{5}{8}$	·078	$1\frac{7}{8}$	·234	$4\frac{1}{2}$	·562
$\frac{3}{4}$	·093	2	·250	5	·625
$\frac{7}{8}$	·109	$2\frac{1}{4}$	·281	$5\frac{1}{2}$	·687
1	·125	$2\frac{1}{2}$	·312	6	·750
$1\frac{1}{8}$	·140	$2\frac{3}{4}$	·343	$6\frac{1}{2}$	·812
$1\frac{1}{4}$	·156	3	·375	7	·875
$1\frac{3}{8}$	·171	$3\frac{1}{4}$	·406	8	1·000

RULE :—Divide the diameter by 8.

These two Tables of the diameters and pitches of screws will, we hope, be found useful in arranging screw-cutting machines. The depth of the thread is supposed to be half of the pitch. The angle which the thread forms on screws with square threads will be about 7°, and on those with V threads about $3\frac{1}{2}$ degrees. The diameter of a screw to work in the teeth of a wheel should be such that the angle of the threads does not exceed 10 degrees.

SECANT, in Geometry, a line which cuts another, whether right or curved.—In Trigonometry, is a right line drawn from the centre of a circle to meet the upper or farther extremity of any tangent, to the same circle.

SECOND, is the sixtieth part of a minute, both as it relates to the measure of angles or time.

SECTION, in Geometry, denotes a side or surface of one body or figure cut by another, or the place where lines, planes, &c. cut each other.

SECTOR, a portion of a circle comprehended between any two radii and their intercepted arcs.—*Similar Sectors*, are those whose radii include equal angles.

To find the area of a sector. Say as 360° is to the degrees, &c. in the arc of the sector; so is the area of the whole circle to the area of the sector. Or multiply the radius by the length of the arc, and half the product will be the area.

SEGMENT OF A CIRCLE, is a part of a circle bounded by an arc and its chord, and is either greater or less than a semicircle. The following are their most remarkable properties: all angles in the same segment of a circle are equal to each other; if the segment is greater than a semicircle, the angle is less than a right-angle; if less than a semicircle, it is greater than a right-angle.

SEGMENT OF A SPHERE, is any part of a sphere cut off by a plane; the section of which, with the sphere, is always a circle. To find the superficies and solidity of spherical segments. Let d denote the diameter of the sphere, or the chord of half the circumference, and c the chord of half the arc of any segment, also a the altitude or versed sine of the same; then, $3{\cdot}1416 \times d^2$ is the surface of the whole sphere, and $3{\cdot}1416c$, or $3{\cdot}1416 \times a \times d$, the surface of the segment.—To find the solidity. 1. To three times the square of the radius of its base, add the square of its height; multiply the sum by the height, and the product by ·5236. Or, 2dly, From three times the diameter of the sphere, subtract twice the height of the frustrum; multiply the remainder by the square of the height, and the product by ·5236. That is, in symbols, the solid content is either

$$= {\cdot}5236\, a \times (3r^2 + a^2) \text{ or } = {\cdot}5236\, a^2 \times (3\,d - 2\,a);$$

where a is the altitude of the segment, r the radius of its base, and d the diameter of the whole sphere.

SEMICIRCLE, is half a circle, or the area comprehended between a diameter and the semicircumference.

SEXTANT, is the sixth part of a circle, or an arc of 60°.

SHAFT, in mill work, a large axle, in contradistinction to a small axle which is called a spindle; thus we say the shaft of a fly wheel, the spindle of a pinion. Shafts are said to be lying when they are in a horizontal direction; and vertical when they are upright. The gudgeon is the arbour or spindle on which the shaft turns. When the gudgeon is subject to tortion it is called a *journal*. When the shaft is made of wood the short iron axles on which it turns are called *gudgeons*. When a horizontal shaft has a support between the points where the power and the resistance act, or between the first mover and the work to be performed, the cylindrical portion revolving in this support is called the *journal*. The part which supports a shaft, or the part in which the journal revolves, is called a *carriage*, if it forms a part of the framework, but if it does not it is called a *plumber block*. The parts in which the lower gudgeons of upright shafts rest are called *steps* or *bearings*. The parts where the journals of vertical shafts turn and bear against are called *bushes*; and if the shaft be small, or a spindle, they are called *breasts*. Motion requires frequently to be conveyed to a greater distance than can be done by a single shaft, in which case two or more shafts are connected together at the ends by a contrivance called a *coupling*. Couplings are of two kinds. When the ends of the shafts are connected by catches, the coupling is called a *clutch* or *gland*, (see *Gland*,) and when the ends of the shafts are fastened into a box, into which they fit, the coupling is called a *coupling box*.

Shafts are exposed to two different kinds of strain. Thus the shaft of a water wheel has, in the first place, to support the weight of the wheel which will cause a deflection or bending; and, in the second place, the shaft may be exposed to the stress arising from the resistance which the work to be done opposes to the moving power, this stress will cause *tortion*, or a tendency in the shaft to twist round its axis. In almost all cases the danger of injuring the shaft arises from the latter kind of strain, and in cases where both causes combine the latter is that which requires the greatest strength of the shaft, and therefore providing against it will ensure security from the effect of the other. Several scientific engineers have paid attention to this subject, among whom may be more particularly noticed Mr Buchanan and Mr Tredgold. Where the theorems of Mr Tredgold differ from practice they are on the safe side, and we will therefore employ them.

Shafts are distinguished into long and short, and square, solid cylindrical, and hollow cylindrical. Though shafts are most commonly made square, and sometimes feathered, or having a cross section similar to the sign $+$; yet it may be shown that the cylindrical shaft is the best. When the shaft is not cylindrical the flexure will vary in different parts of the revolution, and cause want of uniformity in the motion. Feathered shafts are preferable to square ones, cylindrical shafts to both; and for large shafts hollow cylinders to solid.

Let W be the weight or stress upon the shaft in cwts., l the length of the gudgeon in inches, and d the diameter of the gudgeon, then

$$d = \sqrt[3]{(W \times l)} \times 0{\cdot}42,$$

where the gudgeon is not exposed to much wear, but where it is as in water wheels the number 0·6 should be used instead of 0·42.

Let $S =$ the side of a square shaft, d the diameter of a cylindrical one, r the radius of a wheel at the circumference of which the power is applied, t the thickness of metal in a hollow shaft, and w the weight, also let $p = \frac{d - 2t}{d}$; then for short cast iron shafts, where the length does not exceed one-fourth of r, we have,

(1) $S = \sqrt[3]{\frac{r \times w}{150}}$, for a square shaft.

(2) $d = \sqrt[3]{\frac{r \times w}{125}}$, for a solid cylinder.

(3) $d = \sqrt[3]{\frac{r \times w}{125\,(1 - p^4)}}$, for a hollow cylinder.

The same formulæ will answer for malleable iron, if we use the number 168 in (1), and 140 in (2), and 140 $(1 - p^4)$ in (3), as divisions.

For long shafts of cast iron, supposed to be cylindrical, we have this rule. Multiply the weight in lbs. by r in feet, and divide the product by the cube of the length in feet × 5·2, add 5148 to the quotient, extract the square root and subtract 72, then multiply by the square of the length in feet, and the result will be d in inches.

For ready practical application the following rules may be used. For lateral stress on cast iron shafts, the weight w in lbs. acting in the middle of the length l in feet;

$$\sqrt[3]{\frac{w \times}{500}} = d;$$

for malleable iron multiply the result by 0·935, for oak by 1.83, and for fir by 1·72. For shafts to resist tortion we have, estimating in horses' power, h that the shaft will drive making n turns in a minute.

$$\sqrt[3]{\frac{240 \times h}{n}} = d, \text{ for cast iron,}$$

and for malleable iron multiply the last result by 0·963, for oak by 2·238, and for fir by 2·06. These are shafts for first movers, for second movers multiply the first by 0·8, and for third movers by 0·793.

We take the liberty of inserting the following Tables from Mr Tredgold.

Table of Shafts.

Name.	Horses' power.	Revolutions per minute.	Diameter of journals in inches.	Length of Shaft.	Section in the middle.	Diameters of journals by calculating from a multiplier of 400.	Remarks.
Cast Iron Lying Shaft.	20	20	6	11·	7¾	7,368	Feathered Shafts.
	18	22	5¾	11·	7	6,889	
	16	22	5¼	10·6	7	6,621	
	14	24	5	10	6¾	6,153	
	12	25	5	9·6	6	5,768	
	10	25	4¾	9·	6¼	5,428	
	8	27	4	9·	6	4,904	
	6	28	4¼	8·6	5¾	4,414	
	5	30	3⅞	8·6	5¼	4,061	
	4	32	3¾	8·	4¾	3,484	
	3	34	3¼	8·	4	1,203	Square Shafts.
	2	46	2¾	8·	3	2,802	
	1	40	2	8·	8¼	2,154	
Malleable Iron Lying Shaft.	6	28	3	8·6			
	5	30	3¼	8·			
	4	32	2	8·			
	3	34	2	8·			
	2	36	1¾	8·			
	1	40	1	7·6			

Table of Shafts of Cast Iron to resist lateral Pressure.

Length in feet.	Diameter in inches.	Diameter in inches.	Diameter in inches.	Diameter in inches.	Diameter in inches.
2	·237	·31	·44	·54	·62
4	·67	·88	1·24	1·5	1·76
6	1·23	1·61	2·28	2·79	3·22
8	1·9	2·48	3·51	4 30	4 96
10	2·65	3·47	4·9	6 0	6·93
12	3·48	4·55	6·44	7·89	9·10
14	4·38	5·74	8·12	9·94	11·48
16	5·36	7·01	9·92	12·15	14·02
	Own weight only.	Stress equal to its own weight, or $n = 1$.	Stress double its own weight, or $n = 2$.	Stress three times its own weight, or $n = 3$.	Stress four times its own weight, or $n = 4$.

Table of Hollow Shafts of Cast Iron to resist lateral Stress.

Length.	Exterior diameter in inch.	Interior diameter in inch.	Exterior diameter in inch.	Interior diameter in inch.	Exterior diameter in inch.	Interior diameter in inch.	Exterior diameter in inch.	Interior diameter in inch.
4	1·5	0·9	1·9	1·1	2·2	1·3	2·4	1·4
6	2·8	1·6	3·5	2·1	4·0	2·4	4·5	2·7
8	4 3	2·5	5·3	3·1	6·1	3·6	6·9	4·1
10	6·0	3·6	7·4	4·4	8·5	5·	9·5	5·7
12	7·9	4·7	9·8	5·8	11·2	6·7	12·6	7·5
14	10·0	6·0	12·3	7·3	14·2	8·5	15·9	9·5
16	12·2	7·3	15·0	9·0	17·3	10·3	19·4	11·6
	Stress four times the weight of the shaft.		Stress six times the weight of the shaft.		Stress eight times the weight of the shaft.		Stress ten times the weight of the shaft.	

Table of Cylindrical Shafts of Cast Iron to resist Torsion.

Diameter of shafts in inch.	Revolutions of the Shafts in a minute.					
	5 rev.	10 rev.	20 rev.	30 rev.	40 rev.	50 rev.
	Horses' power.	Horses' power.	Horses' power.	Horses' power.	Horses' power.	Horses' power.
2	0·17	0·33	0·66	0·99	1·33	1·66
3	0·56	1·13	2·25	3·37	4·5	5·62
4	1·33	2·66	5·33	7·99	10·66	13·33
5	2·6	5·2	10·4	15·6	20·8	26 0
6	4·5	9·0	18·00	27·0	36·0	45·0
7	7·15	14 3	28·6	42·9	57·2	71·5
8	10 66	21·33	42 66	64·0	85·0	106·6
10	20·83	41·66	83·33	125·0	166·0	208·3
12	36·00	72·00	144·0	216·0	288·0	360·0
14	63·83	127·66	255·33	383·0	510·0	638·3
16	85·33	170·66	341·33	512·0	682·0	853·3

SIDE, a term used for any line which forms one of the boundaries of a right-lined figure, as the side of a triangle, square, &c. Similar figures are to each other as the squares of their like sides.

SIMILAR PLANE FIGURES, in Geometry, are such as have the angles of the one respectively equal to the angles of the other, and the sides about those angles proportional; and such figures are to each other as the squares of their like sides.—*Similar Sectors*, and *Segments of Circles*, are such as are contained under arcs, having the same measures, or being the same part or parts of their respective circles.—*Similar solids*, are those which are contained under the same number of similar planes alike placed, or such as have their solids, angles, equal each to each; and all such bodies are to each other as the cubes of their like sides, or like linear dimensions.

SLIDING, is the motion of a body along a plane, when the same face or surface of the moving body keeps in contact with the surface of the plane.

SOLID, in Geometry, is a body of three dimensions, having length, breadth, and thickness: being thus distinguished from a surface which has but two dimensions, and from a line which has but one.—In Physics, is that whose parts adhere to each other with a greater or less force; being thus distinguished from a fluid whose parts yield to the least external pressure.

Regular Solids, are those bounded by equal and regular plane figures.

Solid Angle, is that formed by three or more plane angles meeting in a point, like an angle of a die, or the point of a diamond, &c. Or, more generally, a solid angle is the angular space included between several plane surfaces.

SOLIDITY, in Geometry, denotes the quantity of space contained or occupied by a solid body, called also its solid content, being estimated by the number of solid or cubic inches, feet, yards, &c. which it contains.

SPHERE, or GLOBE, in Geometry, is a solid contained under one uniform surface, every point of which is equally distant from a point within, called the centre of the sphere, and may be conceived to be generated by the revolution of a semi-circle about its diameter, which remains fixed, and which is hence called the axis of the sphere.

A sphere is equal to two-thirds of its circumscribing cylinder; or it is equal to a pyramid or cone, whose base is equal to the whole surface of the sphere, and its altitude equal to half the diameter. All spheres are similar figures, and are to each other as the cubes of their diameters or circumferences. The surface of a sphere is equal to the area of four of its great circles, or to the curve surface of its circumscribing cylinder; and, therefore, the surface of different spheres are to each other as the squares of their diameters. The surface of a sphere is equal to the area of a circle, whose radius is equal to the diameter of the sphere; and the curve surface of any segment of a sphere is equal to a circle, having for its radius the chord of half the arc of that segment. The surface of any segment or zone of a sphere is equal to the curve surface of a corresponding portion of the circumscribing cylinder; that is, any two planes passing through the sphere and its circumscribing cylinder parallel to the base of the latter, the surface of the segment of the sphere and cylinder thus cut off will be equal to each other. Most of these properties we owe to Archimedes, being given by that celebrated geometrician in his treatise on the sphere and cylinder. Let d represent the diameter, and c the circumference of a sphere; also s the surface, and S the solidity of the same, then

1. $s = c\, d = 3{\cdot}14159\, d^2 = {\cdot}3183\, c^2$
2. $s = {}_6\, s\, d = {\cdot}5236\, d^3 = {\cdot}01688\, c^3$.

Spherical Segments, the same notation remaining, and r being put for the radius of the base, and h for the height of the segment

3. surface $= 3{\cdot}14159\, d\, h$
4. solidity $= {\cdot}5236\, h\, (3\, r^2 + h^2)$, or,
5. solidity $= {\cdot}5236\, h\, (3\, d - 2\, h)$.

Spherical Zones. Put R and r for the radii of the ends, and h for the height, then

6. surface $= 3{\cdot}14159\, d\, h$
7. solidity $= 1{\cdot}5708\, (R^2 + r^2 + \frac{1}{3} h^2)$.

SPHEROID, a solid body resembling a sphere, which is supposed to be generated by the revolution of any oval figure about an axis.

SPINDLE, in Geometry, a solid generated by the revolution of a curve about its base or double ordinate, and is farther denominated elliptic, parabolic, hyperbolic, &c. according to the figure from which it is generated. See *Shaft*.

SPIRAL, in Geometry, a curve line of the circular kind, which in its progress always recedes more and more from its centre. There are various kinds of spirals, according to the law by which the point recedes from the centre. See *Heart Wheel*.

SQUARE, is a quadrilateral figure, having its four sides equal to each other, and its angles all right-angles; the area of which is found by multiplying its side by itself.

STEAM. When water, exposed to the pressure of the atmosphere, is heated to the temperature of 212°, globules of steam, composed of heat and water in a state of combination, are formed at tho bottom of the vessel, and rising through the fluid, may be collected at its surface. In its perfect state it is transparent, and consequently invisible, but when it has been deprived of a part of its heat by coming in contact with cold air, it becomes of a cloudy appearance, as when it issues from a tea-kettle. By increasing the heat, the temperature of the water never rises above 212°, nor that of the steam which is generated; the only effect being a more copious production. If the water is confined in a strong copper vessel, both it and the steam which is produced may be brought to any temperature.

Steam is highly elastic; but when separated from the fluid from which it is generated, it does not possess a greater elastic force than the same quantity of air. If, for instance, a copper vessel is filled with steam only, at 212°, it may be brought even to the temperature of red heat, without any danger of bursting; but if water is also in the vessel, each additional quantity of heat causes a fresh quantity of steam to rise, which adds its elastic force to that of the steam already generated, till the constantly accumulating force bursts the vessel in pieces. The latent heat of steam, according to the experiments of different philosophers, is given in the following table:

Rumford	1021°	Desprete	956°
Thomson	1016	Watt	950 or 960
Lavoisier	1000	Southern	955
Clement	990	Black	800

The mean of these results is 950°, agreeing with the measure obtained by Mr Watt. The estimate of Lavoisier cannot be far from the truth, and affords a most convenient number for calculation, i. e. 1000.

Let us suppose that steam of the temperature of 212° contains 950° of heat, which is not detected by the thermometer, while it retains the gaseous state, its real quantity of heat will be $950^{\circ} + 212^{\circ} = 1162^{\circ}$; consequently, if we mix a quantity of steam with $5\frac{1}{2}$ times its weight of water, at 32°, the temperature of the water will rise nearly to the temperature of ebullition, because $5\frac{1}{2} \times 32^{\circ} + 32^{\circ} = 208^{\circ}$. Hence the great utility of steam not only in manufactures where great quantities of hot water are required, but also for heating large buildings, and for drying whatever is liable to combustion.

The elasticity of steam, arising no doubt, from the great quantity of heat which it contains, is very great, and from its extensive application as an impelling power, it has been investigated with considerable attention.

Mr Watt was the first philosopher who made any accurate experiments on the elasticity of steam. The following is a table of his results.

Table of the Elasticities of Steam for Heats below and above the Boiling Point.

Heats.	Elasticities.	Heats.	Elasticities.	Heats.	Elasticities.	Heats.	Elasticities.
Deg.	Inches.	Degrees.	Inches.	Degrees.	Inches.	Degrees.	Inches.
55	0·15	175	12·88	223·5	36	248·5	56
74	0·65	177·5	13·81	225	37	250·5	58
81	0·80	180	14·73	226·5	38	252·5	60
95	1·30	182·5	15·66	228	39	255	62
104	1·75	185	16·58	229·5	40	257	64
118	2·68	187	17·51	231	41	259	66
128	3·60	189	18·45	232·5	42	261	68
135	4·53	191	19·38	234	43	262·5	70
142	5·46	193·5	20·34	235	44	264·5	72
148	6·40	196·5	21·26	236·5	45	266·5	74
153	7·325	213	30	237·5	46	468	76
157	8·25	215	31	238·5	47	269·5	78
161	9·18	217	32	240	49	271	80
164	10·10	219	33	242·5	50	272·5	82
167	11·07	220·5	34	244·5	52		
172	11·95	222	35	247	54		

Mr Achard of the Royal Academy of Berlin, published, in the Memoirs of 1782, a series of experiments on the elasticity of steam, from the temperature of 32° to that of 212°. The following are a few of the results, which are here compared with those of Mr Watt and Mr Robison:

Temperature.	Achard. Elasticities. Inches.	Watt. Elasticities. Inches.	Robison. Elasticities. Inches.
168°	11·05	11·24	10·60
189	18·5	18·45	17·47
209	28·1	27·88	26·05

The following results were obtained by Dr Robison.

Temperatures.	Elasticities.	Temperatures.	Elasticities.
32°	0·0	160	8·65
40	0·1	170	11·05
50	0·2	180	14·05
60	0·35	190	17·85
70	0·55	200	22·62
80	0·82	210	28·65
90	1·18	220	35·8
100	1·6	230	44·5
110	2·25	240	54·9
120	3·0	250	66·8
130	3·95	260	80·3
140	5·15	270	94·1
150	6·72	280	105·9

The next experiments on the elasticity of steam were made by Bettancourt; the following are some of the results.

Temp. Fah.	Elasticities. Inches.	Temp. Fah.	Elasticities. Inches.	Temp. Fah.	Elasticities. Inches.	Temp. Fah.	Elasticities. Inches.
0		104	1·86	167	10·27	230	44·38
41	0·0796	113	2·43	176	12·80	239	53·77
50	0·1856	122	3·17	185	15·88	248	64·45
59	0·3133	131	4·05	194	19·66	257	76·32
68	0·5093	140	5·16	203	24·26	266	88·81
77	0·7326	149	6·52	212	29·87	275	100·07
86	1·02	158	8·21	221	36·53	279½	104·91
95	1·39						

Mr Bettancourt made similar experiments on the elasticity of the vapour of spirit of wine, and he found it at all temperatures equal to 2⅓ times that of steam.

The next set of experiments on steam were made by Mr Dalton about 1800, with a degree of accuracy and care, which gives them a high value.

Mr Dalton's Table of the Force of Vapour from Water at every Temperature, from that of the congelation of Mercury, or 40 *degrees below Zero, to* 160 *degrees.*

Temperature. Fah.	Elastic force in inches of mercury.	Temperature. Fah.	Elastic force in inches of mercury.	Temperature. Fah.	Elastic force in inches of mercury.	Temperature. Fah.	Elastic force in inches of mercury.	Temperature. Fah.	Elastic force in inches of mercury.
40	0·013	29	0·180	62	0·560	95	1·58	128	4·11
30	0·020	30	0·186	63	0·578	96	1·63	129	4·22
20	0·030	31	0·193	64	0·597	97	1·68	130	4·34
10	0·043	32	0·200	65	0·616	98	1·74	131	4·57
0	0·064	33	0·207	66	0·635	99	1·80	132	4·60
1	0·066	34	0·214	67	0·655	100	1·86	133	4·73
2	0·068	35	0·221	68	0·676	101	1·92	134	4·86
3	0·071	36	0·229	69	0·698	102	1·98	135	5·00
4	0·074	37	0·237	70	0·721	103	2·04	136	5·14
5	0·076	38	0·247	71	0·745	104	2·11	137	5·29
6	0·079	39	0·254	72	0·770	105	2·18	138	5·44
7	0·082	40	0·263	73	0·796	106	2·25	139	5·59
8	0·085	41	0·273	74	0·823	107	2·32	140	5·74
9	0·087	42	0·283	75	0·851	108	2·39	141	5·90
10	0·090	43	0·294	76	0·880	109	2·46	142	6·05
11	0·093	44	0·305	77	0·910	110	2·53	143	6·21
12	0·096	45	0·316	78	0·940	111	2·60	144	6·37
13	0·100	46	0·328	79	0·971	112	2·68	145	6·53
14	0·104	47	0·339	80	1·00	113	2·76	146	6·70
15	0·108	48	0·351	81	1·04	114	2·84	147	6·87
16	0·112	49	0·363	82	1·07	115	2·92	148	7·05
17	0·116	50	0·375	83	1·10	116	3·00	149	7·23
18	0·120	51	0·388	84	1·14	117	3·08	150	7·42
19	0·124	52	0·401	85	1·17	118	3·16	151	7·61
20	0·129	53	0·415	86	1·21	119	3·25	152	7·81
21	0·134	54	0·429	87	1·24	120	3·33	153	8·01
22	0·139	55	0·443	88	1·28	121	3·42	154	8·20
23	0·144	56	0·458	89	1·32	122	3·50	155	8·40
24	0·150	57	0·474	90	1·36	123	3·59	156	8·60
25	0·156	58	0·490	91	1·40	124	3·69	157	8·81
26	0·162	59	0·507	92	1·44	125	3·79	158	9·02
27	0·168	60	0·524	93	1·48	126	3·89	159	9·24
28	0·174	61	0·542	94	1·53	127	4·00		

Dissatisfied with his own experiments, in the results of which he observed irregularities which he could not explain; Mr Watt, in the year 1796, requested Mr Southern to try them over again, and, in fulfilling his requests he was assisted by Mr William Creighton. The results of these experiments are as follows :—

Temperature. Fah.	Elastic force in inches of mercury.	Temperature. Fah.	Elastic force in inches of mercury.
32	0·180	132	4·71
42	0·230	142	6·10
52	0·350	152	7·90
62	0 520	162	10·05
72	0·730	172	12·72
82	1·02	182	16·01
92	1·42	212	30·00
102	1·96	250	60·00
112	2·66	293	120·00
122	3 58	343·6	240·00

The next experiments on the elasticity of steam were those of Dr Ure, which were made at temperatures from 24° to 312°.

Table of Dr Ure's Experiments on the Elastic Force of Steam from 24° to 312°.

Temp.	Elastic force	Temp.	Elastic force	Temp.	Elastic force	Temp.	Elastic force
24°	0.170	155°	8·500	242°	53·600	281·8	104·400
32	0·200	160	9·600	245	56·340	283·8	107·700
40	0·250	165	10·800	245·8	57·100	285·2	112·200
50	0·360	170	12·050	248·5	60·400	287·2	114·800
55	0·416	175	13·550	250	61·900	289	118·200
60	0·516	180	15·160	251·6	63·500	290	120·150
65	0·630	185	16·900	254·5	66·700	282·3	123·108
70	0·726	190	19·000	255	67·250	294	126·700
75	0·860	195	21·100	257·5	69·800	295·6	130·400
80	1·010	200	23·600	260	72·300	295	129·000
85	1·170	205	25·900	260·4	72·800	297·1	133·900
90	1·360	210	28·880	262·8	75·900	298·8	137·400
95	1·640	212	30·000	264·9	77·900	300	139·700
100	1·860	216·6	33·400	265	78·040	300·6	140·900
105	2·100	220	35·540	267	81·900	302	144·300
110	2·456	221·6	36·700	269	84·900	303·8	147·700
115	2·820	225	39·110	270	86·300	305	150·560
120	3·300	226·3	40·100	271·2	88·000	306·8	154·400
125	3·830	230	43·100	273·7	91·200	308	157·700
130	4·366	230·5	43·500	275	93·480	310	161·300
135	5·070	234·5	46·800	275·7	94·600	311·4	164·800
140	5·770	235	47·220	277·9	97·800	312	167·000
145	6·600	238·5	50·300	279·5	101·600	312	165·5
150	7·530	240	51·700	280	101·900		

The next experiments on the elasticity of steam, were those of Mr Philip Taylor, at temperatures from 212° to 320°. The results which he obtained, are given in the following table.

Mr Philip Taylor's Experiments on the Elasticity of Steam, from 212° to 320° Fahrenheit.

Temp.	Elasticity in inches.	Temp.	Elasticity in inches.	Temp.	Elasticity in inches.	Temp.	Elasticity in inches.
214°	31·00	242°	51·75	269°	81·14	295°	124·15
216	32·30	243	52·62	270	82·50	296	126·05
217	33·00	244	53·5	271	83·9	297	128·06
218	33·70	245	54·4	272	85·45	298	129·8
219	34·2	246	55·3	273	86 95	299	131·62
220	35	247	56·25	274	88·50	300	133·75
221	35·5	248	57·2	275	90·00	301	135·60
222	36·2	249	58·2	276	91·55	302	137·55
223	37·00	250	59·12	277	93·15	303	139·75
224	37·5	251	60·1	278	94·70	304	141·90
225	38	252	61·12	279	96·26	305	144·05
226	38·8	253	62·15	280	97·75	306	146·15
227	39·5	254	63·20	281	99·25	307	148·30
228	40·2	255	64·4	282	100·70	308	150·65
229	40·85	256	65·5	283	102·20	309	153·70
230	41·55	257	66·6	284	103·8	310	155·00
231	42·25	258	67·75	285	105·6	311	157·20
232	43	259	69·00	286	107·3	312	159·45
233	43·75	260	70·12	287	109·0	313	161·75
234	44·6	261	71·25	288	110·8	314	164·20
235	45·5	262	72·45	289	112·65	315	166·70
236	46·4	263	73·52	290	114·50	316	169·15
237	47·3	264	74·80	291	116·40	317	171·70
238	48·2	265	76·00	292	118·30	318	174·30
239	49·1	266	77·25	293	120·25	319	176·80
240	50·0	267	78·50	294	122·20	320	179·40
241	50·9	268	79·8				

The most recent experiments on the elastic force of steam are those by a committee of the Franklin Institute, appointed by the Treasury directors of the United States. The object of the committee was to enquire into the causes of the explosion of steam boilers, to investigate which they were requested to make experiments on the properties of steam, the expense of which was defrayed out of the treasury of the United States. The appointment of this committee is highly honourable to the government of the North American republic, and has been rewarded by results of great advantage to science, and highly creditable to the gentlemen who conducted the experiments. We give here an extract from the report, as published in the Journal of the Franklin Institute.

The committee, determined to put the apparatus which was necessary for other experiments, to the best use possible, in determining the elastic force of steam, at different temperatures; and accordingly great pains were bestowed upon the graduation of the guage, the regulation of the temperature of its parts, &c., the comparison of the thermometers, the maintenance of the scales at about the same temperature, &c. The small size of the boiler, and the various openings required to be made in it for the experiments which were the immediate objects of the committee, were unfavourable to the attainment of considerable pressures, but the discrepancies, even at working pressures, of the different tables of the elastic force of steam, made it important to push those trials as far as could be done without material changes. They succeeded without much difficulty in reaching ten atmospheres, which is but one atmosphere less than the reputed working pressure of our high-pressure engines, and as the experiments on the safety valves have rendered probable, is very near the true working pressure.

A series of results obtained in the trials of the fusible plates, is given below in the tabular form.

The table contains the temperature, observed by the thermometer in the water, corrected for the error of the graduation; the temperature of the scale of the thermometer, with a view to show that it was not allowed to vary too considerably; the observed height of the mercury in the gauge, reduced to its mean height; the temperature of the air in the gauge; its volume at the observed temperature; the volume reduced to 48°, the temperature of graduation of the gauge at which the column of mercury, equivalent to an atmosphere, is very nearly 30 inches; the elasticity of the compressed air, in inches of mercury; the correction in the height of the column of mercury, for the depression produced in the cistern below; the height thus corrected; the height after subtracting the sensibly constant number for the column of water between the level of the steam-pipe from the boiler and the cistern of the gauge; the total elasticity in inches of mercury; the elasticity in atmospheres. The first number in the table is merely introduced for the convenience of presenting certain data required for subsequent calculation, it gives the height of the mercury in the gauge before beginning the observations, after correcting for the height of the barometer.

TABLE I.— *Of the Elastic force of Steam at different Temperatures.*

Temperature of steam.	Temperature of scale of thermometer.	Height of air gauge.	Temperature of air in gauge.	Volume of air at observed temperature.	Volume of air at 48° Fah.	Elasticity of air in inches of mercury.	·01 height of gauge.	Height + ·01 height.	Height + ·01 height — ·129 inches.	Total elasticity in inches of mercury.	Elastic force in atmospheres of 30 inches.
Fah.°	Fah.°	Inch.	Fa.°	Vols.	Vols.	Inches.	inch	Inches.	Inches.	Inches.	Atmos.
		3·99	62	8·33	8·101	27·26	·04	4·03	2·74	30·00	1·00
$262\frac{1}{4}$	63	15·04	74	3·93	3·737	59·09	15	15·19	13·90	72·99	2·43
$268\frac{1}{2}$	71	16·34	—	3·43	3·259	67·76	·16	16·50	15·21	82·97	2·76
$275\frac{1}{2}$	—	17·34	—	3·05	2·898	76·20	·17	17·51	16·22	92·42	3·08
$286\frac{1}{2}$	—	18·91	—	2·44	2·319	95·23	·19	19·13	17·84	113·07	3·77
$296\frac{1}{2}$	—	19·94	—	2·05	1·948	113·36	·20	20·14	18·65	132·21	4·41
$298\frac{1}{2}$	73	20·11	—	1·99	1·891	116·76	·20	20·31	19·02	135·80	4·53
302	—	20·44	—	1·86	1·767	124·98	·20	20·64	19·35	144·33	4·81
$305\frac{1}{2}$	76	20·79	75	1·73	1·641	134·57	·21	21·00	19·71	154·28	5·14
$313\frac{1}{2}$	79	21·39	—	1·50	1·422	155·30	·21	21·60	20·31	175·61	5·85
$317\frac{3}{4}$	80	21·64	—	1·405	1·332	165·79	·22	21·86	20·57	186·36	6·21
$320\frac{1}{4}$	—	21·79	76	1·347	1·275	173·20	·22	22·01	20·72	193·92	6.46
$327\frac{3}{4}$	—	22·24	—	1·176	1·113	198·41	·22	22·02	20·73	219·14	7·30
$333\frac{3}{4}$	—	22·69	—	1·004	0·950	232·46	·23	22·92	21·63	254·09	8·47

A curve traced to represent these observations, the ordinates representing the pressures, and the abscissæ the temperatures, is quite regular, until the temperature corresponding to eight atmospheres is attained, when it rises abruptly. This fact was explained by examining the gauge; it was found that the cement used in attaching the glass tube to its ferule had become softened, and had permitted the tube to rise. This defect was remedied and its recurrence prevented. It was then determined to repeat the entire series of observations, and to carry them as high as could be done, with reasonable convenience, aiming particularly to embrace the range of working pressures of the American engines.

The results are contained in the following table, in which the observed data, and calculated numbers, are arranged as in the last table. This table extends to 9·91 atmospheres, and to the temperature of 352° Fah.

Care was taken that the elasticities were increased not too rapidly, and the last numbers obtained, were verified by keeping the temperature sensibly constant for a considerable time.

There is one observation, namely, that at 329¾°, which is certainly recorded erroneously; but omitting this one, the rest which are given present a very tolerable regularity in the curve traced to represent them.

TABLE II.—*Of the Elastic Force of Steam at different Temperatures.*

Temperature of steam.	Temperature of scale of thermometer.	Height of mercury in air gauge.	Temperature of air in gauge.	Volume of air at observed temperature.	Volume of air at 48° Fah.	Elasticity of air in inches of mercury.	·01 height of gauge.	Height + ·01 height.	Height + ·01 height − 1·29 inches.	Total elasticity in inches of mercury.	Elastic force in atmospheres of 30 inches.
Fah.°	Fah.°	Inch.	Fa.°	Vols.	Vols.	Inches.	inch	Inches.	Inches.	Inches	Atmos.
		5·56	48	7·695	7·695	25·67	·06	5·84	4·55	30·00	1·00
248¼	54	14·04	53	4·32	4·277	46·19	·14	14·18	12·89	59·08	1·97
269½	—	17·34	52	3·05	3·026	65·29	·17	17·51	16·22	81·51	2·72
284½	—	19·64	—	2·17	2·152	91·76	·19	19·83	18·54	110·30	3·68
289½	—	20·06	—	1·99	1·974	100·05	·20	20·26	18·97	119·02	3·97
294½	—	20·56	53	1·82	1·802	109·63	·21	20·77	19·48	129·11	4·30
299½	—	21·04	54	1·63	1·611	122·66	·21	21·25	19·96	142·62	4·75
304½	—	21·34	54½	1·52	1·500	131·66	·21	21·55	20·26	151·92	5·06
310½	—	21·64	—	1·405	1·382	142·94	·22	21·86	20·57	163·51	5·45
314¼	58	22·04	55	1·25	1·233	160·26	·22	22·26	20·97	181·23	6·04
319¼	—	22·34	55½	1·14	1·124	175·86	·22	22·56	21·27	197·13	6·57
329¾	—	22·84	56	0·95	0·937	210·84	·23	23·07	21·78	232·62	7·75
334½	66	22·94	57	0·92	0·904	213·60	·23	23·17	21·88	240·48	8·02
338½	—	23·04	57½	0·887	0·870	226·92	·23	23·29	22·00	248·92	8·30
345	—	23·24	—	0·82	0·805	245·44	·23	23·47	22·18	267·62	8·92
348	—	23·34	58	0·787	0.771	256·05	·23	23·57	22·28	278·33	9·28
350	—	23·44	—	0·752	0·737	267·97	·23	23·67	22·38	290·35	9·68
352	—	23·50	—	0·733	0·719	274·92	·23	23·73	22·44	297·36	9·91
356	—	23·28	62	0·807	0·785	251·78	·23	23·51	22·22	274·00	9·13

For the sake of adding to the force of these results the scattered observations of temperatures and pressures incidentally made during the other experiments of the committee, are brought together in the annexed table.

A column is added to the table, to show the number of observations employed in obtaining the results.

This table enables us to go as low as 1·43 atmospheres, and is strikingly accordant with the two others as far as they extend in common.

TABLE III.—*Of the Elastic Force of Steam at different Temperatures.*

Temperature of steam.	Temperature of scale of thermometer.	Height of mercury in air gauge.	Temperature of air in gauge.	Volume of air at observed temperature.	Volume of air at 48° Fah.	Elasticity of air in inches of mercury.	·01 height of gauge.	Height of gauge + ·01 height.	Height + ·01 height — 1·29 inches.	Elasticity of steam in inches of mercury.	Elastic force in atmospheres.	No. of observations.
Fah.°	Fah.°	Inch.	Fa.°	Vols.	Vols.	Inches.	inch	Inches.	Inches.	Inches.	Atmos.	
		3 91	59	8·35	8·169	27·34	·04	3·95	2·66	30·00	1·00	
234	54	8·80	55	6·38	6·301	35·45	·09	8·89	7·60	43·05	1·43	1
239½	62	9·94	61	5·94	5·788	38·59	·10	10·04	8·75	47·34	1·58	1
245¾	68	11·16	63	5·46	5·300	42·14	·11	11·27	9·98	52·12	1·74	5
250¼	70	12·54	63	4·92	4·776	46·77	·12	12·66	11·37	58·14	1·94	4
256¼	73	13·88	64	4·38	4·243	52·64	·14	14·02	12·73	65·37	2·18	5
262¾	77	15·14	64	3·89	3·768	59·27	·15	15·99	14·00	73 27	2·44	2
271	70	16·34	65	3·43	3·316	67·35	·16	16·50	15·21	82·56	2·75	4
278	75	17·44	70	3·01	2·882	77·49	·17	17·61	16·32	93·81	3·13	3
288¼	75	18·74	68	2·50	2·403	92·94	·19	18·03	17 64	110·58	3·69	3
291	76	19·14	65	2·36	2·282	97·88	·19	19·34	18·04	115·92	3·86	2
292½	65	19·44	63	2·25	2·184	102·26	·19	19·93	18·34	120·60	4·02	3
300	73	20·12	65	1·98	1·914	117·33	·20	20·32	19·03	136·36	4·55	4
303½	74	20·54	66	1·82	1·756	127·27	·20	20·74	19·45	146·72	4·89	1

A curve which would be traced by the following table, and which may be considered to represent the mean of the foregoing, would differ little more than one-tenth of an atmosphere in any part of the range, from the observations, omitting one noticed in the first, and another noticed in the second table; the pressures in general differing less than one-tenth of an atmosphere from the observed pressures.

Table of the Elastic Force of Steam, from One to Ten Atmospheres.

Pressure.	Observed temperature.	Pressure.	Observed temperature.	Pressure.	Observed temperature.	Pressure.	Observed temperature.	Pressure.	Observed temperature.
Atmos.	Fah.°	Atmos.	Fah.°	Atmos.	Fah.°	Atmos.	Fah.°	Atmos.	Fah.°
1	212	3	275	5	304½	7	326	9	345
1½	235	3½	284	5½	310	7½	331	9½	349
2	250	4	291½	6	315½	8	336	10	352½
2½	264	4½	298½	6½	321	8½	340½		

To compare our results with those given by the Committee of the French Academy, we have traced, on paper, a curve, from the above table, and another from those of the thirty observations, selected by the Committee of the Academy, from their experiments, below ten atmospheres. The curve of our observations, passes at low pressures nearer to a line AB* than that of the French experiments, and after coinciding at the medium pressures of the table, crosses the latter, different at ten atmospheres 5 degrees, or at 352½ degrees ·65 of an atmosphere.

The difference here noticed is too considerable to be admitted, as within the limits of errors in the apparatus or in observation. Having an authority of so much weight against them, the Committee have been driven to examine their results very closely. The care employed in the graduation of the gauge seems to exclude the idea of error from it; the upper portion of the scale was divided to ·05 of an inch, and could easily be read to half of that distance, making about ·1 of an atmosphere at the highest pressure attained. A specific correction for capillarity was ascertained and employed. In one point of manipulation, namely, the method employed to dry the air, the Committee differed from what was usual, and though they think there is reason to confide in that method, they have examined what effect would be produced if the air were saturated with moisture. Recent experiments, on the passage of gases, out and into vessels placed over mercury, and observations connected with them, warrant, moreover, a suspicion that dry air standing in a glass vessel over mercury, the surface of which is covered with water, may become impregnated with vapour. The effect of such a source of error they have calculated in the highest and lowest results of Table No. II., and find it to be as follows :—

For 248¼° the tension of the vapour is 1·96 instead of 1·97, and
... 352 .... 9·78 .... 9·91.

Differing from the numbers given in table No. II, by ·01 and ·13 of an atmosphere.

This supposition is thus shown to be inadequate to explain the discordance, and must, in fact, be deemed, to a certain extent, gratuitous.

The Committee have next compared the results furnished by the safety valves graduated independently of the gauge, and these, as has already been shown, gave calculated pressures 4 per cent. and 10 per cent. higher than the pressure indicated by the gauge. From these

* The pressures are understood to be laid down on a line AB, which is horizontal, and the temperatures on a line which is perpendicular to it, and the curve is formed by the intersections of the two sets of lines, drawn from the respective temperatures and pressures.

independent experimental data we have, then, an evidence that our results are, probably, not too high.

The question of the elastic force of steam has been examined by many experimenters, and with very various results. The Committee propose to show the state of knowledge on the subject by comparing the principal series of experiments referring to temperatures above 212°, with their own, which are now under examination. In the first table, below, they have compared their results with those of Robison, of Ure, and of Taylor.

The first two experimenters named used an open mercury gauge in their experiments, and the thermometers were exposed to the pressure of the steam.

This latter circumstance would tend to render the observed temperature slightly too high, or the observed pressure, relatively to the temperature, too low, as far as it produced any effect.

Elastic force of Steam in Atmospheres.							
Temperature of steam in degrees Fah.	Com. of Franklin Institute.	Professor Robison.	Difference.	Dr Ure.	Difference.	Mr Taylor.	Difference.
212°	1·00	1·00	·00	1·00	·00	1·00	·00
240	1·64	1·83	—·19	1·72	—·08		
250	2·00	2·23	—·23	2·06	—·06	1·97	+·03
260	2·35	2·68	—·33	2·41	—·06	2·34	+·01
270	2·74	3·14	—·40	2·88	—·14	2·75	—·01
280	3·25	3·53	—·28	3·40	—·15	3·26	—·01
290	3·89			4·00	—·11	3·82	+·07
300	4·60			4·66	—·06	4·46	+·14
310	5·50			5·38	+·12		
320	6·40					5·98	+·42

The experiments of Watt are not referred to, as he states himself that he has doubts of their accuracy, and defers to the results of Mr Southern, which will be given presently.

The results of the Committee as to pressure corresponding to temperature, all fall below those of professor Robison, the extremes being ·14 and ·40 of an atmosphere, they approach nearer to those of Dr Ure, differing in the extremes —·06 and + ·12 of an atmosphere. They agree even more nearly with the experiments of Mr Taylor, tending, generally, to gain upon them; thus at 260° the difference is ·01 of an atmosphere, and at 320° is ·42. The temperature corresponding to six atmospheres, in the table of the Committee, is 315½°, to the same

(5·98) in that of Mr Taylor, 320°, and to the same in that of the French Commission, 320·4, the latter two agreeing very closely.

In the following table are given a comparison of the experiments of the Committee, with those of Mr Southern, professor Arzberger, of Vienna, and the Commission of the Academy of Paris. The pressures were obtained in the experiments of Mr Southern by a piston-valve, which is stated to have been checked, in part, by a mercury gauge; in the experiments of professor Arzberger by a spherical valve of steel; and in those of the French Commission by a closed gauge, containing air. The numbers for these last-named results are those deduced from the empyrical formula adopted as representing, most closely, the experiments.

Pressure in atmospheres.	TEMPERATURES.						
	By experiments of Committee of Franklin Institute.	By Mr Southern.	Difference.	By Professor Arzberger.	Difference.	By Commission of French Academy.	Difference.
	Fah.°	Fah.°	Fah.°	Fah.°	Fah.°	Fah.°	Fah.°
1	212						
2	250	250·3	—0·3	249	+1·0	250·5	—0·5
3	275			274	+1·0	275·2	—0·2
4	291½	293·4	+1·9			293·7	—2·2
5	304½					308·8	—4·3
5·87	314¼			322	—7·7	318·8	—4·5
6	315½					320·4	—4·9
7	326					331·7	—5·7
8	336	343·6	—5·6			342·0	—6·0
9	345					350·8	—5·8
10	352½					358·9	—6·4
10·83				372		362·8	

From these comparisons it appears, that for given temperatures the pressures determined by the Committee are lower than those found by professor Robison, between 1 and 3½ atmospheres; lower than those of Dr Ure, from 1 to 5½ atmospheres, except at the highest pressure, differing, however, but little from them; nearly the same from 1 to 2¾ atmospheres with those of Mr Taylor, and higher from 2¾ to 6 atmospheres; higher than those of Mr Southern; much higher than those of professor Arzberger; higher than those of the French Commission.

The temperature given by the Committee for the pressure of 8 atmospheres differs about 3° from that inferred from the temperature given by Christian for 7·8 atmospheres; viz. 337° Fah.

The empyrical formula, adopted by the Committee of the French Academy, as representing the law of relation between the pressure and temperature of steam, is of the form,

$$e = (a + n\,t)^5$$

Where e represents the elastic force of the steam, t the temperature, and a and n are constants, determined, as well as the index 5, from observation.

Tredgold had previously adopted a formula similar to this in form, as agreeing nearly with the best experiments to which he had access, and which have already been compared with the results obtained by this Committee. Of this formula the French Commission remark, that the numbers which it gives accord, at the lower temperatures of their series, better with their experiments than those furnished by their own formula. Besides the differences in the numerical coefficients between the two formulæ now in question, Tredgold's formula has the number 6 instead of 5 for an index.

With this law the experiments of the Committee coincide; the index 6 applying much more nearly to their results than 5. The empyrical formula adopted to represent their results is,

$$e = (\cdot 00333\,t + 1)^6$$

where e is the elasticity of the steam in atmospheres, and t the excess of temperature above the boiling point of water in degrees of Fahrenheit's scale.

This formula will be found to accord very well at the higher pressures with the experiments of this Committee, and its variations from them at other pressures to be sometimes in excess, and at others in defect.

Comparison of Temperatures calculated by the Formula, with those deduced from Experiment.

Elastic force.	Calculated temperature.	Temperature by experiment.	Difference.	Elastic force.	Calculated temperature.	Temperature by experiment.	Difference.
Atmos.	Fah.°	Fah.°	Fah.°	Atmos.	Fah.°	Fah.°	Fah.°
1	212·0	212	0·0	6	316·5	315½	+1·0
2	248·8	250	—1·2	7	327·3	326	+1·3
3	272·3	275	—2·7	8	336·4	336	+0·4
4	290·1	291½	—1·4	9	344·8	345	—0·2
5	304·4	304½	—0·1	10	352·5	352½	0·0

The comparison indicates that at the lower temperatures the elasticity, as shown by the formula, increases too rapidly, but from 4 up to 10 atmospheres, the difference between the calculated and mean temperatures are less than 1½° of Fahrenheit's scale. The differences have sometimes the positive and sometimes the negative sign, which is favourable to the correctness of the formula as representing the law of increase of elasticity, in terms of the temperature.

In conclusion, it seems to the Committee, that while the differences in the results of experimenters are greater than the present state of experimental science warrants, yet at pressures even exceeding ordinary working pressures, the relation of the temperature and pressure of steam may be considered, in a practical point of view, as sufficiently determined.

Table showing the Elastic Power of Steam at different degrees of Temperature, as resulting from the Experiments of different Authors, within the limits of six atmospheres. The degrees are those of Fahrenheit's thermometer.

WATT.		ROBISON.		DALTON.		URE.		SOUTHERN.		TAYLOR.	
Temperature.	Elasticity in inches of mercury.	Temperature.	Elasticity in inches of mercury.	Temperature.	Elasticity in inches of mercury.	Temperature.	Elasticity in inches of mercury.	Temperature.	Elasticity in inches of mercury.	Temperature.	Elasticity in inches of mercury.
First	Series										
55°	0·15	32°	0·0	32°	0·2	24°	0·170	32°	0·16	212°	30·00
74	0·65	40	0·1	43¼	0·297	32	0·200	42	0·23	220	34·95
81	0·80	50	0·2	54½	0·435	40	0·250	52	0·35	230	41·51
95	1·30	60	0·35	65¾	0·63	50	0·360	62	0·52	240	50·00
104	1·75	70	0·55	77	0.91	55	0·416	72	0·73	250	59·12
118	2·68	80	0·82	88¼	1·29	60	0·516	82	1·02	260	70·10
128	3·60	90	1·18	99½	1·82	70	0·726	92	1·42	270	82·50
135	4·53	100	1·6	110¾	2·54	80	1·010	102	1·96	280	97·75
142	5·46	110	2·25	122	3·5	90	1·360	112	2·66	290	114·50
148	6·40	120	3·0	133¼	4·76	100	1·860	122	3·58	300	133·75
153	7·325	130	3·95	144½	6·45	110	2·456	132	4·71	320	179·40
157	8·25	140	5·15	155¾	8·55	120	3·300	142	6·10		
161	9·18	150	6·72	167	11·25	130	4·366	152	7·90		
164	10·10	160	8·65	178¼	14·6	140	5·770	162	10·05		
167	11·07	170	11·05	189½	18·8	150	7·53	172	12·72		
172	11·95	180	14·05	200¾	24·0	160	9·600	182	16·01		
175	12·88	190	17·85	212	30·0	170	12·050	212	30·00		
177·5	13·81	200	22·62	Dal	ton	180	15·160	250·3	60·00		
180	14·73	210	28·68	second	series	190	19·000	293·4	120·00		
182·5	15·66	220	35·8	36	0·29	200	23·600	343·6	240·00		
185	16·58	230	44·5	64	0·75	210	28·880				
187	17·51	240	54·9	96	1·95	212	30·000				
189	18·45	250	66·8	132	5·07	220	35·540				
191	19·38	260	80·3	173	13·18	225	39·110				
193·5	20·34	270	94·1	220	34·20	230	43·100				
196·5	21·26	280	105·9	272	38·9	240	51·700				
				340	231·0	250	61·900				
						260	72·300				
						270	86·300				
						280	101·900				
						290	120·150				
						295	129·000				
						300	139·700				
						310	161·300				
						312	167·000				
						312	165·5				

Table showing the Pressure, Specific Gravity of Steam, and Weight of a cubic foot at different temperatures.

Pressure in inches of mercury.	Temperature Fahrenheit therm.	Weight of cubic foot in grains.	Specific gravity. air being unity.	Pressure in inches of mercury.	Temperature Fahrenheit therm.	Weight of cubic foot in grains.	Specific gravity. air being unity.
0·55	60·00	6·10	0·0115	75·00	263·00	593·50	1·123
1·00	77·00	10·70	0·0202	90·00	274·70	700·00	1·33
2·00	98·70	20·50	0·0388	105·00	284·50	810·00	1·53
3·00	112·50	30·00	0·0568	120·00	293·10	910·00	1·728
4·00	123·00	39·00	0·0744	150·00	308·00	1110·00	2·12
7·50	147·60	71·00	0·134	180·00	320·60	1317·00	2·5
15·00	178·00	135·00	0·255	210·00	331·50	1520·00	2·86
22·50	197·40	196·00	0·371	240·00	341·20	1660·00	3·25
30·00	212·00	254·70	0·484	270·00	350·00	1910·00	3·61
35·00	220·00	292·00	0·553	300·00	358·00	2100·00	3·97
45·00	233·80	363·00	0·687	600·00	414·00	3940·00	7·44
52·50	242·50	427·00	0·81	900·00	450·00	5670·00	10·75
60·00	250·20	483·00	0·915	1200·00	477·00	7350·00	13·68

Steam Engine. The first idea of employing steam as a motive power seems to have occurred to Hero of Alexandria, who flourished about 40 B.C. He introduced high pressure steam into the interior of a hollow globe, revolving upon an axis, and having two projecting tubes from the sides, through which the steam escaped into the atmosphere, and by the resistance which it met with from the air the globe was made to revolve. This engine acted on the same principle as Barker's mill. In 1629, Bronca, an Italian, published an account of another form of steam engine, in which the steam, issuing out from a tube in the boiler, impinged upon the floats of a wheel, and turned it round. These contrivances are so trifling in their nature, so far as utility is concerned, that they need scarcely be mentioned. The first approaches at anything like a useful machine was made by the marquis of Worcester, who, in a work entitled a *Century of Inventions*, gave an account of it, from which we may infer that his engine acted somewhat after the following manner. Suppose a long upright tube, furnished at the top with a valve opening upwards, and communicating with a vessel containing water. When steam is thrown upon the surface of the water it will force the water up the pipe to a height greater in proportion as the force of the steam exceeds the elasticity of the air. The valve at the top of the pipe would prevent the water from returning when the steam was cut off. Sir Samuel Moreland contrived an engine for raising water by steam, about the year 1682, but no account is left of the nature of its construction; he has, however, left some tables of the force of steam which form an important link in the history of experimental science. In 1698, Papin proposed the formation of a partial vacuum below a piston in a cylinder, thus using the pressure of the atmosphere as the motive power; but his contrivance was impracticable. In 1692, Amontons and Deflander invented steam wheels, but neither were practicable. Thomas Savary took out a patent, in 1698, for his steam engine, and the year following exhibited a working model of it before the Royal Society. In this engine he employed both the elastic and condensing properties of steam. A long pipe was inserted into the well to be drained, and at a point of not more than 20 feet above the surface of the water a valve was placed in it, opening upwards. Immediately above this valve a side pipe was led to a hollow vessel, called the receiver, and the main pipe had a second valve, opening upwards, situated immediately above the receiver pipe. The top of the main pipe opened into the cistern where the water was to be delivered. The receiver communicated with a strong boiler, by means of a pipe furnished with a stop cock that might be opened or shut at pleasure, and a pipe with a stop cock was likewise led from the cold water cistern to the receiver. Steam was admitted into the receiver, and, consequently, into the main pipe above the lower valve. When this was the case, the steam cock was shut, and cold water let into the receiver by the other pipe, the steam was condensed and a vacuum formed in the receiver and main pipe, and the water, by the action of the atmosphere, pressed up the main pipe from the well, and prevented from returning by the lower valve which was closed by the weight of the fluid above it. In this state of things the steam was again admitted into the receiver, and acting upon the water in the main pipe, forced it through the upper valve up the pipe and into the cistern. The steam, of course, would at the same time force down the under valve and prevent the water from returning to the well. Several ingenious mechanics have endeavoured to improve the engine of Savary, among whom may be more especially mentioned Mr Pontifax, Mr J. Boaz, and Mr George Whitelaw. There were several engines erected on Savary's principle, but the introduction of Newcomen's, in 1705, caused it to be abandoned. Letters patent were granted in that year to Thomas Newcomen, blacksmith, John Cawley, a plumber, both of Dartmouth, in conjunction with captaiu Savary, for a new engine for raising water from mines. The nature of this invention may be described as follows. A solid piston was fitted into a hollow cylinder, and so contrived that it was capable of moving up and down without difficulty, yet at the same time so accurately fitted that while even in a state of motiou no air or steam was allowed to escape between it and the cylinder. Into this piston a rod was fixed, attached to one end of a long beam, suspended in the middle, and having the pump rods at the other end. The weight of the pump rods was such as to draw down that end of the beam, and by raising the other lift the piston to the top of the cylinder. In this position steam was introduced into the bottom of the cylinder, so as to fill the whole space below the piston, and when this was done cold water was introduced which converted the steam into water, or condensed it, and formed a vacuum in the cylinder below the piston. The pressure of the air on the upper surface of the piston forced it down to the bottom of the cylinder, raised the pump rods at the other end of the beam, and thus drew the water from the well. The re-admission of steam below the piston would destroy the vacuum, and the piston would be drawn to the top of the cylinder by the weight of the pump rods. Another condensation by the injection of cold water would cause the piston to descend, and so the alternate rising and falling of the piston and pump rods was continued. The steam and cold water were admitted, at the proper intervals of time, by an attendant, who turned stop cocks. It is recorded that a boy, named Potter, contrived, by attaching cords and catches to the beam and cocks, to cause the engine to admit and cut off the steam and the cold water at proper intervals. This occurred about the year 1712, but in 1717, Mr Henry Brighton, of Newcastle-upon-Tyne, made a more complete and effective arrangement for opening and shutting the valves. In the year 1720, one Leupold, a German, made the first proposal of a *high pressure engine*. He placed two cylinders above the boiler, the cylinders being placed side by side, and furnished with pistons. At the bottom of each cylinder an opening was made into a cavity, in which a four way cock was placed, so constructed that when a free passage was opened between the bottom of one cylinder and the boiler, a free passage was opened at the same instant between the bottom of the other cylinder and the atmosphere. Steam of an elastic force greater than the atmospheric pressure, was generated in the boiler, and being admitted into the bottom of one of the cylinders, forced up the piston to the top, while at tho same time a free communication was opened between the bottom of the other cylinder, which allowed the steam it contained to make a free escape and the piston to descend. The four way cock was now turned so as to permit the steam in the cylinder whose piston was up to escape, and therefore the piston would descend, while the other piston would be forced up by the steam from the boiler being admitted below it; and thus the operation was continued. In 1736, Jonathan Hulls made an attempt to apply the steam engine of Newcomen, as improved by Brighton, to navigation. He contrived a method of converting the reciprocating motion of the piston rod into a continuous circular motion; the contrivance was not so simple as the crank, but very ingenious. About 1757, Fitzgerald proposed the use of the *fly wheel*. The celebrated Smeaton did a great deal to improve the construction of Newcomen's engines, and his labours contributed in no small degree to hasten the engine to that state of perfection in which we now find it. John Blakey took out a patent, in 1766, for a proposed improvement on Savary's engine, in which he used two receivers, one placed above the other, preventing the contact of the steam and water by a floating stratum of oil, but his contrivance was impracticable. He had, however, the merit of inventing tubulated boilers now so extensively employed in locomotive engines. The greatest improvements ever yet made on the steam engine were reserved for Dr James Watt, a native of Greenock, but at the time his attention was drawn to the subject, a mathematical instrument maker in Glasgow. He began his researches on the nature of steam as early as 1763, but his plans for improving the steam engine seem not to have been matured until about 1768, and the year following he obtained his first patent for "Methods of lessening the consumption of Steam, and consequently of fuel in fire engines." The great improvement held forth in the specification consists in condensing the steam, not in the steam cylinder, but in a separate vessel, with which it was made to communicate occasionally by the opening and shutting of a valve. By this means the steam cylinder was not cooled down by the injection of cold water at every condensation, and all the steam which was expended in heating the cylinder in Newcomen's engine was thus saved. He also specified his method of extracting the air and water from the condenser, by means of pumps, and likewise the employment of high pressure, or what he terms expansive, steam to work the engine, either with or without condensation. In the same specification he also includes the rotatory engine to be applied to the turning of mills. Instead of rendering the piston air-tight by water on its upper surface, he proposes oil, wax, mercury, &c. In 1781, one Steed obtained a patent for the crank motion, in order to convert the alternating motion of the beam into a continuous rotatory motion; but there is strong proof that the invention was stolen from Mr Watt, as a pattern of the crank was lying in the yard of Boulton and Watt's foundery, at Soho, for some time previous to the date of Steed's patent. (See *Life of James Watt*, *Chambers' Biography of Eminent Scotsmen*.) Watt was thus driven to the invention of that beautiful motion, the sun and planet wheel, as a substitute for the crank, for which he obtained a patent the same year. Mr Jonathan Hornblower took out a patent, in 1781, for an ingenious method of employing steam so as to act expansively. He employed two cylinders; first allowing the steam to act in one, and then to act by expansion in the other; but as the employment of a separate condenser he could not bring his engine into use. This was compensated for by Watt, who, in the year following, i. e. 1782, took out letters patent for his expansive engine. He employed only one cylinder, and effected the action by expansion, by admitting high pressure steam at the beginning of the stroke, but cutting it off after the piston had moved a certain space, after which the steam expanded to the end of the stroke. It is but justice to add, that Watt had employed the expansive engine both at Soho and Shadwell, between the years 1776 and 1778. In the patent of 1782, Watt included many contrivances for regulating the power of the double-acting engine. In 1784, Watt obtained letters patent for the parallel motion, together with other contrivances; and in the year following he obtained a patent for an improved smoke consuming furnace, the governor, steam gauge, condenser gauge, and indicator.

The next modification of the steam engine, of any consequence, was that of Cartwright, who proposed to condense the steam by means of cold water applied to the external surface of the condenser. The condenser consisted of two cylinders, one placed within the other, the cold water flowing through the inner and enveloping the outer. The valves to change the steam were placed in the piston, so that the condenser was always open. This engine was ingenious, but nothing more can be said of it. The metallic piston, however, was invented by Cartwright, and employed in his engine, and this invention is of itself sufficient to rank him as one to whom we are indebted for one of the great improvements in the steam engine. Much was done by Mr Murray, of the firm Fenton, Murray, and Wood, of Leeds, in improving several parts of the steam engine, which he included in his patents of 1799, 1801, and 1802. About the same period, Mr W. Murdoch, the well-known inventor of gas lighting, made several important improvements in constructing the cylinders and working the valves of steam engines. In 1801, Mr Bramah contrived the four way cock, as a substitute for the valves, the cock turning always in one direction. As before stated, Leupold had projected a high pressure engine, and so had Watt, but it was not until 1802 that the principle was applied with success, in the simple high pressure engine of Trevithick and Vivian, whose principal object seems to have been the formation of a simple and portable engine, where water was scarce, and where economy of fuel was an object of less moment. These engines were intended chiefly to propell carriages on railways. In 1804, Arthur Woolf projected a new form of expansion engine, somewhat after the construction of Hornblower's, but he used high pressure steam in the small cylinder, whereas Hornblower did not. Wonderful advantages were expected from Woolf's engine, from the supposed existence of a law in the expansion of steam which he stated he had discovered. He stated that from numerous experiments he had made, he found that the temperature remaining the same the bulk of steam is inversely as the pressure in lbs. above the atmosphere; and thus, that steam generated at 50 lbs. above the pressure of the atmosphere would expand, when allowed to escape into a large vessel of the same temperature, to 50 times its former bulk. But in this discovery he deceived himself, and has led many others astray, for the expansion will be inversely as the pressure; thus, a cubic foot of steam, generated at a pressure of 50 above the atmospheric pressure, will (reckoning the atmospheric pressure at 15 lbs. per square inch) expand in the proportion of 15 to 15 + 50, or 15 to 65, or 1 to 4⅓, that is, the steam, when expanded, will only occupy 4⅓ cubic feet, instead of 50, according to Woolf's assertion. The engine of Woolf is said, however, notwithstanding this immense deduction from its proposed advantages, to work better than the single cylindered expansion engine of Watt.

We have thus given a short sketch of the history of the steam engine, chiefly with a view to give the reader a notion of the principal dates and names. To enter into detail would occupy a work of no small magnitude, in which would be laid open much that is ingenious, much that is useful, and much more that is of no value. We have not noticed the many attempts that have hitherto been made to form rotatory steam engines, or steam wheels, as these, however ingenious, have hitherto been failures, and when found to work at all, their effect has been inferior to that of the piston and cylinder engine, employing the same quantity of steam. Neither have we included in this short view any statements regarding the invention and progress of steam navigation, or locomotion, these subjects have been discussed under the articles *Navigation*, *Steam*, and *Railways*, in this Dictionary.

We shall now endeavour to make the reader acquainted with the principle of action of the steam engine. We have reserved a description of that part of it for this place, where the action may be considered more especially to go on, the minute details of the several departments will be found under the respective names by which they are designated, and a general view of the whole in combination will be found in our description of the plates annexed to this Dictionary.

Let there be a hollow cylinder, A, fig. 1, accurately bored and turned in the interior, so that it shall be smooth, and of the same diameter from bottom to top. Into this cylinder let a solid piston of metal, B, be fitted so that it may easily move up and down in the cylinder, so tightly adapted to the cylinder as to allow of no air, water, or steam, and yet so as to oppose little resistance, or cause little friction in the motion up and down. To the centre of this piston let the upright rod, C, be attached, the upper end of which is connected with a long beam, or lever, D E F, poised in the middle E, to the other end F of this beam there is a weight, W, attached. G is a small tube, also containing a piston similar to that in the large cylinder. The pipe in which this piston moves is closed at the top with a cover or lid, through the centre of which a small hole is bored, to admit of the rod H moving easily up and down, yet so as not to allow any air or steam to escape. This rod is also connected with the beam at *e*. A pipe I is led from the boiler and enters the tube, or small cylinder G, near the bottom, and from the top of the cylinder G another pipe is led which opens into a cistern, K, containing cold water. A connexion is formed between the large and the small cylinders by the cross pipe L.

Let us now suppose that the weight W is so adjusted as just to draw the end, F, of the beam down, and, consequently, raise the other end D, and cause both pistons to rise to the top of the cylinders, it is manifest that a direct communication is formed between the cold water cistern and the large cylinder, for the small piston is above the pipe L, which enters the large cylinder, and a free passage is open from that to the cistern, as will at once be seen on looking at the diagram. The large cylinder, we shall suppose, has been previously filled with steam, that is, all the space below the piston is filled with steam. But the cold water having now access to the large cylinder, will condense the steam, and form a vacuum below the piston. The atmospheric pressure now exerts its force, with effect, on the upper surface of the piston, and presses it down to the bottom of the cylinder, with a force of 15 lbs. for every square inch on the surface of the piston. Suppose there are 60 square inches on the surface of the piston, then it will descend with a force of $60 \times 15 = 900$ lbs., and unless the weight is greater than this it will be raised by the descent of the piston. The piston has now arrived at the bottom of the cylinder, and the descent of the end of the beam to which the piston rod is attached causes the rod of the small piston also to descend, and the piston to pass below the pipe L, the consequence of which will be that the connection between the large cylinder and the cold water cistern will be cut off, and the passage between the boiler and the large cylinder opened. Steam will thus be admitted into the large cylinder, below the piston, the vacuum will be destroyed below the piston, and the weight W will draw the piston up to the top of the cylinder. When the large piston ascends, the small piston also ascends, and shuts the passage between the boiler and the large cylinder, opening at the same time the passage between the cylinder and the cold water cistern. Thus the steam is again condensed, and the piston will fall to the bottom of the cylinder. In this way the alternate ascent and descent of the piston, and consequently of the weight W. This is the nature of the action of the engine of Newcomen, commonly called the *Atmospheric engine*. This engine is commonly used to raise water, the pump rods being substituted instead of the weight W.

Instead of injecting the cold water into the cylinder, Watt formed a communication between the bottom of it and another hollow vessel, M, fig. 2, called the condenser. Into this vessel a shower of cold water is continually flowing through a rose, the steam is condensed in consequence, and the cold water, together with the condensed steam, are taken out of the condenser by means of a pump worked by the engine itself, so that the condenser is continually cleared. See *Condenser*.

In order to keep the piston parallel it was usual to attach the top of it to a chain, which adapted itself to a wood arch at the end of the beam, but this has, in general, been abandoned for the more perfect contrivance for the same purpose, called the parallel motion. See *Parallel Motion*.

It is not difficult to see that a very considerable addition of power could be derived from this engine were the pressure of the atmosphere taken off the top of the piston when it is in the act of rising. This is accomplished in the following manner. The cylinder is closed at the top, by a cover, as shown in fig. 3. Through the centre of the cover a circular opening is made to permit the piston rod to rise and fall, and a small metallic box is placed upon it, containing hemp, which envelopes the piston rod, and prevents the passage of air or steam by the opening. The upright tube A B communicates with the cylinder, both at the bottom and top, and also communicates with the steam boiler by a pipe S, as likewise with the condenser by means of a pipe at C. The upright pipe A B contains a rod passing up through it, and moveable up and down through a hemp stuffed box in the end, similar to that for the piston rod in the cylinder cover. This upright rod, or spindle, carries two valves, A and B, which, in this case, are pieces of metal ground so as to fit accurately on the face of the pipe next to the cylinder, and slide easily up and down past the openings into the cylinder at the top and bottom. When the valves are below the openings, or port holes as they are called, as shown in fig. 2, then it is plain that there will be a free communication between the top of the cylinder, and the steam from the boiler, and at the same time a free communication between the bottom of the cylinder and the condenser. When the valves are slided up above the port holes, as in fig. 3, then the case is reversed, the steam is cut off from the top of the cylinder, and admitted to the bottom, while the condenser is opened to the top and closed to the bottom. On whichever side of the piston the steam acts it will move the piston in the direction of its own motion, that is, when the steam issues in at the top of the cylinder the piston will descend to the bottom, and when admitted at the bottom, the piston will rise to the top, there being nothing but its own friction to oppose its ascent or descent, as the moment that the steam is opened to one side, the other side is put into a state of vacuo, by being opened to the condenser. Such is the principle of the double acting condensing engine of Watt. If the steam be used of higher pressure than 14 lbs. to the square inch, and cut off before the piston has moved through the whole length of the cylinder, being then allowed to expand itself, the engine is of the expansive kind. If there be no condenser at all, and the steam be used of very high pressure, and instead of being condensed be allowed to escape into the open air, after it has moved the piston, then the engine is of the high pressure kind.

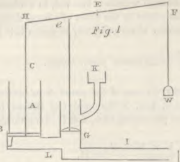


Fig. 1

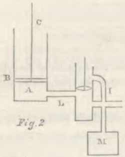


Fig. 2

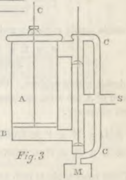


Fig. 3

Particulars as to the proportions of the various parts will be found under our articles *Condenser*, *Cylinder*, *Fly Wheel*, *Governor*, *Parallel Motion*, &c. &c.; and the connexion of the whole will be seen by inspecting our plates of fixed, locomotive, and marine engines. We also subjoin tables of the general proportions, which will be found useful.

In estimating the power of a steam engine the first thing to be taken into consideration is the pressure of the steam in the boiler. For low pressure engines it is common to load the safety valve with a weight of from $2\frac{1}{2}$ to $3\frac{1}{2}$ lbs. on every square inch. The vacuum in the condenser is never perfect, seldom exceeding 26 inches on the barometer guage, and therefore we may calculate that the pressure on the piston instead of being $15 + 2\frac{1}{2}$, or $17\frac{1}{2}$ lbs. is about $15\frac{1}{2}$. But this must be diminished still farther, in consequence of friction and the alternating motion of the piston, deducting one-fifth for the former, and one-third for the latter, in all eight-fifteenths, leaving about $7\frac{1}{4}$ lbs. as the effective pressure upon the piston per square inch. Hence, if a piston contain 100 square inches, and move through a space of 1000 feet per minute, then will its effect be $100 \times 1000 \times 7\frac{1}{4} = 725000$ lbs. But a horse will raise 33000 lbs., through a space of one foot, in a minute; therefore dividing the effect of the piston by the effect of a horse during the same time, we obtain the number of horses' power to which it is equivalent.

$$\frac{725000}{33000} = 22 \text{ horses' power nearly.}$$

An easy rule is, calling the area of the piston A in square inches, L the length of the stroke in feet, N the number of strokes in a minute, P the pressure of steam per square inch, and H the number of horses' power.

$$\frac{A \times L \times N \times P}{33000} = H,$$

for single acting engines; and

$$\frac{A \times L \times 2N \times P}{33000} = H,$$

for double acting engines. Or taking D for the diameter of the cylinder instead of A the area, we have another form of the rules, where division is not necessary.

$D^2 \times L \times N \times P \times 0{\cdot}0000238 = H$, for single acting engines, and

$D^2 \times L \times N \times P \times 0{\cdot}0000476 = H$, for double acting engines.

These rules apply to both low and high pressure engines; but when the steam acts expansively we must find its mean pressure as follows. Divide the length of the stroke in inches by the distance that the piston travels before the steam is cut off, and divide the pressure in lbs. by the quotient. Add 1 to $3\frac{1}{2}$ times the hyperbolic logarithm of the number of times the steam is expanded, and multiply the logarithm by the number of times the steam is expanded, the product is the uniform force of the steam. In the table of Hyperbolic logarithms in this work, the logarithms of the fractional numbers are already taken $3\frac{1}{2}$ times. p. 304.

In a high pressure engine the cylinder is 8 inches diameter, length of stroke 2 feet, makes 50 strokes per minute, the pressure on the safety valve is 30 lbs. per square inch, the engine being double acting.

$8^2 \times 2 \times 50 \times 30 \times 0{\cdot}0000476 = 6{\cdot}09$ horses' power nearly.

Table of the Proportions of the parts of an Atmospheric Engine founded on Experiments by Mr Smeaton.

Cylinders. Diameter.	Cylinders. Square of Diameter.	Cylinders. Area in square inches.	Strokes. No.	Strokes. Length.	Journey per minute.	Boilers. Centre Diameter.	Boilers. Fire Surface	Diameter of Steam pipe.	Square hole for jet of injection.	Injection water per stroke. In Ale gall.	Injection water per stroke. Cyl. Inch. Ft.	Boiler's feed per stroke.	Coals per hour.	Pumpage.	Great product per minute.	Effect per minute of one bushel per hour.
Inch.	Cir. In.	Sq. In.		Ft. In.	Feet.	Ft. In.	Sq. ft.	Inches.	Inches.			Cub. In.	Bushels.	Cyl. ft. in.		Per min.
12	144	113	16½	4 0	66	8 0	37¼	2·50	·33	·6	18	12·7	·74	2·592	,171,072	231
14	196	153	16¼	4 2	67·71	6 6	44	2·78	·375	·76	23	15·9	·91	3·528	,238,881	263
16	256	201	16	4 4	69·3	7 0	51½	3·06	·42	·93	28	19·7	1·11	4·608	,319,488	288
18	324	254	15¾	4 6	70·88	7 6	58¾	3·35	·47	1·13	34	23·9	1·33	5·832	,413,372	311
20	400	314	15½	4 6	72·3	8 0	66¾	3·64	·51	1·36	41	28·5	1·56	7·200	,520,800	334
22	484	380	15¼	4 10	73·71	6 6	75½	3·93	·56	1·6	48	33·6	1·81	8·712	,642,162	355
24	576	452	15	5 0	75	9 0	84	4·22	·60	1·86	56	39·3	2·08	10·368	,777,600	374
26	676	531	14¾	5 2	76·21	9 6	94	4·52	·645	2·16	65	45·3	2·36	12·168	,927,323	393
28	784	615	14½	5 4	77·3	10 0	104	4·82	·69	2·48	74½	52	2·66	14·112	1,091,328	410
30	900	706	14¼	5 6	78·36	10 6	115	5·12	·735	2·82	84¼	59·1	2·97	16·200	1,269,432	427
32	1024	614	14	5 6	79·6	11 0	126	5·43	·78	3·18	95⅔	66·6	3·30	18·432	1,462,272	443
34	1156	907	13¾	5 10	80·21	11 6	138	5·74	·825	3·56	107	75	3·64	20·808	1·669,010	459
36	1296	1018	13½	6 0	61	12 0	150	6·05	·87	4	120	84	4·00	23·328	1,889,568	472
38	1444	1134	13¼	6 2	81·71	12 6	163	6·37	·91	4·46	134	93·4	4·37	25·992	2,123,806	486
40	1600	1256	13	6 4	82·3	13 0	176	6·69	·95	4·95	148½	103·7	4·78	28·800	2,371,000	498
42	1764	1385	12¾	6 6	82·88	13 6	190	7·01	·99	5·46	164	114·6	5·16	31·752	2,631,606	510
44	1936	1520	12½	6 6	83·3	14 0	204	7·34	1·03	6·03	181	126·5	5·56	34·848	2,904,000	520
46	2116	1662	12¼	6 10	83·71	14 6	219	7·67	1·07	6·63	199	139	6·01	38·088	3,188,346	531
48	2304	1809	12	7 0	84·3	15 0	234	6	1·11	7·26	216	152·5	6·46	41·472	3,483,648	539
50	2500	1963	11¾	7 2	84·21	11 0	252	6·33	1·15	7·96	239	166·9	6·92	45·000	3,789,450	548
52	2704	2123	11½	7 4	84·3	11 6	276	8·66	1·19	8·7	261	182·3	7·40	48·672	4,104,672	555
54	2915	2290	11¼	7 6	84·36	12 0	300	9	1·225	9·48	284½	198·7	7·89	52·488	4,427,888	561
56	3136	2463	11	7 6	64	12 0	326	9·33	1·26	10·3	310	216·4	8·40	56·448	4,760,448	567
58	3364	2642	10¾	7 10	84·21	12 0	354	9·66	1·295	11·22	336½	235·1	6·92	60·552	5,099,084	572
60	3600	2827	10½	6 0	84	12 0	384	10	1·33	12·16	365½	255·3	9·46	64·800	5,443,200	575
62	3844	3019	10¼	6 2	83·71	12 0	402	10·33	1·36	13·2	396	276·7	10·01	69·192	5,792,062	579
64	4096	3216	10	6 4	83·3	12 0	426	10·66	1·39	14·3	429	299·8	10·56	73·728	6,144,000	581
06	4358	3421	9¾	6 6	82·88	12 0	450	11	1·425	15·46	464	324·3	11·16	78·408	6,498,455	581
68	4624	3631	9½	6 6	82·3	12 0	476	11·33	1·45	16·73	502	350·7	11·78	83·232	6,852,768	583
70	4900	3848	9¼	8 10	61·71	12 0	502	11·66	1·475	18·08	542½	378·9	12·37	88·200	7,206,822	583
72	5184	4071	9	9 0	61	12 0	530	12	1·50	19·53	586	409·3	13·00	93·312	7,556,272	581

(Boilers, Centre Diameter, sizes 50 to 72: These have two boilers.)

(Fire Surface: The surface in the flues is taken at half.)

Steam acting expansively.								Steam acting at full pressure throughout the stroke in the same engine.	
Number of horses' power.	Diameter of the steam piston in inches.	Mean pressure on the piston in lbs., at 4·8 lbs. per circular inch.	Velocity of the steam piston in feet per minute.	Length of the stroke in feet.	Number of strokes per minute.	Water required per hour to supply the boiler.	Coals consumed per hour in lbs.	Number of horses' power.	Coals consumed per hour in lbs.
	inches.	lbs.	feet	feet.		cub. ft.	lbs.		lbs.
1	7·8	289	114	1·3	44	·8	15	1·46	31·5
2	10·25	516	131	1·75	37½	1·57	23	2·95	48
3	12·05	697	141	2·	35	2·36	30	4·4	64
4	13·52	877	149	2·25	33	3·13	38	5·9	80
5	14·9	1049	157	2·5	31½	3·92	45	7·4	94
6	15·9	1214	162	2·65	30½	4·7	53	8·55	111
7	16·9	1373	167	2·8	29¼	5·5	60	10·3	126
8	17·85	1527	171	2·97	29	6·3	67	11·8	140
9	18·7	1678	175	3·1	28½	7·05	73	13·3	153
10	19·5	1826	180	3·25	26¾	7 82	80	14·6	168
12	20·9	2113	186	3·5	26½	9·4	95	17 7	199
14	22·3	2390	191	3·7	25¾	11·0	109	20·7	230
16	23·6	2659	196	3·9	25	12·6	122	23·6	256
18	24·7	2922	201	4·1	24½	14·1	135	26·5	283
20	25·75	3179	206	4·3	24	15·7	149	29·5	312
22	26·75	3433	211	4·5	23½	17·3	163	32·5	341
24	27·7	3678	213	4·6	23¼	18·8	176	35 8	370
26	28·6	3922	216	4·75	22¾	20·4	189	38·4	395
28	29·45	4161	220	4·9	22½	22·	203	41·3	425
30	30·27	4397	222	5·04	22¼	23·5	216	44·2	451
32	31·1	4630	226	5·2	21¾	25·1	230	47·3	480
34	31·82	4860	229	5·3	21½	26·7	243	50·	510
36	32·56	5088	232	5·43	21¼	28·3	256	53·	535
38	33·3	5313	234	5·55	21	29·7	269	56·	561
40	34·	5535	237	5·67	21	31·4	283	59·	596
42	34·63	5756	239	5·77	20¾	33·0	297	62·	624
44	35·13	5919	241	5·85	20½	34·5	311	65·	652
46	35·9	6190	244	6·0	20½	36·2	324	67·5	680
48	36·5	6404	246	6·1	20¼	37·7	338	70·5	709
50	37·13	6617	248	6·2	20	39·3	353	73·5	739
52	37·7	6828	250	6·3	20	40·7	367	76·4	768
54	38·3	7036	252	6·4	19¾	42·4	381	79·3	798
56	38·65	7245	254	6·49	19½	44·0	396	82·2	827
58	39·4	7453	255	6·59	19½	45·4	409	85·1	850
60	39·9	7656	257	6·65	19½	47·0	423	88·1	887
62	40·5	7860	259	6·75	19¼	48·6	437	91·0	916
64	41·0	8062	260	6·83	19	50·2	452	93·9	946
66	41·5	8263	261	6·9	19	51·8	466	96·8	975
68	42·0	8462	263	7·0	18¾	53·4	481	99·7	1005
70	42·5	8662	265	7·1	18¾	55·0	495	102·7	1035
72	43·0	8858	266	7·17	18½	56·6	509	105·6	1064
74	43·4	9043	268	7·23	18½	58·1	514	108·5	1094
76	43·9	9250	269	7 3	18½	59·8	538	111·4	1123
78	44·4	9444	270	7·4	18¼	61·5	554	114·3	1153
80	44·8	9637	272	7·47	18¼	62·5	563	117·3	1182
85	45·9	10120	275	7·65	18	66·5	599	124·6	1256
90	46·97	10590	279	7·83	17¾	70·5	635	131·9	1330
95	48·0	11060	282	8·0	17¾	74·4	670	139·2	1404
100	49·	11520	284	8·16	17½	78·2	704	146·	1478
105	49·95	11980	287	8·32	17¼	82·1	739	153·3	1552
110	50·9	12430	290	8·5	17	86·0	774	161·6	1626
115	51·6	12760	292	8·6	17	89·9	809	167·9	1700
120	52·7	13330	294	8·8	16¾	93·8	844	175·2	1774
125	53·6	13760	297	8·9	16¾	97·7	879	182·5	1848
130	54·4	14210	299	9·0	16½	101·7	915	189·8	1921
135	55·3	14740	300	9·2	16½	105·6	950	197·1	1995
140	56·1	15080	302	9·35	16¼	109·5	986	204·4	2069
145	56·84	15510	306	9·47	16¼	113·4	1021	211·7	2143
150	57·6	15930	308	9·6	16	117·3	1055	219·0	2217
155	58·4	16360	310	9·7	16	121·2	1091	226·3	2291
160	59·1	16780	312	9·83	15¾	125·2	1127	233·6	2364
175	61·3	18030	318	10·2	15½	129·1	1162	240·9	2438
180	62·0	18440	320	10·3	15½	133·0	1197	248·4	2512
200	67·7	22000	334	11·3	14¾	156·4	1408	292·	2956

The above Table of the Proportions of double acting Steam Engines, is given by Mr Tredgold in his valuable work on that subject.

STEEL is a compound of iron and carbon. The furnace in which iron is converted into steel, has the form of a large oven, or arch, terminating in a vent at the top. The floor of this oven is flat and level. Immediately under it there is a large arched fire-place, with grates, which runs quite across from one side to the other, so as to have two doors for putting in the fuel from the outside of the building. A number of vents, or flues, pass from the fire-place to different parts of the floor of the oven, and throw up their flame into it, so as to heat all parts of it equally. In the oven itself, there are two large and long cases or boxes, built of good fire stone; and in these boxes the bars of iron are regularly stratified with charcoal powder, ten or twelve tons of iron being put in at once, and the box is covered on the top with a bed of sand. The heat is kept up, so that the boxes and all their contents are red hot for eight or ten days. A bar is then drawn out and examined; and if it be found then sufficiently converted into steel, the fire is withdrawn and the oven allowed to cool. This process is called *cementation*. The bars of steel formed in this way are raised, in many parts, into small blisters, obviously by a gas evolved in the interior of the bar, which has pushed up, by its elasticity, a film of the metal. On this account, the steel made by this process is usually called *blistered steel*. The bars of blistered steel are heated to redness, and drawn out into smaller bars by means of a hammer, driven by water or steam, and striking with great rapidity. This hammer is called a *tilting hammer*, on which account, the small bars formed by it are called *tilted steel*. When the bars are broken in pieces and welded repeatedly, and then drawn out into bars, they acquire the name of *German* or *shear steel*. Steel of cementation, however carefully made, is never quite equable in its texture; but it is rendered quite so by fusing it in a crucible, and then casting it into bars. Thus treated, it is called *cast-steel*. When the steel is to be cast, it is made by cementation in the usual way, only the process is carried somewhat farther, so as to give the steel a whiter colour. It is then broken into small pieces, and put into a crucible of excellent fire clay, after which the mouth of the crucible is filled up with vitrifiable sand, to prevent the steel from being oxidized by the action of the air. The crucible is exposed for five or six hours to the most intense heat that can be raised, by which the steel is brought into a state of perfect fusion. It is then cast into parallelopipeds about a foot and a half in length. To fuse one ton of steel, about twenty tons of coals are expended; which accounts for the high price of cast-steel, when compared with that of iron, or even of common steel. Every time that cast-steel is melted, it loses some of its characteristic properties; and two or three fusions render it quite useless for the purposes for which it was intended. It has recently been proved that the steel of which the Damascus blades were made, and which was steel from Golconda, owed the peculiarity which these blades have of showing a curious waving texture on the surface, when treated with a dilute acid, to their consisting of two different compounds of iron and carbon, which have separated during the cooling. It is cast-steel in which the process is carried farther than usual, and which is cooled slowly; both common steel and cast-steel is formed, which separate during the slow cooling. The steel is rendered black by the acid, while the cast-iron remains white. This kind of steel can only be hammered at a heat above that of cherry-red.

The specific gravity of good blistered steel is 7·823. When this steel is heated to redness, and suddenly plunged into cold water, its specific gravity is reduced to 7·747. The specific gravity of a piece of cast-steel, while soft, is 7·82; but when hardened by heating it red-hot, and plunging it into cold water, it is reduced to 7·7532. Hence it appears, that when steel is hardened, its bulk increases. The colour of steel is whiter than that of iron. Its texture is granular, and not hackly, like that of iron. The fracture is whitish-gray, and much smoother than the fracture of iron. It is much harder and more rigid than iron; nor can it be so much softened by heat without losing its tenacity and flying in pieces under the hammer. It requires more attention to forge it well, than to forge iron; yet it is by its toughness and capability of being drawn out into bars, that good steel is distinguished from bad. Steel is more readily broken by bending it than iron. If it be heated to redness, and then plunged into cold water, it becomes exceedingly hard, so as to be able to cut or make an impression upon most other bodies. But, when iron is treated in the same way, its hardness is not in the least increased. When a drop of nitric acid is let fall upon a smooth surface of steel, and allowed to remain on it for a few minutes, and then washed off with water, it leaves a black spot; whereas the spot left by nitric acid on iron, is whitish-green. Doctor Thomson gives the following as the composition of cast-steel :—

Iron, ...	99
Carbon, with some silicon, . .	1
	100

The *natural steel*, or *German steel*, is an impure and variable kind of steel, procured from cast-iron, or obtained at once from ore. It has the property of being easily welded, either to iron or to itself. Its grain is unequally granular, sometimes even fibrous; its colour is usually blue; it is easily forged; it requires a strong heat to temper it, and it then acquires only a middliug hardness. When forged repeatedly, it does not pass into iron so easily as the other kinds. The natural steel yielded by cast-iron, manufactured in the refining houses, is known by the general name of *furnace steel;* and that which has only been once treated with a refining furnace, is particularly called *rough steel*, and is frequently very unequally converted into steel. The best cast-iron for the purpose of making natural steel, is that obtained from the brown hæmatite, or from the sparry iron ore, which should be of a gray colour.

SUPERFICIES, or SUPERFICE, in Geometry, the outside or exterior surface of any body.

SUPPLEMENT OF AN ARC, is what it wants of 180°.

T

TANGENT, in Geometry, is a line that touches a circle or other curve without cutting it.

TENACITY; that quality of bodies by which they sustain a considerable pressure or force without breaking, being the opposite quality to brittleness or fragility.

TENSION, that state which a chord, string, &c. is in when stretched beyond its natural length.

TETRAEDRON, or TETRAHEDRON, in Geometry, one of the five regular or Platonic bodies or solids, comprehended under four equilateral and equal triangles.

TETRAGON, a quadrangle, or a figure having four angles.

THERMOMETER, an instrument used for the purpose of measuring the degrees of heat in bodies in general. It consists of a glass tube with a bulb at one end, the bulb and part of the tube being filled with a fluid. The tube is hermetically sealed, and the part of it not occupied by the fluid ought to be a vacuum. The method of constructing Fahrenheit's thermometer, which is in general use in this country, is as follows. Having procured a uniform glass tube with a ball at one end, the ball and part of the tube are to be filled with mercury which has been previously boiled to expel the air. The open end of the tube is then to be hermetically sealed. It is found by experiment that melting snow or freezing water is always at the same temperature. If, therefore, a thermometer be immersed in either the one or the other, the mercury will always stand at the same point. It has been observed, also, that water boils under the same pressure of the atmosphere at the same temperature. A thermometer, therefore, immersed in boiling water, will uniformly stand at the same point. Here, then, we have two fixed points, and by dividing the distance between them into equal parts, and extending the same divisions as far above and below these points as may be thought convenient, we shall have a scale by which two thermometers may be easily compared together; for the mercury will always stand at the same degree on the two scales. Quicksilver is found to be the best, because its expansions are most equable. The freezing point of Fahrenheit's thermometer is marked 32°, and the reason for this is said to have been, that this artist thought he had produced the greatest degree of cold possible, by a mixture of snow and salt, and the point at which the thermometer then stood in this temperature he marked zero. The point at which mercury begins to boil, he conceived to be the greatest degree of heat, and this he made the limit of his scale. The distanee between these two points he divided into 600 equal parts, or degrees, and by trials he found that the mercury stood at 32°, or at the 32nd division, when water began to freeze; it was, therefore, called the freezing point. When the tube was put into boiling water, the mercury rose to 212°, which is, therefore, the boiling point, and it is just 180° above the former, or the freezing point. In De L'Isle's thermometer the whole bulk of the mercury when placed in boiling water is conceived to be divided into 100,000 parts, and from this one fixed point, the various degrees of heat, either above or below it, are marked in these parts on the scale by the various expansions or contractions of the mercury in all the imaginable varieties of heat. In Reaumur's thermometer, or more properly De Luc's, the scale begins at the freezing point, which is marked *o*, or zero; and the point to which the mereury rises when the thermometer is in boiling water is marked 80°, which of course corresponds with the 212° of Fahrenheit's. The thermometer of Celcius has 100° between the freezing point and that of boiling water. The temperatures indicated by any one of those thermometers may be reduced to the corresponding degrees of any of the others, by the following theorems. Thus let R denote the degrees on the scale of Reamur; F those of Fahrenheit; C those of Celcius; then

1. To convert the degrees of Reaumur into those of Fahrenheit.

$$F = \frac{9\,R}{4} + 32.$$

2. To convert the degrees of Fahrenheit into those of Reaumur.

$$R = \frac{(F - 32) \times 4}{9}$$

3. To convert the degrees of Celcius into those of Fahrenheit.

$$F = 32 + \frac{9\,C}{5}$$

4. To convert the degrees of Fahrenheit into those of Celcius.

$$C = \frac{(F - 32) \times 5}{9}$$

5. To convert the degrees of Celcius into those of Reaumur.

$$R = \frac{4}{5} \times C.$$

6. To convert the degrees of Reaumur into those of Celcius.

$$C = \frac{5}{4} \times R.$$

Ex.—What point in Reaumur's thermometer answers to 55°, or temperate in Fahrenheit's ?

By the second formula above, we have $\frac{(55 - 32) \times 4}{9} = 10\frac{2}{9}$ = the answer. Or thus by the rule of three; as 180° (the distance between the freezing and boiling points in Fahrenheit) : 55° — 32° = 23° (the distance between freezing and temperature in Fahrenheit) : : 80° (the distance between the boiling and freezing points in Reaumur) : $10\frac{2}{9}$ the distance between freezing and temperate in Reaumur.

The following Table gives the correspondence between the degrees of the different scales mentioned, without the trouble of calculation.

Fahr.	Reaum.	Cen.	Fahr.	Reaum.	Cen.	Fah.	Reaum.	Centi.	Fah.	Reaum.	Centi.
212	80	100	180	65·7	82·2	148	51·5	64·4	116	37·3	46·6
211	79·5	99·4	179	65·3	81·6	147	51·1	63·8	115	36·8	46·1
210	79·1	98·8	178	64·8	81·1	146	50·6	63·3	114	36·4	45·5
209	78·6	98·3	177	64·4	80·5	145	50·2	62·7	113	36	45
208	78·2	97·7	176	64	88	144	49·7	62·2	112	35·5	44·4
207	77·7	97·2	175	63·5	79·4	143	49·3	61·6	111	35·1	43·8
206	77·3	96·6	174	63·1	78·8	142	48·8	61·1	119	34·6	43·3
205	76·8	96·1	173	62·6	78·3	141	48·4	60·5	109	34·2	42·7
204	76·4	95·5	172	62·2	77·7	140	48	60	108	33·7	42·2
203	76	05	171	61·7	77·2	139	47·5	59·4	107	33·3	41·6
202	75·5	94·4	170	61·3	76·6	138	47·1	58·8	106	32·8	41·1
201	75·1	93·8	169	60·8	76·1	137	46·6	58·3	105	32·4	40·5
200	74·6	93·3	168	60·4	75·5	136	46·2	57·7	104	32	40
199	74·2	92·7	167	60	75	135	45·7	57·2	103	31·5	39·4
198	73·7	92·2	166	59·5	74·4	134	45·3	56·6	102	31·1	38·8
197	73·3	91·6	165	59·1	73·8	133	44·8	56·1	101	30·6	38·3
196	72·8	91·1	164	58·6	73·3	132	44·4	55·5	100	30·2	37·7
195	72·4	90·5	163	58·2	72·7	131	44	55	99	29·7	37·2
194	72	90	162	57·7	72·2	130	43·5	54·4	98	29·3	36·6
193	71·5	89·4	161	57·3	71·6	129	43·1	53·8	97	28·8	36·1
192	71·1	88·8	160	56·8	71·1	128	42·6	53·3	96	28·4	35·5
191	70·6	88·3	159	56·4	70·5	127	42·2	52·7	95	28	35
190	70·2	87·7	158	56	70	126	41·7	52·2	94	27·5	34·4
189	69·7	87·2	157	55·5	69·4	125	41·3	51·6	93	27·1	33·8
188	69·3	86·6	156	55·1	68·8	124	40·8	51·1	92	26·6	33·3
187	68·8	86·1	155	54·6	68·3	123	40·4	50·5	91	26·2	32·7
186	68·4	85·5	154	54·2	67·7	122	40	50	90	25·7	32·2
185	68	85	153	53·7	67·2	121	39·5	49·4	89	25·3	31·6
184	67·5	84·4	152	53·3	66·6	120	39·1	48·8	88	24·8	31·1
183	67·1	83·8	151	52·8	66·1	119	38·6	48·3	87	24·4	30·5
182	66·6	83·3	150	52·4	65·5	118	38·2	47·7	86	24	30
181	66·2	82·7	149	52	65	117	37·7	47·2	85	23·5	29·4

Table on Thermometers, continued.

Fah.	Reaum.	Cen.	Fah.	Reaum.	Cen.	Fah.	Reaum	Cen.	Fah.	Reaum.	Cen.
84	23·1	28·8	52	8·8	11·1	20	—5·3	—6·6	—11	—19·1	—23·8
83	22·6	28·3	51	8·4	10·5	19	—5·7	—7·2	—12	—19·5	—24·4
82	22·2	27·7	50	8	10	18	—6·2	—7·7	—13	—20	—25
81	21·7	27·2	49	7·5	9·4	17	—6·6	—8·3	—14	—20·4	—25·5
80	21·3	26·6	48	7·1	8·8	16	—7·1	—8·8	—15	—20·8	—26·1
79	20·8	26·1	47	6·6	8·3	15	—7·5	—9·5	—16	—21·3	—26·6
78	20·4	25·5	46	6·2	7·7	14	—8	—10	—17	—21·7	—27·2
77	20	25	45	5·7	7·2	13	—8·4	—10·5	—18	—22·2	—27·7
76	19·5	24·4	44	5·3	6·6	12	—8·8	—11·6	—19	—22·6	—28·3
75	19·1	23·8	43	4·8	6·1	11	—9·3	—11·1	—20	—23·1	—28·8
74	18·6	23·3	42	4·4	5·5	10	—9·7	—12·2	—21	—23·5	—29·4
73	18·2	22·7	41	4	5	9	—10·2	—12·7	—22	—24	—30
72	17·7	22·2	40	3·5	4·4	8	—10·6	—13·3	—23	—24·4	—30·5
71	17·3	21·6	39	3·1	3·8	7	—11·1	—13·8	—24	—24·8	—31·6
70	16·8	21·1	38	2·6	3·3	6	—11·5	—14·4	—25	—25·3	—31·1
69	16·4	20·5	37	2·2	2·7	5	—12	—15	—26	—25·7	—32·2
68	16	20	36	1·7	2·2	4	—12·4	—15·5	—27	—26·2	—32·7
67	15·5	19·4	35	1·3	1·6	3	—12·8	—16·1	—28	—26·6	—33·3
66	15·1	18·8	34	0·8	1·1	2	—13·3	—16·6	—29	—27·1	—33·8
65	14·6	18·3	33	0·4	1·5	1	—13·7	—17·2	—30	—27·5	—34·4
64	14·2	17·7	32	0	1·	0	—14·2	—17·7	—31	—28·4	—35
63	13·7	17·2	31	—0·4	—1·5	—1	—14·6	—18·3	—32	—28	—35·5
62	13·3	16·6	30	—0·8	—1·1	—2	—15·1	—18·8	—33	—28·8	—36·1
61	12·8	16·1	29	—0·3	—1·6	—3	—15·5	—19·4	—34	—29·3	—36·6
60	12·4	15·5	28	—1·7	—2·2	—4	—16	—20	—35	—29·7	—37·2
59	12	15	27	—2·2	—2·7	—5	—16·4	—20·5	—36	—30·2	—37·7
58	11·5	14·4	26	—2·6	—3·3	—6	—16·8	—21·1	—37	—30·6	—38·3
57	11·1	13·8	25	—3·1	—3·8	—7	—17·3	—21·6	—38	—31·1	—38·8
56	10·6	13·3	24	—3·5	—4·4	—8	—17·7	—22·2	—39	—31·5	—39·4
55	10·2	12·7	23	—4	5	—9	—18·2	—22·7	—40	—32	—40
54	9·7	12·2	22	—4·4	—5·5	—10	—18·6	—23·3			
53	9·3	11·6	21	—4·8	—6·1						

TORSION, FORCE OF, a term applied by Coulomb in some of his experiments, to denote the effort made by a thread which has been twisted to untwist itself. See ***Materials, Strength of.***

TRACTION, in Mechanics, is the drawing of one body towards an other. See ***Carriage.***

TRAPEZIUM, in Geometry, a plane figure contained under four right lines, of which neither of the opposite sides are parallel.

TRAPEZOID, a quadrilateral figure, having two of its opposite sides parallel.

TRIANGLE, a figure bounded by three sides, and consequently containing three angles, whence it derives its name. Triangles are of different kinds, as ***plane*** or ***rectilinear***, ***spherical***, and ***curvilinear***.

V

VALVE, a contrivance for opening and shutting alternately a passage for the ingress or egress of some liquid or fluid. Under this view a stop cock may be regarded as a valve, and the stop cock is frequently used for the valve commonly so called, as the four-way cock in the steam engine. Valves are of various forms, as the clack valve, the conical valve, the slide valve, &c., references to which will be found under various articles in this Dictionary. There are many methods of working the valves of a steam engine, some being wrought by an eccentric, (see *Eccentric*,) others by means of what is called a *plug tree*, or projections upon the air pump rod which strikes levers attached to the valves, at the proper part of the stroke. A very ingenious method of working the valves of a steam engine, by means of the governor, has lately been invented by Mr James Whitelaw, which will be found described under the article *Steam Engine*, in the *Popular Encyclopedia*.

VELOCITY, is that affection of motion, by which a moving body passes a certain space in a certain time. It is always proportional to the space passed over in a given time when the velocity is uniform, or constant during that time. Velocity is either uniform or variable. Uniform, or equal velocity, is that with which a body passes always over equal spaces in equal times. And it is variable, or unequal, when the spaces passed over in equal times are unequal; in which case it is either accelerated or retarded velocity; and this acceleration, or retardation, may also be equal or unequal, i. e. uniform or variable. Velocity is also either absolute or relative. Absolute velocity is that we have hitherto been considering, in which the velocity of a body is considered simply in itself, or as passing over a certain space in a certain time. But relative or respective velocity is that with which bodies approach to, or recede from one another, whether they both move, or one of them be at rest. Thus, if one body move with the absolute velocity of two feet per second, and another with that of six feet per second; then if they move directly towards each other, the relative velocity with which they approach is that of eight feet per second; but if they move both the same way, so that the latter overtake the former, then the relative velocity with which that overtakes it, is only that of four feet per second, or only half of the former; and consequently it will take double the time of the former before they come in contact together.—*Initial Velocity*, the velocity with which a body begins to move.—*Virtual Velocity* of a point solicited by any force, is the element of the space which it would describe in the direction of the power when the system is supposed to have undergone an indefinitely small derangement.

VIBRATION, the regular reciprocating motion of a body, as a pendulum, musical chord, &c.—See *Oscilation*.

VIS ABSOLUTA, or ABSOLUTE FORCE, is that kind of centripetal force which is measured by the motion that would be generated by it in a given body, at a given distance, and depends on the efficacy of the cause producing it.—*Vis Acceleratix*, or *Accelerating Force*, is that centripetal force which produces an accelerated motion, and is proportional to the velocity which it generates in a given time; or it is as the motive or absolute force directly, and as the quantity of matter moved inversely. —*Vis Impressa*, is defined by Newton to be the action exercised on any body to change its state, either of rest, or moving uniformly in a right line.—*Vis Inertiæ*, or *Power of Inactivity*, is defined by Newton to be a power implanted in all matter, by which it resists any change endeavoured to be made in its state, that is, by which it becomes difficult to alter its state, either of rest or motion.—*Vis Motrix*, or *Moving Force* of a centripetal body, is the tendency of the whole body towards the centre, resulting from the tendency of all the parts, and is proportional to the motion which it generates in a given time; so that the vis motrix is to the vis acceleratix as the motion is to the celerity; and as the quantity of motion in a body is estimated by the product of the velocity into the quantity of matter, so the vis motrix, from the vis acceleratix, multiplied into the quantity of matter.—*Vis Mortua*, or *Dead Force*, a term used by Leibnitz to denote the power of pressure in a body at rest; whereas *Vis Viva*, or *Living Force*, is used by the same authors to denote the force or power of a body in motion.

UNDECAGON, a polygon of eleven sides.

W

WATER. The specific gravity of rain water is 1000; weight of a cubic foot $62\frac{1}{2}$ lbs., weight of a column one inch square and a foot in height 0·434 lbs., of an ale gallon 10·2 lbs. Expands $\frac{1}{17}$th of its bulk in freezing, and $\frac{1}{2500}$ for every degree of heat. Boils at 212°, under the ordinary pressure of the atmosphere. Maximum density 39·38° of Fah. The specific gravity of sea water is 11·0271.

WATER WHEEL. The most usual means of applying water to move machinery is through the agency of a water wheel. Water wheels may be distinguished into two great classes; 1st., those which are put in motion by the weight of water; and, 2nd., those which derive their motion from the velocity of running water. The first are called overshot, and the second undershot. In the first the stream of water falls into buckets near the top of the wheel, and by its weight causes the buckets to descend to the bottom, where they empty themselves. Such a wheel is employed at Catrine, in Ayrshire, which is certainly one of the largest wheels in the country. The frame work is constructed of iron, and motion is given to the machinery from teeth on the side of the circumference.

The undershot water wheel consists of flat pieces of wood, called floats, disposed on the circumference of a wheel, which floats being acted upon by the stream of running water the wheel is turned round. The breast wheel partakes of the nature of both of these, its form being exactly like that of the undershot wheel, the only difference between the two being that in the breast wheel the water strikes the floats about half way up its circumference, and thus acts by its weight as well as its velocity, while on the other hand the water strikes the floats of the undershot wheel as nearly as possible at the bottom, so that the water may have acquired as great a velocity as possible before it has reached the floats of the wheel. Under the article *Breast Wheel* we have given particulars as to the construction of that species of wheel, and in our article *Mill* we have given the data for calculating the effect of a fall of water; in this place it only remains for us to lay down a summary of the maxims for overshot and undershot wheels.—See also *Overshot Wheel.*

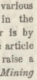
The ratio between the power and effect of an undershot wheel is as 10 to 3·18. The velocity of the periphery of the undershot wheel should be equal to half the velocity of the stream; the float-boards should be so constructed as to rise perpendicularly from the water; not more than one half should ever be below the surface; and from 3 to 5 should be immersed at once. The virtual or effective head of water being the same, the effect will be nearly as the quantity expended. That is, if a mill, driven by a fall of water, whose virtual head is 10 feet, and which discharges 30 cubic feet of water in a second, grind four bolls of corn in an hour; another mill, having the same virtual head, but which discharges 60 cubic feet of water, will grind eight bolls of corn in an hour. The expence of water being the same, the expence will be nearly as the height of the virtual or effective head. The quantity of water expended being the same, the effect is nearly as the square of its velocity. That is, if a mill, driven by a certain quantity of water moving with the velocity of four feet per second, grind three bolls of corn in an hour; another mill, driven by the same quantity of water, moving with the velocity of five feet per second, will grind nearly $4\frac{7}{10}$ bolls in the hour, because $3 : 4\frac{7}{10} : : 4^2 : 5^2$ nearly.

The aperture being the same, the effect will be nearly as the cube of the velocity of the water. That is, if a mill, driven by water, moving through a certain aperture, with a velocity of four feet per second, grind three bolls of corn in an hour; another mill, driven with water, moving through the same aperture with the velocity of five feet per second, will grind $5\frac{43}{50}$ bolls nearly in an hour, for as $3 : 5\frac{43}{50} : : 4^3 : 5^3$ nearly.

The effect of the overshot wheel, under the same circumstances of quantity and fall, is, at a medium, double to that of the undershot. The velocity of the periphery of an overshot wheel should be from $6\frac{1}{2}$ to $8\frac{1}{2}$ feet per second. The higher the wheel is, in proportion to the whole descent, the greater will be the effect; and the effects, as well as the powers, are as the quantities of water and perpendicular heights multiplied together respectively.

WATER WORKS. Under this head may be comprehended the raising of water by means of pumps, wheels, &c. A description of the various kinds of pumps will be found under the head Pneumatics, in the Mechanic's Calculator. A very ingenious mode of raising water is by means of Montgolfier's water ram, which is described under the article Hydrodynamics in this Dictionary. The power necessary to raise a given quantity of water will be found specified under the articles *Mining Engine*, and *Pumping*.

WEDGE, one of the six mechanical powers, the properties of which depend upon somewhat the same principles as those of the inclined plane. The wedge is made of some hard material, as wood or iron, and has that form which, in geometry, is called the triangular prism. The annexed diagram is a side view of the wedge, in which



A B is the thickness,
C D the depth,
C A, or C B the length.

The wedge is commonly used for splitting timber; its edge being introduced and forced inwards by the application of mechanical power at the back. In theoretical mechanics it is shown that there will be an equilibrium when the power acting against the back is to the resistance acting perpendicularly against either side as is the thickness to the length of that side.

Notwithstanding what has been said on the theory of the wedge, there are introduced in it so many conditions which are inapplicable in practice, and inconsistent with practical truth, that the whole doctrine has little value. In the first place, in theory the resistance is supposed to be that modification of force called pressure, and the power which is opposed to it, is that description of action denominated, percussion, or striking. These two modifications of force are so different as not to admit even of comparison; and it is evident that this difference is sufficient to demonstrate the total impossibility of establishing the condition of equilibrium of a machine, in which the weight or resistance is a force of the one, and the power of a force of the other species.

In all cases where the wedge is used practically, the friction of its sides with the surface of the substance to be cleft, is sufficient of itself to keep the equilibrium, and to prevent the wedge recoiling; so that strictly speaking, it requires no force whatever to sustain the equilibrium, and to propel or drive forward the wedge; percussion is always resorted to in preference to pressure, as being infinitely more effective. The only general theoretical principle which holds true in the practical application of the wedge is, that its power is increased by diminishing the angle.

The wedge is a mechanical power of singular efficacy, and the percussion by which its power is increased, is precisely that force which we may with ease increase almost indefinitely.

WEIGHTS, TABLES OF.

ENGLISH.

AVOIRDUPOIS WEIGHT.

Drams.
16 = 1 Ounce.
256 = 16 = 1 Pound.
7168 = 448 = 28 = 1 Quarter.
286782 = 1792 = 112 = 4 = 1 Cwt.
573440 = 35840 = 2240 = 80 = 20 = 1 Ton.

Tons are marked *t.*; hundred-weights, *cwt.*; quarters, *qr.*; pounds, *lbs.*; ounces, *oz.*; and drams, *dr.*

TROY WEIGHT.

Grains.
24 = 1 Penny weight.
480 = 20 = 1 Ounce.
5760 = 240 = 12 = 1 Pound.

Pounds are marked *lbs.*; ounces, *oz.*; penny weights, *dwt.*; and grains, *gr.*

REMARKS ON ENGLISH WEIGHTS AND MEASURES.

Troy weight is used frequently by chemists. and also in weighing gold, silver, and jewels; but all metals, except gold and silver, are weighed by avoirdupois weight.

175 troy pounds are equal to 144 avoirdupois pounds.

175 troy ounces = 192 avoirdupois ounces.

14 oz., 11 dwt., 15½ grs. troy = 1 lb. avoirdupois.

18 dwt., 5½ gr. troy = 1 oz. avoirdupois.

A chaldron of coals in London = 36 bushels, and weighs 3136 lbs. avoirdupois, or nearly 1 ton, 8 cwt.

The ale gallon contains 282 cubic inches, and the wine gallon contains 231 cubic inches,—the wine gallon being to the ale gallon nearly as 1 lb. avoirdupois to 1 lb. troy.

The imperial gallon contains 277·274 cubic inches.

The pound troy contains 5760 grains.

The pound avoirdupois contains 7000 grains.

FRENCH WEIGHTS.

OLD SYSTEM.

		English Troy Grains.
The Paris Pound	=	7561
Ounce	=	472·5625
Gros	=	59·0103
Grain	=	·8204

NEW SYSTEM.

	English Grains.
Milligramme . . . =	·0154
Centigramme . . . =	·1544
Decigramme . . . =	1·5444
Gramme . . . . =	15·4440
Decagramme . . . =	154·4402
Hecatogramme . . . =	1544·4023
Chiliogramme (Kilogram) =	15444·0234
Myrigramme . . . =	154440·2344

A Decagramme is 6 dwts. 10·44 gr. troy; or 5·65 dr. avoir.
A Hecatogramme is 3 oz. 8·5 dr. avoir.
A Chiliogramme is 2 lbs. 3 oz. 5 dr. avoir.
A Myriogramme is 22 lbs. 1·15 oz. avoir.
100 Myriogrammes are 1 ton, wanting 32·8 lbs.

WELDING, the operation of combining or joining two pieces of iron or steel, by bringing the surfaces to be joined to a heat nearly equal to that of fusion. When the metal is heated to the proper temperature it appears to be covered with a sort of varnish, an appearance which is still more marked in the case of steel than of iron. When the pieces are brought to the proper heat they are speedily scraped, placed in contact, and fixed together by hammering. Care should be taken to prevent the iron from running, as also to keep the fire free from clinkers and sulphur. In endeavouring to weld iron with steel it should be remembered that cast steel is incapable of welding, shear steel therefore must be employed. Care must be taken not to raise the temperature of the steel beyond the requisite point.

WHEEL AND AXLE. See *Axle*.

WHEEL CARRIAGE. See *Carriage*.

WHEEL. The rules for determining the respective numbers of the teeth of wheels to effect a given change in speed will be found in the section Mechanics, in the Mechanic's Calculator, as also the method of determining their proper forms. To expedite calculation in determining the pitches of teeth and corresponding diameter of wheels, the following table has been inserted. The table has been calculated with great care by Mr Frazer, and is the most correct and extensive hitherto published.

Table of the Diameter, in inches, of Wheels, from 10 to 340 teeth, and the pitch from 1¼ to 3½ inches.

No. of teeth.	Pitch. 1¼ Diam.	Pitch. 1½ Diam.	Pitch. 1¾ Diam.	Pitch. 2 Diam.	Pitch. 2¼ Diam.	Pitch. 2½ Diam.	Pitch. 2¾ Diam.	Pitch. 3 Diam.	Pitch. 3¼ Diam.	Pitch. 3½ Diam.
10	3·978	4·774	5·570	6·366	7·161	7·957	8·753	9·549	10·345	11·140
11	4·376	5·252	6·127	7·002	7·878	8·753	9·628	10·504	11·379	12·254
12	4·774	5·729	6·684	7·639	8·594	9·549	10·504	11·459	12·414	13·368
13	5·172	6·207	7·241	8·276	9·310	10·345	11·379	12·414	13·448	14·482
14	5 570	6·684	7·798	8·912	10·026	11·140	12·254	13·368	14·482	15·596
15	5·968	7·161	8·355	9·549	10·742	11·936	13·130	14·324	15·517	16·710
16	6 366	7·639	8·912	10·185	11·459	12·732	14·005	15·278	16·552	17·824
17	6·764	8·116	9·469	10·822	12·175	13·528	14·880	16·233	17·586	18·939
18	7·161	8·594	10·026	11·459	12·891	14·324	15·756	17·188	18·621	20·053
19	7·559	9·071	10·583	12·095	13·607	15·119	16·631	18·143	19·655	21·167
20	7·957	9·549	11·140	12·732	14·324	15·915	17·507	19·098	20·690	22·281
21	8·355	10·026	11·697	13·368	15·040	16·711	18·382	20·053	21·724	23·396
22	8·753	10·504	12·254	14·005	15·756	17·507	19·257	21·008	22·759	24·510
23	9·151	10·981	12·811	14·641	16·472	18·303	20·132	21·963	23·793	25·624
24	9·549	11·459	13·368	15·278	17·188	19·098	21·008	22·918	24·828	26·738
25	9·947	11·936	13·926	15·915	17·905	19·894	21·883	23·873	25·862	27·852
26	10·345	12·414	14·483	16·552	18·621	20·690	22·759	24·828	26·897	28·966
27	10·742	12·891	15·040	17·188	19·337	21·485	23·634	25·783	27·931	30·080
28	11·140	13·368	15·596	17·824	20·053	22·281	24·509	26·738	28·966	31·194
29	11·538	13·845	16·153	18·460	20·770	23·077	25·384	27·693	30·000	32·308
30	11·936	14·324	16·711	19·098	21·485	23·873	26·260	28·647	31·035	33·422
31	12·334	14·801	17·268	19·734	22 202	24·668	27·135	29·602	32·069	34·536
32	12·732	15·278	17·824	20·370	22·918	25·464	28·010	30·557	33·104	35·650
33	13·130	15·755	18·382	21·008	23·635	26·260	28·885	31·512	34·139	36·764
34	13·528	16·233	18·939	21·644	24·352	27·056	29·760	32·468	35·173	37·878
35	13·926	16·711	19·496	22·280	25·069	27·852	30·635	33·423	36·208	38·992
36	14·324	17·188	20·053	22·918	25·783	28·647	31·512	34·377	37·242	40·106
37	14·722	17·666	20·610	23·554	26·499	29·443	32·387	35·332	38·276	41·221
38	15·119	18·143	21·167	24·191	27·215	30·239	33·263	36·287	39·311	42·335
39	15 517	18·621	21·724	24·828	27·931	31·035	34·138	37·242	40·345	43·449
40	15·915	19·098	22·281	25·464	28·647	31·830	35·014	38·197	41·380	44·563
41	16·313	19·575	22·838	26·101	29·363	32 626	35·889	39·151	42·414	45·677
42	16·711	20·053	23·395	26·737	30·080	33·422	36·764	40·106	43·449	46·791
43	17·109	20·530	23·952	27·374	30·796	34·218	37·640	41·061	44·483	47·905
44	17·507	21·008	24·509	28·011	31·512	35·013	38·515	42·016	45·518	49·019
45	17·905	21·485	25·066	28·647	32·228	35·809	39·390	42·971	46·552	50·133
46	18.303	21·963	25·623	29·284	32·944	36·605	40·266	43·926	47·587	51·247
47	18·700	22·440	26·180	29·920	33·661	37·401	41·141	44·881	48·621	52·361
48	19·098	22 918	26·737	30·557	34·377	38·197	42·016	45·836	49·656	53·475
49	19·496	23·395	27·294	31·194	35·093	38·992	42·892	46·791	50·690	54·589
50	19·894	23·873	27·852	31·830	35·809	39·788	43·767	47·746	81·725	55·704
51	20·292	24·350	28·409	32·467	36·525	40·584	44 642	48·701	52·757	56·818
52	20·690	24·828	28·966	33·104	37·242	41·380	45·518	49·656	53·794	57·932
53	21·088	25·305	29·523	33·740	37·958	42·175	46·393	50·611	54·828	59·046
54	21·486	25·782	30·080	34·377	38·674	42·971	47·268	51·565	55·863	60·160
55	21·884	26·260	30·637	35·013	39·390	43·767	48·144	52·520	56·897	61·274
56	22·281	26·737	31·194	35·650	40·106	44·563	49·013	53·475	57·923	62·388
57	22·679	27·215	31·751	36·287	40·823	45·358	49·894	54·430	58·966	63·502
58	23·077	27·692	32·308	36·923	41·539	46·154	50·770	55·385	60 001	64·618
59	23·475	28·170	32·865	37·560	42·255	46·950	51·645	56·340	61·035	65·730
60	23·873	28·647	33·422	38·197	42·971	47·746	52·520	57·295	62·070	66·844
61	24·271	29·125	33·979	38·833	43·687	48·542	53·395	58·250	63·104	67·958
62	24·668	29·602	34·536	39·470	44·404	49·337	54·271	59·205	64·139	69·073
63	25·066	30·080	35·093	40·106	45·120	50·733	55·146	60·160	65·173	70·187
64	25·464	30·557	35·650	40·743	45·836	50·929	56·021	61·115	66·208	71·301
65	25·862	31·035	36·207	41·380	46·552	51·725	56·897	62·070	67·242	72·415
66	26·260	31·512	36·764	42·016	47·268	52·520	57·772	63·025	68·277	73·529
67	26·658	31·990	37·321	42·653	47·985	53·316	58 648	63·980	69·311	74·643
68	27·056	32·467	37·878	43·289	48·701	54·112	59·523	64·935	70·346	75·757
69	27·454	32·944	38·435	43·926	49·417	54·908	60·398	65·889	71·380	76·871
70	27·851	33·422	38·992	44·563	50·133	55·704	61·274	66·844	72·415	77·985
71	28·249	33·899	39·549	45·199	50·849	56·499	62·149	67·799	73·449	79·099
72	28·647	34·377	40·106	45·836	51·566	57·295	63·025	68·754	74·484	80·213
73	29·045	34·854	40·663	46·473	52·282	58·091	63·900	69·709	75·518	81·327
74	29·443	35·332	41·220	47·109	52·998	58·887	64·775	70·664	76·553	82·442

Table of the Diameter of Wheels, continued.

No. of teeth.	Pitch. 1¼ Diam.	Pitch. 1½ Diam.	Pitch. 1¾ Diam.	Pitch. 2 Diam.	Pitch. 2¼ Diam.	Pitch. 2½ Diam.	Pitch. 2¾ Diam.	Pitch. 3 Diam.	Pitch. 3¼ Diam.	Pitch. 3½ Diam.
75	29·841	35·809	41·778	47·746	53·714	59·682	65·651	71·619	77·587	83·556
76	30·239	36·287	42·335	48·382	54·430	60·478	66·526	72·574	78·622	84·670
77	30·637	36·764	42·892	49·019	55·146	61·274	67·401	73·529	79·656	85·784
78	31·034	37·242	43·449	49·656	55·863	62·070	68·277	74·484	80·691	86·898
79	31·432	37·719	44·006	50·292	56·579	62·866	69·152	75·439	81·725	88·012
80	31·830	38·197	44·563	50·929	57·295	63·661	70·028	76·394	82·760	89·126
81	32·228	38·674	45·120	51·565	58·011	64·457	70·903	77·349	83·794	90·240
82	32·626	39·151	45·677	52·202	58·727	65·253	71·778	78·304	84·829	91·354
83	33·024	39·629	46·234	52·839	59·444	66·049	72·654	79·258	85·863	92·468
84	33·422	40·106	46·791	53·475	60·160	66·844	73·529	80·213	86·898	93·582
85	33·820	40·584	47·348	54·112	60·876	67·640	74·404	81·168	87·932	94·696
86	34·218	41·061	47·905	54·748	61·592	68·436	75·280	82·123	88·967	95·810
87	34·615	41·539	48·462	55·385	62·308	69·232	76·155	83·078	90·001	96·925
88	35·013	42·016	49·019	56·022	63·025	70·027	77·030	84·033	91·036	98·039
89	35·411	42·494	49·576	56·658	63·741	70·823	77·906	84·988	92·070	99·153
90	35·809	42·971	50·133	57·295	64·457	71·619	78·781	85·943	93·105	100·267
91	36·207	43·449	50·690	57·932	65·173	72·415	79·656	86·898	94·139	101·381
92	36·605	43·926	51·247	58·568	65·889	73·211	80·532	87·853	95·174	102·495
93	37·003	44·404	51·804	59·205	66·606	74·006	81·407	88·808	96·208	103·609
94	37·401	44·881	52·361	59·841	67·322	74·802	82·282	89·763	97·243	104·723
95	37·798	45·358	52·918	60·478	68·038	75·598	83·158	90·717	98·277	105·837
96	38·196	45·836	53·475	61·115	68·754	76·394	84·033	91·672	99·312	106·951
97	38·594	46·313	54·032	61·751	69·470	77·189	84·908	92·627	100·346	108·065
98	38·992	46·791	54·589	62·388	70·186	77·985	85·784	93·582	101·381	109·179
99	39·390	47·268	55·146	63·024	70·903	78·781	86·659	94·537	102·415	110·294
100	39·788	47·746	55·704	63·661	71·619	79·577	87·535	95·492	103·450	111·408
101	40·186	48·223	56·261	64·298	72·335	80·373	88·410	96·447	104·484	112·522
102	40·584	48·701	56·818	64·935	73·051	81·168	89·285	97·402	105·519	113·636
103	40·982	49·178	57·375	65·571	73·768	81·964	90·161	98·357	106·553	114·750
104	41·380	49·656	57·932	66·208	74·484	82·760	91·036	99·312	107·588	115·864
105	41·778	50·133	58·489	66·844	75·200	83·556	91·911	100·267	108·622	116·978
106	42·175	50·611	59·046	67·481	75·916	84·351	92·787	101·222	109·657	118·092
107	42·573	51·088	59·603	68·118	76·632	85·147	93·662	102·177	110·691	119·206
108	42·971	51·566	60·160	68·754	77·349	85·943	94·537	103·132	111·726	120·320
109	43·369	52·043	60·717	69·391	78·065	86·739	95·413	104·087	112·760	121·434
110	43·767	52·520	61·274	70·027	78·781	87·534	96·288	105·042	113·795	122·548
111	44·165	52·998	61·831	70·664	79·497	88·330	97·163	105·996	114·829	123·663
112	44·563	53·475	62·388	71·301	80·213	89·126	98·039	106·951	115·864	124·777
113	44·960	53·953	62·945	71·937	80·930	89·922	98·914	107·906	116·898	125·891
114	45·358	54·430	63·502	72·574	81·646	90·718	99·789	108·861	117·933	127·005
115	45·756	54·908	64·059	73·210	82·362	91·513	100·665	109·816	118·967	128·119
116	46·154	55·385	64·616	73·847	83·078	92·309	101·540	110·771	120·002	129·233
117	46·552	55·863	65·173	74·484	83·794	93·105	102·415	111·726	121·036	130·347
118	46·950	56·340	65·730	75·120	84·510	93·901	103·291	112·681	122·071	131·461
119	47·348	56·818	66·287	75·757	85·227	94·696	104·166	113·636	123·105	132·575
120	47·746	57·296	66·844	76·394	85·943	95·492	105·042	114·591	124·140	133·689
121	48·144	57·773	67·401	77·030	86·659	96·288	105·917	115·546	125·175	134·803
122	48·542	58·250	67·958	77·667	87·375	97·084	106·792	116·501	126·209	135·918
123	48·939	58·728	68·516	78·303	88·091	97·880	107·668	117·456	127·244	137·032
124	49·337	59·205	69·073	78·940	88·808	98·675	108·543	118·410	128·278	138·146
125	49·735	59·682	69·630	79·577	89·524	99·471	109·418	119·365	129·313	139·260
126	50·133	60·160	70·187	80·213	90·240	100·267	110·294	120·320	130·347	140·374
127	50·531	60·637	70·744	80·850	90·956	101·063	111·169	121·275	131·382	141·488
128	50·929	61·115	71·301	81·486	91·672	101·858	112·044	122·230	132·416	142·602
129	51·327	61·592	71·858	82·123	92·389	102·654	112·920	123·185	133·451	143·716
130	51·725	62·070	72·415	82·760	93·105	103·450	113·795	124·140	134·485	144·830
131	52·122	62·547	72·972	83·396	93·821	104·246	114·670	125·095	135·520	145·944
132	52·520	63·025	73·529	84·033	94·537	105·042	115·546	126·050	136·554	147·058
133	52·918	63·502	74·086	84·670	95·254	105·837	116·421	127·005	137·589	148·172
134	53·316	63·980	74·643	85·306	95·971	106·633	117·296	127·960	138·623	149·287
135	53·714	64·457	75·200	85·943	96·687	107·429	118·172	128·915	139·658	150·401
136	54·112	64·935	75·757	86·579	97·403	108·225	119·047	129·870	140·692	151·515
137	54·510	65·412	76·314	87·216	98·119	109·020	119·922	130·824	141·727	152·629
138	54·908	65·890	76·871	87·853	98·835	109·816	120·798	131·779	142·761	153·743
139	55·305	66·367	77·428	88·489	99·551	110·612	121·673	132·734	143·796	154·857

Table of the Diameter of Wheels, continued.

No. of teeth.	Pitch. 1¼ Diam.	Pitch. 1½ Diam.	Pitch. 1¾ Diam.	Pitch. 2 Diam.	Pitch. 2¼ Diam.	Pitch. 2½ Diam.	Pitch. 2¾ Diam.	Pitch. 3 Diam.	Pitch. 3¼ Diam.	Pitch. 3½ Diam.
140	55·703	66·844	77·985	89·126	100·267	111·408	122·548	133·689	144·830	155·971
141	56·101	67·322	78·542	89·762	100·983	112·203	123·424	134·644	145·865	157·085
142	56·499	67·799	79·099	90·399	101·699	112·999	124·299	135·599	146·899	158·199
143	56·897	68·277	79·656	91·036	102·415	113·796	125·174	136·554	147·934	159·313
144	57·295	68·754	80·213	91·673	103·132	114·591	126·050	137·509	148·968	160·427
145	57·693	69·232	80·770	92·309	103·848	115·387	126·925	138·464	150·003	161·541
146	58·091	69·709	81·327	92·946	104·564	116·182	127·801	139·419	151·037	162·655
147	58·489	70·187	81·884	93·582	105·280	116·978	128·676	140·374	152·072	163·770
148	58·887	70·664	82·442	94·219	105·996	117·774	129·551	141·329	153·106	164·884
149	59·285	71·142	82·999	94·856	106·713	118·570	130·427	142·284	154·141	165·998
150	59·682	71·619	83·556	95·492	107·429	119·365	131·302	143·239	155·175	167·112
151	60·080	72·097	84·113	96·129	108·145	120·161	132·177	144·193	156·210	168·226
152	60·478	72·574	84·670	96·765	108·861	120·957	133·053	145·148	157·244	169·340
153	60·876	73·051	85·227	97·402	109·577	121·753	133·928	146·103	158·279	170·454
154	61·274	73·529	85·784	98·039	110·294	122·548	134·803	147·058	159·313	171·568
155	61·672	74·006	86·341	98·675	111·010	123·344	135·679	148·013	160·348	172·682
156	62·070	74·484	86·898	99·312	111·726	124·140	136·554	148·968	161·382	173·796
157	62·468	74·961	87·455	99·948	112·442	124·936	137·429	149·923	162·417	174·910
158	62·865	75·439	88·012	100·585	113·158	125·732	138·305	150·878	163·451	176·024
159	63·263	75·916	88·569	101·222	113·875	126·527	139·180	151·833	164·486	177·139
160	63·661	76·394	89·126	101·858	114·591	127·323	140·056	152·788	165·526	178·253
161	64·059	76·871	89·683	102·495	115·307	128·119	140·931	153·743	166·559	179·367
162	64·457	77·349	90·240	103·132	116·023	128·915	141·806	154·698	167·585	180·481
163	64·855	77·826	90·797	103·768	116·739	129·710	142·682	155·653	168·624	181·595
164	65·253	78·303	91·354	104·405	117·455	130·506	143·557	156·607	169·658	182·709
165	65·651	78·781	91·911	105·041	118·172	131·302	144·432	157·562	170·693	183·823
166	66·049	79·258	92·468	105·678	118·888	132·098	145·308	158·517	171·727	184·937
167	66·446	79·736	93·025	106·315	119·604	132·893	146·183	159·472	172·762	186·051
168	66·844	80·213	93·582	106·951	120·320	133·689	147·058	160·427	173·796	187·165
169	67·242	80·601	94·139	107·588	121·036	134·485	147·934	161·382	174·831	188·279
170	67·640	81·168	94·696	108·225	121·753	135·281	148·809	162·337	175·865	189·393
171	68·038	81·646	95·253	108·862	122·469	136·077	149·684	163·292	176·900	190·508
172	68·436	82·123	95·811	109·499	123·185	136·872	150·560	164·247	177·934	191·622
173	68·834	82·601	96·368	110·135	123·901	137·668	151·435	165·202	178·969	192·736
174	69·232	83·078	96·925	110·772	124·617	138·464	152·310	166·157	180·003	193·850
175	69·629	83·556	97·482	111·408	125·334	139·260	153·186	167·112	181·038	194·964
176	70·027	84·033	98·039	112·045	126·050	140·055	154·061	168·067	182·072	196·078
177	70·425	84·510	98·596	112·682	126·766	140·851	154·936	169·022	183·107	197·192
178	70·823	84·988	99·153	113·318	127·482	141·647	155·812	169·977	184·141	198·306
179	71·221	85·465	99·710	113·955	128·198	142·443	156·687	170·931	185·176	199·420
180	71·619	85·943	100·267	114·591	128·915	143·239	157·563	171·886	186·210	200·534
181	72·017	86·420	100·824	115·227	129·631	144·034	158·438	172·841	187·245	201·648
182	72·415	86·898	101·381	115·864	130·347	144·830	159·313	173·796	188·279	202·762
183	72·813	87·375	101·938	116·501	131·063	145·626	160·189	174·751	189·314	203·876
184	73·211	87·853	102·495	117·137	131·779	146·422	161·064	175·706	190·348	204·991
185	73·608	88·330	103·052	117·774	132·496	147·217	161·939	176·661	191·383	206·105
186	74·006	88·808	103·609	118·410	133·212	148·013	162·815	177·616	192·417	207·219
187	74·404	89·285	104·166	119·047	133·928	148·809	163·690	178·571	193·452	208·333
188	74·802	89·763	104·723	119·684	134·644	149·605	164·565	179·526	194·486	209·447
189	75·200	90·240	105·280	120·320	135·360	150·401	165·441	180·481	195·521	210·561
190	75·598	90·718	105·837	120·957	136·077	151·196	166·316	181·436	196·555	211·675
191	75·996	91·195	106·394	121·593	136·793	151·982	167·19.	182·391	197·590	212·789
192	76·394	91·673	106·951	122·230	137·509	152·788	168·067	183·346	198·624	213·903
193	76·792	92·150	107·508	122·867	138·225	153·584	168·942	184·300	199·659	215·017
194	77·189	92·627	108·065	123·503	138·941	154·379	169·817	185·255	200·693	216·131
195	77·587	93·105	108·622	124·140	139·658	155·175	170·693	186·210	201·728	217·245
196	77·985	93·582	109·180	124·777	140·374	155·971	171·568	187·165	202·762	218·360
197	78·383	94·060	109·737	125·413	141·090	156·767	172·444	188·120	203·797	219·474
198	78·781	94·537	110·294	126·050	141·806	157·563	173·319	189·075	204·831	220·588
199	79·179	95·015	110·85.	126·686	142·522	158·358	174·194	190·030	205·886	221·702
200	79·577	95·492	111·408	127·323	143·239	159·154	175·070	190·985	206·900	222·816
201	79·975	95·970	111·965	127·960	143·955	159·950	175·945	191·949	207·935	223·930
202	80·372	96·447	112·522	128·596	144·671	160·746	176·820	192·695	208·969	225·044
203	80·770	96·925	113·079	129·233	145·387	161·541	177·696	193·850	210·004	226·158
204	81·168	97·402	113·636	129·870	146·103	162·337	178·571	194·805	211·038	227·272

Table of the Diameter of Wheels, continued.

No. of teeth	Pitch. 1¼ Diam.	Pitch. 1½ Diam.	Pitch. 1¾ Diam.	Pitch. 2 Diam.	Pitch. 2¼ Diam.	Pitch. 2½ Diam.	Pitch. 2¾ Diam.	Pitch. 3 Diam.	Pitch. 3¼ Diam.	Pitch. 3½ Diam.
205	81·566	97·880	114·193	130·506	146·820	163·133	179·446	195·760	212·073	228·386
206	81·964	98·357	114·750	131·143	147·536	163·929	180·322	196·714	213·107	229·500
207	82·362	98·834	115·307	131·779	148·252	164·724	181·197	197·669	214·142	230·614
208	82·760	99·312	115·864	132·416	148·968	165·520	182·072	198·624	215·176	231·729
209	83·158	99·789	116·421	133·053	149·684	166·316	182·948	199·579	216·211	232·843
210	83·556	100·267	116·978	133·686	150·400	167·112	183·823	200·534	217·245	233·957
211	83·953	100·744	117·535	134·329	151·117	167·908	184·698	201·489	218·280	235·071
212	84·351	101·222	118·092	134·963	151·833	168·703	185·574	202·444	219·314	236·185
213	84·749	101·699	118·649	135·599	152·549	169·499	186·449	203·399	220·349	237·299
214	85·147	102·177	119·206	136·236	153·265	170·295	187·324	204·354	221·383	238·413
215	85·545	102·654	119·763	136·872	153·982	171·091	188·200	205·309	222·418	239·527
216	85·943	103·132	120·320	137·509	154·698	171·886	189·075	206·264	223·453	240·641
217	86·341	103·609	120·877	138·146	155·414	172·682	189·950	207·219	224·487	241·755
218	86·739	104·087	121·434	138·782	156·130	173·478	190·826	208·174	225·522	242·869
219	87·137	104·564	121·991	139·419	156·846	174·274	191·701	209·129	226·557	243·983
220	87·534	105·041	122·549	140·055	157·562	175·070	192·577	210·083	227·591	245·098
221	87·932	105·519	123·106	140·692	158·279	175·865	193.452	211·038	228·626	246·212
222	88·330	105·996	123·663	141·329	158·995	176·661	194·327	211·993	229·660	247·326
223	88·728	106·474	124·220	141·965	159·711	177·457	195·203	212·948	230·695	248·440
224	89·126	106·951	124·777	142·602	160·427	178·253	196·078	213·903	231·729	249·554
225	89·524	107·429	125·334	143·239	161·143	179·048	196·953	214·858	232·764	250·668
226	89·922	107·906	125·891	143·875	161·860	179·844	197·829	215·813	233·798	251·782
227	90·320	108·384	126·448	144·512	162·576	180·640	198·704	216·768	234·833	252·896
228	90·718	108·861	127·005	145·148	163·292	181·436	199·579	217·723	235·867	254·010
229	91·115	109·339	127·562	145·785	164·008	182·231	200·455	218·678	236·901	255·124
230	91·513	109·816	128·119	146·422	164·725	183·027	201·330	219·633	237·936	256·238
231	91·911	110·294	128·676	147·058	165·441	183·823	202·205	220·588	238·970	257·352
232	92·309	110·771	129·233	147·695	166·157	184·619	203·081	221·543	240·005	258·467
233	92·707	111·249	129·790	148·332	166·873	185·415	203·956	222·498	241·039	259·581
234	93·105	111·726	130·347	148·968	167·589	186·210	204·831	223·452	242·074	260·695
235	93·503	112·203	130·904	149·605	168·305	187·006	205·707	224·407	243·108	261·809
236	93·901	112·681	131·461	150·241	169·022	187·802	206·582	225·362	244·143	262·923
237	94·299	113·158	132·018	150·878	169·738	188·598	207·457	226·317	245·177	264·037
238	94·696	113·636	132·575	151·515	170·454	189·393	208·333	227·272	246·212	265·151
239	95·094	114·113	133·132	152·151	171·170	190·189	209·208	228·227	247·246	266·265
240	95·492	114·591	133·689	152·788	171·886	190·985	210·084	229·182	248·281	267·739
241	95·890	115·068	134·246	153·424	172·603	191·781	210·959	230·137	249·315	268·493
242	96·288	115·546	134·804	154·061	173·319	192·576	211·834	231·092	250·350	269·607
243	96·686	116·023	135·361	154·698	174·035	193·372	212·710	232·047	251·384	270·721
244	97·084	116·501	135·918	155·334	174·751	194·168	213·585	283·002	252·419	271·835
245	97·482	116·978	136·475	155·971	175·467	194·964	214·460	233·957	253·453	272·950
246	97·879	117·456	137·032	156·607	176·184	195·760	215·336	234·912	254·488	274·064
247	98·277	117·933	137·589	157·244	176·900	196·555	216·211	235·866	255·522	275·178
248	98·675	118·410	138·146	157·881	177·616	197·351	217·086	236·821	256·557	276·292
249	99·073	118·888	138·703	158·517	178·332	198·147	217·962	237·776	257·591	277·406
250	99·471	119·365	139·260	159·154	179·048	198·943	218·837	238·731	258·626	278·520
251	99·869	119·843	139·817	159·790	179·764	199·738	219·712	239·686	259·660	279·634
252	100·267	120·320	140·374	160·427	180·481	200·534	220·588	240·641	260·695	280·748
253	100·665	120·798	140·931	161·064	181·197	201·330	221·463	241·596	261·729	281·862
254	101·063	121·275	141·488	161·701	181·913	202·126	222·338	242·551	262·764	282·976
255	101·461	121·753	142·045	162·337	182·629	202·922	223·214	243·506	263·798	284·090
256	101·858	122·230	142·602	162·974	183·346	203·717	224·089	244·461	264·833	285·204
257	102·256	122·708	143·159	163·610	184·062	204·513	224·964	245·416	265·867	286·319
258	102·654	123·185	143·716	164·247	184·778	205·309	225·840	246·371	266·902	287·433
259	103·052	123·663	144·273	164·884	185·494	206·105	226·715	247·326	267·936	288·547
260	103·450	124·140	144·830	165·520	186·210	206·900	227·591	248·281	268·971	289·661
261	103·848	124·618	145·387	166·157	186·927	207·696	228·466	249·236	270·005	290·775
262	104·246	125·095	145·944	166·793	187·643	208·492	229·341	250·190	271·040	291·889
263	104·644	125·572	146·501	167·430	188·359	209·288	230·217	251·145	272·074	293·003
264	105·041	126·050	147·058	168·067	189·075	210·084	231·092	252·100	273·109	294·117
265	105·439	126·527	147·615	168·703	189·791	210·879	231·967	253·055	274·143	295·231
266	105·837	127·005	148·172	169·340	190·507	211·675	232·843	254·010	275·178	296·345
267	106·235	127·482	148·729	169·977	191·224	212·471	233·718	254·965	276·212	297·459
268	106·633	127·960	149·286	170·613	191·940	213·267	234·593	255·920	277·247	298·573
269	107·031	128·437	149·844	171·250	192·656	214·062	235·469	256·875	278·281	299·688

Table of the Diameter of Wheels, continued.

No. of teeth	Pitch. 1¼ Diam.	Pitch. 1½ Diam.	Pitch. 1¾ Diam.	Pitch. 2 Diam.	Pitch. 2¼ Diam.	Pitch. 2½ Diam.	Pitch. 2¾ Diam.	Pitch. 3 Diam.	Pitch. 3¼ Diam.	Pitch. 3½ Diam.
270	107·429	128·915	150·401	171·886	193·372	214·858	236·344	257·830	279·316	300·802
271	107·827	129·392	150·958	172·523	194·088	215·654	237·219	258·785	280·350	301·916
272	108·225	129·870	151·515	173·160	194·805	216·450	238·095	259·740	281·385	303·030
273	108·622	130·347	152·072	173·796	195·521	217·245	238·970	260·695	282·419	304·144
274	109·020	130·825	152·629	174·433	196·237	218·041	239·845	261·650	283·454	305·258
275	109·418	131·302	153·186	175·069	196·953	218·837	240·721	262·604	284·488	306·372
276	109·816	131·779	153·743	175·706	197·669	219·633	241·596	263·559	285·523	307·486
277	110·214	132·257	154·300	176·343	198·386	220·429	242·471	264·514	286·557	308·600
278	110·612	132·734	154·857	176·979	199·102	221·224	243·347	265·469	287·592	309·714
279	111·010	133·212	155·414	177·616	199·818	222·020	244·222	266·424	288·626	310·828
280	111·408	133·689	155·971	178·253	200·534	222·816	245·098	267·379	289·661	311·942
281	111·806	134·167	156·528	178·889	201·250	223·612	245·973	268·334	290·695	313·057
282	112·203	134·644	157·085	179·526	201·967	224·407	246·848	269·289	291·730	314·171
283	112·601	135·122	157·642	180·162	202·683	225·203	247·724	270·244	292·764	315·255
284	112·999	135·599	158·199	180·799	203·399	225·999	248·599	271·199	293·799	316·399
285	113·397	136·077	158·756	181·436	204·115	226·795	249·474	272·154	294·833	317·513
286	113·795	136·554	159·313	182·072	204·831	227·591	250·350	273·109	295·868	318·627
287	114·193	137·032	159·870	182·709	205·548	228·386	251·225	274·064	296·902	319·741
288	114·591	137·509	160·427	183·346	206·264	229·182	252·100	275·019	297·937	320·855
289	114·989	137·987	160·984	183·982	206·980	229·978	252·974	275·974	298·971	321·969
290	115·387	138·464	161·541	184·619	207·696	230·774	253·851	276·928	300·006	323·083
291	115·784	138·941	162·098	185·255	208·412	231·569	254·726	277·883	301·040	324·197
292	116·182	139·419	162·655	185·892	209·129	232·565	255·632	278·838	302·075	325·311
293	116·580	139·896	163·213	186·529	209·845	233·161	256·477	279·793	303·109	326·426
294	116·978	140·374	163·770	187·165	210·561	233·957	257·352	280·748	304·144	327·540
295	117·376	140·851	164·327	187·802	211·277	234·752	258·228	281·703	305·178	328·654
296	117·774	141·329	164·884	188·438	211·993	235·548	259·103	282·658	306·213	329·768
297	118·172	141·806	165·441	189·075	212·710	236·344	259·978	283·613	307·247	330·882
298	118·570	142·284	165·998	189·712	213·426	237·140	260·854	284·568	308·282	331·996
299	118·967	142·761	166·555	190·348	214·142	237·936	261·729	285·523	309·316	333·110
300	119·365	143·239	167·112	190·985	214·858	238·731	262·605	286·478	310·351	334·224
301	119·763	143·716	167·669	191·622	215·574	239·527	263·480	287·433	311·385	335·338
302	120·161	144·193	168·226	192·258	216·291	240·323	264·355	288·388	312·420	336·452
303	120·559	144·671	168·783	192·895	217·007	241·119	265·231	289·342	313·454	337·566
304	120·957	145·148	169·340	193·531	217·723	241·914	266·106	290·297	314·489	338·680
305	121·355	145·626	169·897	194·168	218·439	242·710	266·981	291·252	315·523	339·794
306	121·753	146·103	170·454	194·805	219·155	243·506	267·857	292·207	316·558	340·909
307	122·151	146·581	171·011	195·441	219·872	244·302	268·732	293·162	317·592	342·023
308	122·548	147·058	171·568	196·078	220·588	245·098	269·607	294·117	318·627	343·137
309	122·946	147·536	172·125	196·714	221·304	245·893	270·483	295·072	319·661	344·251
310	123·344	148·013	172·682	197·351	222·020	246·689	271·358	296·027	320·696	345·365
311	123·742	148·491	173·239	197·988	222·736	247·485	272·233	296·982	321·730	346·479
312	124·140	148·968	173·796	198·624	223·453	248·281	273·109	297·937	322·765	347·593
313	124·538	149·446	174·353	199·261	224·169	249·076	273·984	298·892	323·799	348·707
314	124·936	149·923	174·910	199·898	224·885	249·872	274·859	299·847	324·834	349·821
315	125·334	150·401	175·467	200·534	225·601	250·668	275·735	300·802	325·868	350·935
316	125·732	150·878	176·024	201·171	226·317	251·464	276·610	301·757	326·903	352·049
317	126·129	151·355	176·581	201·807	227·033	252·259	277·485	302·711	327·937	353·163
318	126·527	151·833	177·139	202·444	227·750	253·055	278·361	303·666	328·972	354·278
319	126·925	152·310	177·696	203·081	228·466	253·851	279·236	304·621	330·006	355·392
320	127·323	152·788	178·253	203·717	229·182	254·647	280·112	305·576	331·041	356·506
321	127·721	153·265	178·810	204·354	229·898	255·443	280·987	306·531	332·075	357·620
322	128·119	153·743	179·367	204·991	230·614	256·238	281·862	307·486	333·110	358·734
323	128·517	154·220	179·924	205·627	231·331	257·034	282·738	308·441	334·144	359·848
324	128·915	154·698	180·481	206·264	232·047	257·830	283·613	309·396	335·179	360·962
325	129·313	155·178	181·038	206·900	232·763	258·626	284·488	310·351	336·214	362·076
326	129·710	155·653	181·595	207·537	233·479	259·421	285·364	311·306	337·248	363·190
327	130·108	156·130	182·152	208·174	234·195	260·217	286·239	312·261	338·283	364·304
328	130·506	156·608	182·709	208·810	234·912	261·013	287·114	313·216	339·317	365·418
329	130·904	157·085	183·266	209·447	235·628	261·809	287·990	314·171	340·352	366·532
330	131·302	157·563	183·823	210·083	236·344	262·605	288·865	315·126	341·386	367·647
331	131·700	158·040	184·380	210·720	237·060	263·400	289·740	316·080	342·421	368·761
332	132·098	158·517	184·937	211·357	237·776	264·196	290·616	317·035	343·455	369·875
333	132·496	158·995	185·494	211·993	238·493	264·992	291·491	317·990	344·490	370·989
334	132·894	159·472	186·051	212·630	239·209	265·788	292·366	318·945	345·524	372·103

Table of the Diameter of Wheels, continued.

No. of teeth	Pitch. $1\frac{1}{4}$ Diam.	Pitch. $1\frac{1}{2}$ Diam.	Pitch. $1\frac{3}{4}$ Diam.	Pitch. 2 Diam.	Pitch. $2\frac{1}{4}$ Diam.	Pitch. $2\frac{1}{2}$ Diam.	Pitch. $2\frac{3}{4}$ Diam.	Pitch. 3 Diam.	Pitch. $3\frac{1}{4}$ Diam.	Pitch. $3\frac{1}{2}$ Diam.
335	133·291	159·950	186·608	213·267	239·925	266·583	293·242	319·900	346·559	373·217
336	133·689	160·427	187·165	213·903	240·641	267·379	294·117	320·855	347·593	374·331
337	134·087	160·905	187·722	214·540	241·357	268·175	294·992	321·810	348·628	375·445
338	134·485	161·382	188·279	215·176	242·074	268·971	295·865	322·765	349·662	376·559
339	134·883	161·860	188·836	215·813	242·790	269·766	296·743	323·720	350·697	377·673
340	135·281	162·337	189·393	216·450	243·506	270·562	297·619	324·675	351·731	378·787

This table gives, by inspection, the diameters, in inches, of wheels, from 10 to 340 teeth and the pitch from $1\frac{1}{4}$ to $3\frac{1}{2}$ inches. If any other diameter be wanted (within the tabular number of teeth, but the pitch either a multiple or a measure of the above) it may be found by multiplication or division, thus; let the pitch be 7 inches, and the number of teeth 38; then 7 being the double of $3\frac{1}{2}$, under $3\frac{1}{2}$ and opposite 38 is 42·335, which, being multiplied by 2, gives 84·67 as the diameter required. Or, let the pitch be $\frac{1}{8}$ inch and the teeth 26; then, $\frac{1}{8}$ being the sixteenth part of 2 inches, under 2 and opposite 26 is 16·552, which, divided by 16, gives 1·0345 as the diameter required.

Wind; our limits will not permit us to enter into minute details on this subject. The subject has been treated in the Mechanic's Calculator, to which this volume is intended as a companion. We subjoin a table of the force of winds which may be useful in computations as to the effect of windmills.

Velocity in miles per hour.	A wind may be denominated when it does not exceed the velocity opposite to it.	Velocity per second.	Force on a square foot.
6·8	A gentle pleasant wind..............	10 feet	0·129 lbs.
13·6	A brisk gale....................	20 ..	0·915 ..
19·5	A very brisk gale.................	30 ..	2·059 ..
34·1	A high wind	50 ..	5·718 ..
47·7	A very high wind..................	70 ..	11·207 ..
54·5	A storm or tempest	80 ..	14·638 ..
68·2	A great storm......................	100 ..	22·872 ..
81·8	A hurricane	120 ..	32·926 ..
102·3	A violent hurricane, that tears up trees, overturns buildings, etc..	150 ..	51·426 ..

Mr Smeaton found that when the velocity of the winds was 3, 5, and 6 miles an hour, the velocities of the sails, compared to that of the wind, were respectively as 0·666, 0·809, 0·83 to 1, the radius of the sail is 3 feet.

REFERENCES TO PLATES.

The Plates exhibiting views of the Portable Engine, and also of the Marine Engine, will be understood by a careful inspection after the articles describing their several parts have been read.

Locomotive Engine.—Various views of this railway steam carriage are given in plates No. 1 and 2. A side elevation is shown in fig. 1, No. 1; figs. 2 and 3 are end elevations, the former showing the back, and the latter the front elevation, fig. 4, is an end view of the boiler. Fig. 1, plate No. 2, is a ground plan, and fig. 2 a section and 3 a side view, with some parts taken away, in order to show the more concealed portions of the machinery. The same letters of reference are used in all the figures.

The boiler, an end view of which is represented in fig. 4, plate No. 1, consists of a metallic cylinder, having two flat ends, the cylinder being commonly about six feet in length. The under half of this cylinder is occupied by 80 or 100 copper tubes traversing the whole length, and each of about 1½ inches diameter. These tubes are so many flues, being open at both ends, the one end communicating with the fire box, or furnace, and the other opening into the chimney, thus affording a passage for the smoke and hot air. These pipes being heated, they communicate their caloric to the water which surrounds them, the boiler or cylinder being filled with water to such a height as to cover the tubes. The boiler lies lengthwise in the carriage, as may be seen at A A′ in the longitudinal section, fig. 2, No. 2, and one end of the boiler as was before observed, opens into a fire-box or furnace, seen at *b b a b* in the same section. Tho furnace bars are laid horizontally at *a* as may be seen, also in the ground plan, fig. 1, plate No. 2. The fire box or furnace, is a square box formed of two casings, the one contained within the other. The outside casing communicates with the lower, and also at the upper parts of the boiler, by means of two pipes, therefore when water is poured into the boiler, it flows into the space between the outside casing and the fire-box, and the boiler being constantly kept about half full of water, the casing is consequently well supplied. The steam that is generated in the casing, passes into the boiler by the upper pipe.

Above the fire-box, and communicating with the upper part of the boiler, there is a sort of bell-shaped receiver covered at the top, and opening into the boiler, as seen at E″. From this receiver a pipe is led, one end of which opens into the receiver : at a little distance below, this pipe is bent, having a knee joint, and then traverses horizontally along the whole length of the boiler. At its farther extremity, it opens into two pipes of smaller bore, one of which is seen at *g*, the other being hid in the section. These pipes are bended downwards, in order to supply the cylinders, one of which is seen at R. The hot air and smoke, as before stated, pass along the horizontal tubes in the boiler, rise up through the chimney A, and escape into the air. F is the safety-valve, being of the steel yard kind, but instead of the pressure being regulated by a moveable weight, it is regulated by a spiral steel spring, whose elastic force is measured by a graduated scale. F′ is another safety-valve, wrought in a similar way, but confined withiu a pipe, so that the workmen cannot get at it, in order that should the other valve be too much loaded, the valve F′ will still act, and prevent accident when the force of the steam is greater than it should be. E is the main hole, which is uncovered when the boiler requires to be cleaned. The engine which is of the high pressure kind, is seen at R *r* R′; the cylinders two in number, lie nearly in a horizontal position, being a little inclined upwards towards the fire-box, or back of the carriage.

The alternate motion of the piston rod, gives motion to a crank on the axle of the back wheels, and thus the carriage is propelled. The valves in the nozzles are wrought by an eccentric, V *r*. The rods for putting off or on the steam, as also for working the eccentric that causes the carriage to move either backwards or forwards, are seen at *h* and Z at the end of the fire-box. D is the hot water pump, which may be connected with the gearing at pleasure, by a handle at the command of the engine man, who stands within the rail at the back of the carriage. The whole is suspended on springs, which may be seen at N, in plate No. 1. The above is only intended to be a general description; more particular details will be given in our articles *Railways* and *Steam Engines*.

With regard to locomotive engines, on common roads, it may in general be remarked, that notwithstanding the many ingenious contrivances put in action, to bring them into effective operation, much more requires yet to be done, before they can be brought into competition with railway locomotive engines.

CONTENTS.

THE END.

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