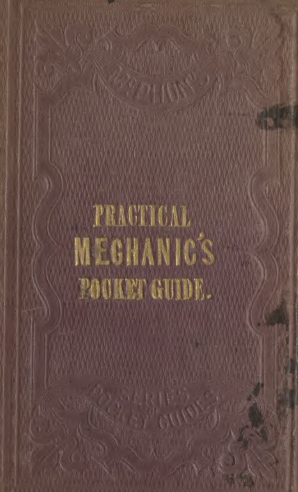

PRACTICAL MECHANIC'S POCKET GUIDE.

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THE GLASGOW

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From the great sale which this work continued to have, long after the completion of the Series, the proprietors were induced to have the whole of it revised throughout from the commencement. In doing this, the plan they adopted was to exclude any articles which appeared of less value to the scientific inquirer, and such as were more of a temporary interest. They are happy to say this has met with the approbation of the public, by a sale *unprecedented in the annals of periodical literature*. To such an extent, indeed, has the sale exceeded their expectations, that they are now enabled to announce

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THE

PRACTICAL MECHANIC'S POCKET GUIDE;

OR A

CONCISE TREATISE

ON THE

PRIME MOVERS OF MACHINERY,

AND THE

WEIGHT AND STRENGTH OF MATERIALS,

WITH NUMEROUS

PRACTICAL RULES AND TABLES.

BY ROBERT WALLACE, A.M.,
Blythswood Hill Mathematical Academy

GLASGOW:
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Seventh Thousand.

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TO

ROBERT NAPIER, Esq.,

VULCAN FOUNDERY, GLASGOW,

MEMBER OF THE GLASGOW PHILOSOPHICAL SOCIETY,

As a testimony of esteem for his character as a Gentleman, and of admiration of his skill and success as a Practical Engineer, this Concise Treatise on subjects of great and increasing importance, and intimately connected with his daily avocations, is respectfully inscribed by his

Most obedient servant,

THE PUBLISHER.

PREFACE.

Among the numerous publications, in the shape of Manuals and Text-books, for the use of Mechanics and Engineers, which have originated in the recent spirit of inquiry, sprung up among the working classes of this country, there seemed still to be wanting, some work which should bring the theory of Mechanical Power, as regards prime movers, to bear more decidedly on practice: and, which should at the same time, take a proper estimate of the limits within which Mechanical constructions are manageable in point of weight, and safe in point of strength. In the first section of this Treatise, is contained an attempt to supply, in some degree, the former desideratum in reference to the prime agents in most common use; in the second section, an attempt is made to supply the latter in reference to the weight and strength of the materials generally employed in constructions. In the third section, will be found a very extensive set of useful tables; first, of the weight of iron, and other metals in various shapes; second, of the specific gravity and weight of materials; third, of steam and steam engines; fourth, of the specific cohesion and strength of materials; fifth, of the mechanical powers. But throughout the whole Treatise, a number of useful tables are interspersed, as may be seen by reference to the table of contents; the *sixth thousand* of this work is now at press. The sequel, under the title of "*The Practical Engineer's Pocket Guide*," just ready for publication, contains the nature and application of Mechanical Forces; the Effects of Friction and other Resistances; and the Elements of Machinery.

These two works, it is hoped, will go far to supply working mechanics and engineers, with a useful manual of practical information, on most subjects of inquiry connected with their daily business; and to the more youthful portion of our readers especially, we embrace this opportunity of recommending to their attention, as likely to add much to their happiness and advancement in the world, another of our publisher's series of Pocket Guides which has just appeared, under the title of "*The Apprentice's Pocket Guide to Wealth and Esteem.*"

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THE

PRACTICAL MECHANIC'S POCKET GUIDE.

SECT. I.—PRIME MOVERS OF MACHINERY.

CHAP. I.

ANIMAL POWER.

1. The force of men and animals to put machinery in motion and to produce mechanical effects of various kinds, depends so much on a variety of complicated circumstances, that it is very difficult to reduce it to a fixed standard of measure. The circumstances which have the greatest share in determining the amount of this force are, the natural constitution of different individuals of the same species, their acquired dexterity or constant practice, the nature of the performance, or the muscles brought into action, and the duration of the labour or the speed with which it is performed. Few of these points can be made the direct subject of calculation, owing to our total ignorance of the divine mechanism by which the living principle is made to operate on the animal structure.

2. *Definitions.*] The laborious effort which an animal can make for a few instants, is greatly superior to that which he can continue to make for the

period of a day's labour. The momentary effort is called the *absolute force*, and the daily effort the *permanent force*. In performing the daily effort there is a certain speed or velocity of action which produces the greatest amount of useful effect; this is called the *maximum effect* of the permanent force. D. Bernouilli considered that the measure of the permanent force of man is nearly a constant quantity, and that it does not vary much either among individuals or in different kinds of labour. Venturoli and others doubt this fact, owing perhaps to the mode in which this force has been estimated; but we think that Bernouilli is right, and that the proposition may be extended to the permanent force of other animals; this force, of course, varying with the species.

The ordinary method of computing mechanical effect or animal power, is by finding the *weight* that can be raised to a certain *height* in a given *time*; then, the *product* of these three quantities is called the *measure* of the labour or force employed in raising the weight, that is, the mechanical effect. Force is also measured by *dynamic units*; thus, a given measure of water or a given weight raised through a given space is a *dynamic unit*; so is the power of an animal exerted during a given unit of time. In France, a dynamic unit is the weight of a cubic metre of water raised to the height of a metre, or 2208 lbs. raised 3.281 feet. In England, the most common dynamic unit is a horse's power, which is variously estimated by engineers. There can be no doubt that a practical man must form a more correct idea of the quantity of mechanical power expressed by this dynamic unit than by any other that could be proposed : because the power of the horse is constantly brought under his observation, both in the impulsion of machinery, and in the transportation of loads.

3. *The Dynamometer* is an instrument for measuring the absolute force of men and animals. Dynamometers of various kinds have been invented; those of the simplest construction are the same in principle as the spring steelyard ; others are either modifications of this instrument or a combination of levers with the spring. The Dynamometer of Regnier consists of an elliptic spring which is bent either by pressing it together at the vertices of the minor axis, or drawing it apart at the vertices of the major axis. In both cases, the sides of the spring are made to approach each other, and thus to move an index which points to a graduated semicircle, and shows the amount of force which has been applied to bend the spring. The semicircle is doubly graduated ; the one scale indicates the force applied at the vertices of the minor axis ; the other scale, that applied at the vertices of the major axis. For a further account of similar instruments, see Lardner's Cyclopædia, vol. v. p. 305.

4. *Human Strength.*] The absolute force of *pressure with the hands* was found by the dynamometer of Regnier, to be on an average equivalent to the weight of 110 lbs. The most advantageous and convenient position of the arms in pressing, is that of a line which makes an angle of 45° with the vertical. The right hand commonly presses with more force than the left ; and the force of both together is equivalent to the sum of the forces of each taken separately.

The absolute force of man in *lifting a weight with both hands* was found by the dynamometer to be on an average equivalent to 286 lbs. The best position of the body in this case is the erect, with the shoulders slightly inclined. The greatest average load which a man can support on his shoulders for some instants, is commonly reckoned 330 lbs.; and it is supposed that he can exert the same force in drawing vertically downwards; but these results are not dynamometrically ascertained.

The mean absolute force of man in *drawing or pulling horizontally* was found by the dynamometer to be the same as that exerted in pressure with the hands, or 110 lbs. The force of the horizontal pull in the strongest men was found to be only about 20 lbs. more than the average; while in the other modes of applying force, much greater differences occurred. The reason appears to be, that in drawing, the force depends more upon the weight of the body than upon muscular force.

5. *Human Labour.*] The permanent force of men and animals cannot be accurately ascertained by the dynamometer; it is only by a series of careful observations on daily labour, that we can arrive at the average useful effect of animal exertion. In order to compare the different estimates of the force of moving powers, Dr. T. Young assumed, as a dynamical unit, the mean effect of the labour of an active man working to the greatest possible advantage: this he considered to be a force capable of raising 10 lbs. 10 feet in a second for 10 hours a day; or, 100 lbs., which is the weight of 10 imperial gallons of water, 1 foot in a second, or 36,000 feet in a day; or, 3,600,000 lbs., or 36,000 impe-

rial gallons, 1 foot in a day: this may be called a force of 1, continued for 36,000 seconds.

M. Schulze, of Berlin, made a series of valuable experiments, in order to determine the accuracy of Euler's empirical formula, or rule expressing the relation between the force and the velocity of animal agents. From experiments on 20 men, of different sizes and constitutions, he found their *mean absolute force*, in lifting weights, to be about 250 lbs.; and in a level pull, about 100 lbs, when standing still, and holding a silken cord passing horizontally over a pulley fixed above a pit, into which weights were suspended at the other end of the cord.

Their mean absolute velocity, that is, when unencumbered by any load, was next ascertained by experiments made on a level plain, where the men marched at a fair pace, without running, for a period of 4 or 5 hours. This velocity was found to be about $5\frac{1}{3}$ feet per second, or 320 feet per minute, or $3\frac{7}{11}$ miles per hour.

6. *Their mean relative or permanent force* was next determined by comparing their force in turning an upright cylindrical machine, with that of the weight which made it revolve, suspended at one end of the cord above mentioned. This mean force was found to be equivalent to about 30 lbs., moving with a velocity of $2\frac{1}{2}$ feet per second.* From numerous comparisons, Smeaton concluded that the mechanical power of a man is equivalent to 3750 lbs., moving at the velocity of one foot per minute: Mr. Tredgold estimates from this conclusion, that the average mechanical power of a man is $31\frac{1}{4}$ lbs., moving

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* Philosophical Magazine, vol. xxxix. No. 168.

at the velocity of 2 feet per second, when the useful effect is the greatest possible; or half a cubic foot of water raised 2 feet per second—a very convenient expression for hydrodynamical inquiries. This estimate is very nearly the same, therefore, as that derived from M. Schulze's experiments. Mr. Tredgold states, that if a man ascend a ladder vertically, the velocity corresponding to the maximum of useful effect will be one foot per second, and the load double what he carries horizontally; consequently, the average of useful effect is $62\frac{1}{2}$ lbs., or 1 cubic foot of water raised 1 foot per second. Dr. O. Gregory states, that according to the best observations, the mean force of a man at rest is 70 lbs., and the utmost velocity with which he can walk is about 6 feet per second, taken at a medium. He thence deduces $31\frac{1}{9}$ lbs. as the greatest useful effect which a man can exert when in motion; the velocity being 2 feet per second, or rather less than $1\frac{1}{2}$ miles per hour.*

7. Dr. Gregory demonstrates the following mechanical theorems, and shows their applicability to the mean action of men and animals:—1. The absolute velocity of an animal is to its relative velocity, that is, when impeded by a given resistance, as the square root of its absolute force is to the difference of the square roots of its absolute and relative forces. 2. The work done by an animal is greatest, when the velocity with which it moves is $\frac{1}{3}$ of its absolute velocity; or, when its relative force is $\frac{4}{9}$ of its absolute force. 3. The greatest useful effect is consequently $\frac{4}{27}$ of the product of the absolute force and the absolute velocity.

* Gregory's Mechanics, vol. i. p. 349.

8. Sir John Leslie,* with his usual tact, has simplified Euler's formula, as confirmed by the above experiments, and we may now express it in the words of the following rule:—*Given the velocity, or rate per hour, at which a man travels, to find his power or force of traction:—Square the difference between 6 miles and the given velocity in miles, multiply by 2, and the product will be the required force in pounds avoirdupois.* This rule gives the following results:—

Velocities,	0	1	2	3	4	5	6
Forces,	72	50	32	18	8	2	0

From this rule, it appears that the greatest useful effect is produced, when a man walks at the rate of 2 miles an hour, his power of traction being then 32 lbs.; this amounts to a force of 3,379,200 lbs., raised 1 foot per day of 10 hours—an estimate which is only about $\frac{1}{16}$ part less than that assumed by Dr. T. Young.

9. In other kinds of human labour, such as climbing stairs, ladders, and mountains, loaded or unloaded; pumping water, sawing wood and stones, driving piles, working at a capstan or windlass, wheeling loaded barrows, digging with a spade, turning a winch, &c., it is almost impossible to establish any proper means of comparison, or to reduce the calculations of the forces employed in each kind of labour to a common or fixed rule. For farther illustration of this subject, therefore, we must refer to the authors already cited, and to such well-known writers as Desaguliers, Emerson, Coulomb, and Hachette. See Gregory's Mechanics, arts. 66—69.

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* Natural Philosophy, p. 281.

10. *Horse Power.*] The *absolute force* of the horse in *drawing horizontally*, as ascertained by the dynamometer, is on an average no less than 770 lbs.; consequently the power of a horse in this kind of momentary exertion, is equal to the force of 7 men. The amount of the *permanent force* of a horse, however, is found to be considerably less than this, varying from that of 6 men to that of 5 men, according to different estimates. Dr. O. Gregory reckons the power of a horse equivalent to that of 6 men; but he states this power as equivalent only to 420 lbs. at a dead pull. Desaguliers, Smeaton, and Leslie, reckon the power of a horse equivalent, on an average, to that of 5 men. Tredgold reckons a horse power equal to that of 6 men, at a medium, and the rate of travelling about the same as, or perhaps rather less than, that of a man, when continued for 8 hours.* On the whole, it appears, when the period of continuance is made an element in the calculation, that the power of a horse, working 8 hours a-day, is, on an average, not more than equivalent to that of five men, working 10 hours a-day.

11. *Permanent Force of a Horse.*] Desaguliers reckons that a horse will walk at the rate of $2\frac{1}{2}$ miles per hour, against a resistance of 200 lbs., that is, at the rate of 220 feet per minute: a horse's power is therefore equivalent to a force that will raise 44,000 lbs. 1 foot per minute, when working 8 hours per day. Mr. Watt found, from repeated experiments, that a horse treading a mill path at the rate of $2\frac{1}{2}$ miles an hour, will, on an average, raise about 150 lbs. by a cord hanging over a pul-

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* Notes to Buchanan on Mill Work, vol. i. p. 167.

ley, which is equivalent to raising 33,000 lbs., 1 foot high in a minute. His steam-engines were calculated to work at the rate of 44,000 lbs. per horse power; but he allowed only 33,000 lbs. in his calculations, considering the difference due to loss by friction. Boulton and Watt ultimately estimated the horse power at 32,000 lbs. Tredgold reckons it at 27,500 lbs. when continued 8 hours a-day, and 33,000 lbs. when continued 6 hours a-day. Smeaton estimated a horse power at 22,916 lbs; this is generally considered too low, otherwise the loss by friction must have been very considerable. It is common in practice, to reckon that it requires one horse's power to drive 100 spindles with preparation of cotton water twist; 1000 spindles with preparation cotton mule yarn; and 75 spindles with preparation flax yarn. See Buchanan on Mill Work, p. 157.

12. Leslie has elegantly simplified Euler's formula, as applied to the power of a horse in drawing;* and we may now express it also in the words of the following rule:—*Given the velocity or rate per hour at which a horse travels, to find his power of traction:—Square the difference between* 12 *miles and the given velocity in miles, the result will be the required power in pounds avoirdupois.* From this rule we obtain the following results:—

Velocities,	0	1	2	3	4	5	6	7	8	9	10	11	12
Forces,	144	121	100	81	64	49	36	25	16	9	4	1	0

Thus it appears that the greatest useful effect is produced when a horse walks at the rate of 4 miles an hour, his power of traction being then 64 lbs.; this amounts to a force of 22,528 lbs., raised 1 foot

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* Natural Philosophy, p. 283.

high per minute—an estimate which agrees very nearly with that of Smeaton.

13. The power of a horse depending greatly on his speed, formulæ have been given for the calculation of this element, according to its duration. The following rule is derived from Leslie's formula:—*Divide the square of the difference between 20 hours, and the given duration of a horse's motion in hours by 25, and the quotient will be his maximum velocity in miles per hour when unloaded.* Hence, we have

Durations,	1	2	3	4	5	6	7	8	9	10
Velocities,	14½	13	11½	10¼	9	7⅞	6¾	5¾	4⅞	4

Tredgold's formula gives the following rule for the same purpose:—*Divide* 14.7 *by the square root of the duration in hours, and the quotient will be the maximum velocity in miles per hour, when unloaded.* Hence, we have

Durations,	1	2	3	4	5	6	7	8	9	10
Velocities,	14¾	10½	8½	7⅓	6⅔	6	5½	5¼	5	4⅔

These results nearly agree with the former in the extreme cases, but differ considerably in the intermediate cases. Tredgold's formula for the power of a horse's traction, expressed in words, is as follows:—*Divide the difference between the maximum velocity, when unloaded, and the given velocity, when loaded, at the given duration of labour per day, by the said maximum velocity, and multiply the quotient by* 250; *the result will be the horse's power of traction in lbs.* Taking the hours of labour at 6 per day, the utmost that he would recommend, the maximum of useful effect will be 125 lbs., moving at the rate of 3 miles an hour; considering the expense of carriage at this rate as unity, the comparative moving force, and proportional expense at different velocities, will be as follows:—

Velocities,	2	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	$5\frac{1}{8}$
Forces,	166	125	104	83	$62\frac{1}{2}$	$41\frac{2}{3}$	$36\frac{1}{2}$
Expense,	$1\frac{1}{8}$	1	$1\frac{1}{35}$	$1\frac{1}{8}$	$1\frac{1}{3}$	$1\frac{4}{5}$	2

Thus it appears that the expense, which is inversely proportional to the effect, that is, the product of the force and the velocity, is doubled when the speed is increased from 3 to $5\frac{1}{8}$ miles per hour.

14. According to the preceding rules of Tredgold, the greatest useful effect of the horse is $125 \times 3 \times 6 = 2250$ lbs. raised 1 mile per day. In comparing this with fact, Mr. Bevan who made many experiments on a horse's power in dragging boats on the Grand Junction canal, found the force of traction to be 80 lbs., and the space travelled in a day 26 miles; this gives the greatest useful effect equal to $80 \times 26 = 2080$ lbs. raised 1 mile per day, the rate of travelling being barely $2\frac{1}{2}$ miles per hour.

15. The most useful mode of applying a horse's power is in draught, and the worst is in carrying a load. This is owing to the structure of the animal. It has been found that 3 men carrying each 100 lbs. will ascend a hill with greater rapidity than 1 horse carrying 300 lbs. When a horse has a large draught in a waggon, however, it is found useful to load his back to a certain extent; this prevents him from inclining so much forward as he would otherwise do, and consequently frees him from the fatigue of great muscular action.

16. The best disposition of the traces in draught is when they are perpendicular to the collar; when the horse stands at ease, the traces are then inclined to the horizon, at an angle of about 15°; but when

he leans forward to draw, the traces should then become nearly parallel to the road. The most proper inclination, however, is determined from the relation which subsists between the friction and the pressure, in every particular case. When a horse is employed in a gin, or in moving a machine by travelling in a circular path, the diameter of his path should not be less than 25 or 30 feet, and in most cases 40 feet should be preferred ; at all events it should not be less than 18 feet.

17. The following is a useful table from Tredgold, *showing the maximum quantity of labour which a horse of average strength is capable of performing at different velocities, on canals, railways and turnpike roads.*

Velocities per Hour.	Day's Work.	Force of Traction.	Useful effect per day for a distance of 1 mile on a		
			Canal.	Level Railway.	Level Road.
Miles.	Hours.	Lbs.	Tons.	Tons.	Tons.
$2\frac{1}{2}$	$11\frac{1}{2}$	$83\frac{1}{3}$	520	115	14
3	8	do.	243	92	12
$3\frac{1}{2}$	$5\frac{9}{10}$	do.	153	82	10
4	$4\frac{1}{2}$	do.	102	72	9
5	$2\frac{9}{10}$	do.	52	57	7·2
6	2	do.	30	48	6·0
7	$1\frac{1}{2}$	do.	19	41	5·1
8	$1\frac{1}{8}$	do.	12·8	36	4·5
9	$\frac{9}{10}$	do.	9·0	32	4·0
10	$\frac{3}{4}$	do.	6·6	28·8	3·6

In comparing this table with practice at the higher velocities, it is reckoned necessary to add $\frac{1}{3}$ more than the useful effect, for the total mass moved. Now, the actual rate at which some of the rapid coaches travel is 10 miles an hour; the stages average about 9 miles; and a coach with its load of luggage and passengers amounts to about 3 tons; therefore the average day's work of 4 coach horses is 27 tons, drawn 1 mile, or $6\frac{3}{4}$ tons drawn 1 mile, by 1 horse. At the rate of 10 miles an hour, the table gives 3·6 tons, which increased by $\frac{1}{3}$ makes 4·8 tons drawn 1 mile, for the extreme quantity of labour of a horse at this rate, upon a good level road. To this result should be added the loss of effect in ascending hills, passing heavy roads, &c., which will make the actual labour performed by a coach horse about double the maximum given in the table. The injurious consequences are well-known.

CHAP. II.

WIND POWER.

18. THE force of the wind is a prime mover of great utility in situations where a supply of water is scarce, or where animal power is expensive. From the variable nature of the atmosphere, the calculation of its force in a given direction, is a matter both of difficulty and uncertainty. The *Anemometer* is an instrument for measuring the force or velocity of the wind. M. Bouguer's anemometer consists of an apparatus like the spring steel-yard, furnished with a float-board or plane surface of given area, which is exposed to the wind, and the pressure or impulse is indicated by the mark on the sliding rod of the spring. Dr. Lynd's anemometer, which is

similar in construction to M. Pitot's potamometer, determines the velocity of the wind, by means of a small quantity of water in the recurved branch of the tube. (See art. 25.)

19. The *force of the wind* is considered to be nearly proportional to the square of the velocity in direct impulse; and nearly proportional to the product of the square of the velocity and the square of the sine of the angle of incidence in oblique impulse. From experiments by Rouse and Smeaton, a formula was ascertained which may be expressed in the following words:—*Given the velocity of the wind in feet per second, to find the force of its perpendicular impulse on a square foot in lbs. avoirdupois:—Multiply the square of the given velocity by* 2⅔ *and divide by* 1000, *the quotient is the required force in lbs.* This rule gives the following forces in lbs. for the velocities in feet:—

Velocities,	10	20	30	40	50	60	70	80	90	100
Forces,	¼	1	2	3⅔	5¾	8¼	11¼	14⅔	18½	22⅞

If the velocities be given in miles per hour, the forces in lbs. will be,

Velocities,	10	20	30	40	50	60	70	80	90	100
Forces,	½	2	4½	7⅞	12⅓	17¾	24	31½	39	49¼

The winds moving with the latter velocities were characterized by the following names, in Rouse's table:—Pleasant gale, brisk gale, very brisk, high winds, very high, storm or tempest, great storm, hurricane, and great hurricane. When the impulse of the winds is oblique, the forces in the preceding tables must be multiplied by the squares of the sines of the angles of incidence, to obtain the true forces. Borda found by experiment that the force of the wind was greater by about a tenth part than what we have assigned above; and that on different surfaces with the same velocity, the force increased more rapidly than the surface. Hutton also showed that the forces at great velocities increased in a somewhat higher ratio than the square of the velocity.

20. It is demonstrated by writers on Mechanics, that *common air rushes from the atmosphere into a void, with the velocity which a heavy body would acquire by falling from the top of a homogeneous atmosphere.* This velocity is ascertained in the following manner: The pressure of the atmosphere is found to support a column of water at the mean height of 33 feet, and air is about 840 times lighter than water; therefore the height of a homogenous atmosphere (that is, of air having the same density throughout,) is equal to $33 \times 840 = 27720$ feet, or $5\frac{1}{4}$ miles. Now, the velocity due to the height from which a heavy body falls, is found by the following rule: *Multiply the square root of the height in feet by 8, and the product is the required velocity in feet per second.* Thus, the velocity with which air rushes into a perfect vacuum is 8 times the square root of 27720, or nearly 1332 feet per second. Now since the pressure of the atmosphere is nearly 15 lbs. on every square inch of surface, the enormous force obtained by the formation of a vacuum under the piston of a cylinder must be obvious. According to the rule in the preceding article, a wind rushing through the atmosphere with the same velocity that air rushes into a vacuum, would act with the extraordinary force of $4055\frac{3}{8}$ lbs. on the square foot, or $28\frac{1}{6}$ lbs. on the square inch, a force equal to double the pressure of the atmosphere, and nearly 200

times greater than that of the most tremendous hurricane.

21. The *time* in which a vessel void of air will be filled with that fluid is found thus: *Multiply the area of the orifice in feet by* 666, *and divide the capacity of the vessel in cubic feet by the product, the quotient is the time in seconds.* If the experiment be made with a hole cut in a thin plate, the time will be greater than that given by this rule, by $\frac{6}{10}$ nearly. Thus, the theoretical and experimental times of filling vessels of the following capacities in cubic feet, through an orifice of 1 square inch, will be,

Capacities,	1	2	3	4	5	6	7	8	9
T. Seconds,	·22	·43	·65	·87	1·08	1·30	1·51	1·73	1·95
E. Seconds,	·35	·69	1·04	1·39	1.73	2·08	2·42	2·77	3·11

The cause of the difference between the theoretical and experimental time of filling a vessel, is one common to all fluids, arising from the contraction of the jet at a short distance from the orifice, where the velocity due to the height is acquired; this will be more distinctly pointed out in the chapter on Water Power.

22. If a piston be employed to expel the air from a cylinder through a *small* hole, the *velocity of its discharge* will be found thus: *Multiply the square of* 1332 *by the pressure on each square inch of the piston, divide the product by the sum of this pressure and the atmospheric pressure, and extract the square root of the quotient for the required velocity in feet per second.* This velocity multiplied by the area of the orifice in square feet will give the cubic feet of condensed air discharged in a second. This *discharge* being multiplied by the sum of the load on the piston per square inch and the atmospheric pressure,

and the product being divided by 15, will give the *quantity of common air* in cubic feet discharged in a second.

The following table, which will be useful in the construction of blowing machines, shows in the first column the number of pounds with which every square inch of the piston is *loaded* above the pressure of the atmosphere; the second, the *velocity* of the condensed air in feet per second; the third, the *discharge* of condensed air in cubic feet, through an aperture of one square inch in area; the fourth, the *mean velocity* of the common air, in feet per second; the fifth, the *discharge* of the common air in cubic feet, through an aperture of a square inch; and the sixth, the height in inches at which the force of the blast would support a column of water if a pipe were inserted in the side of the cylinder.

Load.	Velocity.	Discharge.	Velocity.	Discharge.	Water.
lbs.	feet.	cubic ft.	feet.	cubic ft.	inches.
½	239	1·66	247	1·72	14
1	333	2·31	355	2·47	27
1½	404	2·79	437	3·05	40
2	457	3·17	518	3·60	54
2½	500	3·48	584	4·20	68
3	544	3·76	653	4·53	82
3½	582	4·03	715	4·98	95
4	611	4·24	774	5·38	109
4½	642	4·46	822	5·75	122
5	666	4·67	888	6·17	136
5½	693	4·84	950	6·49	150
6	711	5·06	997	6·92	163

The sixth column will show at all times the power of the blowing machine, and what intensity of blast is required for different purposes. It is proper to remark that the discharges may be found about a third too great in practice, on account of the convergency of the stream of air. This table extends beyond the limits of machines in common use, as very few blast furnaces have a force exceeding that required to support 60 inches of water.

23. The value of inquiries regarding the velocity and force of the wind, both in its application to windmills and sailing vessels, will be manifest from the following demonstrable facts: 1. If the force of the wind be capable of producing a degree of velocity in a ship greater than $\frac{1}{3}$ of its own velocity, the ship may run swifter upon an oblique course than when she sails directly before the wind. 2. The velocity of the sails of a windmill may be such that at their extremity it may be greater than that of the wind, and thus injuriously operate against the motion of the sails.

CHAP. III.

WATER POWER.

24. WE agree with Sir John Leslie in saying that water is the readiest and most powerful agent that can be directed by human skill. The effect of the direct application of the force of water, whether at rest or in motion, is pretty accurately ascertained. This force is proportional to the square of the velocity of the flow, and the velocity is proportional to

the square root of the height of its source. The perpendicular impulse or force of any unimpeded current against a plane surface is estimated, therefore, by the weight of a column of the fluid resting on that surface, and having the altitude due to the velocity.

25. The term *Potamometer* or Stream-measurer may be applied to any instrument employed to ascertain the velocity of a river or stream. An instrument of this kind, invented by M. Pitot, consists of a tube of glass bent at right angles, having the shorter branch formed into a funnel shape at the mouth, to receive the direct impulse of the stream, and the longer branch raised vertically to exhibit the elevation of the water in the tube which corresponds to its velocity. This elevation is measured by a graduated scale, reckoned upwards from the surface of the stream. The scale is graduated by the following rule: — *To find the height due to a given velocity, square the velocity in feet per second, and divide by* 64, *the quotient will be the required height in feet.* On this principle, the divisions of the scale of the Potamometer for *miles*, would be numbered at the following heights above the surface in inches:—

Divisions,	1	2	3	4	5	6	7	8	9
Heights,	·4	1·6	3·6	6·4	10	14·5	19·7	25·8	32·7

Few rivers would require the glass tube to rise higher than 6 feet above the surface of the stream. A similar instrument, made partly of tin, and cemented to a tube of glass, might be introduced into a ship or steam-boat, for measuring the ship's way at sea,* or for ascertaining the velocity of the

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* See Gregory's Mechanics, vol. ii. p. 441.

steam-boat. If introduced into the cabin, the passengers could tell, by consulting the scale, the rate per hour at which the vessel was sailing, and consequently, how soon they were likely to reach port.

26. The *lateral* or rather collateral *draught of water* is capable of producing very splendid effects, without the aid of machinery. When a stream is carried through a reservoir or pool of stagnant water, at a lower level, it has the effect of putting the whole mass in motion; causing a great part of it to mix with the current, and thus effecting its escape. In this way, Venturi took advantage of the rapidity and lateral draught of a millrace to drain a marsh situated considerably below the stream, near the city of Modena.

27. *Definitions.* The *transverse section* of a river or stream is the plane surface that would be formed by cutting it vertically and perpendicularly to the direction of the current, supposing it for an instant to become solid. The *mean hydraulic depth* is the depth that a river would have if it flowed in a new channel, whose sides were vertical, and whose bottom was flat, and equal in breadth to the bottom and sides of its real channel. This depth is found by dividing the area of the transverse section by the breadth of the bottom of the new channel. The *declivity* of a river is the rate of its fall or descent in a given distance, and is generally reckoned in inches or feet per mile. The velocity of the water in a river is most rapid in the middle of the upper surface of the stream, and it gradually diminishes towards the bottom and the sides of the channel. The *mean velocity* is the central velocity of the transverse section.

28. Sir John Leslie has given a very simple formula for finding the mean or central velocity of a river or water-course; and he states that it is quite conformable to actual observation.* Rule:—*Multiply the mean hydraulic depth of a river by the declivity, both in feet, and extract the square root of the product; the result diminished by $\frac{1}{16}$ part, will be the mean velocity of the river in miles per hour.* Thus, we ascertain the rate of the majestic roll of the sacred river of the Hindoos, which has only a fall of 4 inches per mile, and a mean hydraulic depth of 30 feet, to be only about 3 miles an hour. The swelling tide of the mighty Amazon, or Maranon, for the space of 600 miles before it discharges its flood into the deep, has only a fall of 10½ feet,† which is about ⅕ of an inch per mile; yet, reckoning its mean hydraulic depth for that space, at 100 fathoms, it must flow into the ocean with scarcely more than the same velocity as the Ganges. For the space of 600 miles from the embouchure of this great river, the tides of the Atlantic silently oppose its lazy flow; but above this point, the declivity is about 6 inches per mile, and the mean hydraulic depth perhaps about 70 fathoms; hence, the velocity of its waters must be between 14 and 15 miles per hour, surpassing that of our swiftest steam vessels. At this point, therefore, the opposition is dreadfully increased, and the conflict of the water is tremendous; the action of this enormous Hydraulic Ram of nature produces such a revulsion in the waters of the Maranon, that waves, rising sometimes to the height of 180 feet, roll back upon

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* Natural Philosophy, p. 423.

† Murray's Encyclopædia of Geography, art. 883.

the rapid stream with the noise of a cataract, overwhelming all the banks of the Orellanic region. This phenomenon, justly called the *bore*, or by the Indians, *pororoca*, must for ever impede the useful navigation of this king of rivers.

29. *The force of water*, impinging directly against a plane surface, is found by the following rule:—*Multiply the area of the surface in feet by the square of the velocity in feet per second, the product diminished by $\frac{1}{40}$ part will be the force required in lbs. nearly.* Thus, for the following velocities in feet per second, the forces in lbs. on a square foot will be:—

Velocities,	1	2	3	4	5	6	7	8	9
Forces,	1	4	9	15½	24⅜	35	48¾	62½	79

When the velocity is given in miles per hour the rule is: *Multiply the area of the surface in feet, by the square of the velocity, and double the product increased by $\frac{1}{30}$ part, will be the force required in lbs. nearly.* Thus for the following velocities in miles per hour, the forces in lbs. on a square foot will be:

Velocities,	1	2	3	4	5	6	7	8	9
Forces,	2·1	8·4	18·9	33·6	52·5	75·6	102·9	134·4	170·1

When the water impinges obliquely against a plane surface, the forces obtained by the above rules must be multiplied by the square of the sine of the angle of incidence, as in the case of wind; these results must be again corrected by some function of the angle of incidence, so as to make them correspond with observation. This function, however, has not been hitherto accurately determined.

30. *The Effective Power of a Stream* as available for driving machinery is found by the following rule: *Multiply the force due to the velocity and the*

*area of the transverse section, by the velocity per minute, and divide the product by the estimate of a horse's power, the quotient will be the effective power required.** Thus, the effective power of a mill-race 3 feet broad and 2 feet deep, running at the rate of 4 miles an hour, would be equivalent to that of nearly 13 horses. For, by art. 29, the force on a square foot due to the velocity is 33·6 lbs.; hence the whole force of the stream is $3 \times 2 \times 33{\cdot}6 = 201{\cdot}6$ lbs.; this multiplied by the velocity, 352 feet per minute, gives 70963·2 lbs. per minute, for the effective power. Now, a horse's power at the given velocity is 22528 lbs. per minute, by art. 12; but at work a horse could not continue more than six hours a-day, whereas the action of the stream is incessant; the horse's power must therefore be taken at $\frac{1}{4}$ of this, or 5632 lbs.; consequently $70963 \div 5632 = 12{\cdot}6$ horse's power.

The comparison with human labour is still more striking: a man's power at the same velocity is only 2816 lbs. per minute, or $\frac{1}{8}$ of a horse's power; that is, a horse's power is equivalent to that of 8 men; and $12{\cdot}6 \times 8 = 100{\cdot}8$; hence, it appears that the effective power of such a stream, is equal to the ordinary labour of 100 men. If the stream had a fall of $26\frac{2}{3}$ feet, its effective power would then be increased to 50 times this quantity. For the height due to the velocity is 6·4 inches, by art. 25; and the velocity, and consequently the power, being proportional to the fall, we have $320 \div 6{\cdot}4 = 50$ times. The immense acquisition of power that might be thus gained from

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* When an undershot wheel is employed, the effective power is reckoned only $\frac{1}{3}$ of this, in practice: see art. 42.

the numerous streams of this description which could be easily collected over the face of the country, renders the subject one of great importance to the mechanic and engineer.

31. *Definitions.*] When water issues from a small orifice in the bottom or side of a very large vessel or reservoir, it almost instantly acquires and maintains the velocity which a heavy body would acquire by falling from the horizontal surface of the stagnant water.* This velocity is called its *Natural Velocity.* If the area of the orifice be multiplied by this velocity, the product will be the quantity of water discharged. This quantity is called the *Natural Discharge.* In like manner, the mean velocity of a running stream, may be called its natural velocity; and the product of this velocity by the area of its transverse section, its natural discharge. The height due to the velocity of water issuing from a vessel or reservoir is called the *head of water.* When water or any fluid issues through a hole in a *thin plate*, the stream is contracted at a small distance from the hole; at the place of this contraction the fluid acquires its natural velocity; but as the area of the orifice is larger than the area of the transverse section of the jet at the place of contraction, the natural discharge will be diminished in proportion to the *contraction* of the jet. This contraction takes place in every case where water is confined and made to pass through narrow apertures, such as in pipes, canals, and sluices, as well as holes in the sides or bottom of vessels or reservoirs; it occurs also in dams or weirs furnished with a wasteboard, and in bars in streams or rivers.

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* See Robinson's Mechanical Philosophy, Vol. ii. p. 410.

32. *The Natural Discharge* of water in cubic feet per second flowing from any stream or reservoir is found thus: *Multiply the area of the transverse section of the stream, by its mean velocity; or, the area of the orifice by the velocity due to the head of water; and the product, in either case, will be the number of cubic feet discharged per second.* The Effective or Real Discharge will be always less than the natural discharge in proportion to the *contraction* or *obstruction* of the stream. Consequently, when the actual velocity of the discharge is given, the height or head necessary to produce this velocity will be found by squaring the velocity and dividing it by 64 in the case of the natural discharge, or by other *divisors* according to the nature of the orifice which produces the contraction of the stream. The following table contains the *proportions* of the Natural Discharge which constitute the Real or *Effective Discharge* in different circumstances, and the corresponding *divisors* for finding the height or head of water due to the velocity of the actual discharge.

No.	Nature of the Aperture or Flow.	Proportions.	Divisors.
1	Natural Discharge or Flow,	1·00	64
2	Flow over a bar or keep,	·97	60
3	Flow over a weir or dam,	·95	58
4	Tube of the form of the jet,	·96	59
5	Tube two diameters long,	·81	42
6	Tube projecting inwards and full flow,	·68	29·6
7	Aperture in a thin plate,	·62	24·6
8	Tube projecting inwards and contracted flow,	·51	16·6

The proportion of the discharge in No. 4 of this table depends much on the finish of the tube, varying from ·92 to ·98; the tabular proportion answers for wide openings of which the bottom is on a level with the reservoir, for sluices with walls in a line with the orifice, and for bridges with pointed piers. For narrow openings of which the bottom is on a level with that of the reservoir, for smaller openings in a sluice with side walls, and for abrupt projections and square piers of bridges, ·86 is the proportion, and 47·3 the divisor. For openings in sluices without side walls, ·635 is the proportion, and 25 the divisor. In the case of a notch or rectangular slit in the side of a vessel or reservoir, the discharge will be $\frac{2}{3}$ of that due to an equal orifice placed horizontally at the whole depth.

33. The following table exhibits the natural discharges *per minute* and the velocities *per second* due to different heights or heads of water, supposing the area of the transverse section of the stream or the area of the orifice, to be 1 square foot.

Heights.	Velocities.	Natural Discharges.	
feet.	feet.	cubic feet.	Imp. gallons.
1	8·000	480	3000
2	11·314	679	4244
3	13·856	831	5199
4	16·000	960	6000
5	17·889	1073	6706
6	19·596	1176	7350
7	21·166	1270	7937
8	22·627	1358	8487
9	24·000	1440	9000
10	25·298	1518	9487

The discharges in Imperial Gallons are given in round numbers by assuming ·16 of a cubic foot, as the capacity of an imperial gallon, instead of ·16046 of a cubic foot. The weight of water in lbs. will be found by multiplying the number of imperial gallons by 10. The Natural Discharge of the waters of the Ganges into the sea, will be nearly 3½ millions of imperial gallons, or upwards of 15 thousand tons per second, supposing the velocity 3 miles per hour, the mean hydraulic depth 30 feet and the breadth corresponding to this depth ¾ of a mile.

34. *The Effective Power of a Stream or Water Fall* is found by the following rule: *Multiply the effective discharge in cubic feet per minute by the height due to the velocity of the stream, or by the height of the fall, and this product again by 62½ lbs.; divide the result by* 44000, *and the quotient is the amount of horse power equivalent to the force of the stream or fall.* Thus, the effective discharge of the Regulating Basin attached to the Whin Hill Reservoir of the Shaws Water, above Greenock, is according to the printed regulations, 1200 cubic feet of water per minute; consequently, the power of a fall of 30 feet on the line of mills supplied by this water, is upward of 51 horse power; for $1200 \times 30 \times 62\frac{1}{2} = 2250000$ lbs.; and $2250000 \div 44000 =$ 51·14 nearly. The value of a horse power has been assumed here at the highest estimate in order to include every allowance for friction, waste of water, &c. in the application of water power to the impulsion of mill-wheels. That this rule coincides very nearly with practice is evident from the valuable experiments made on this subject by Robert Thom, Esq. of Ascog, Bute, a gentleman whose

eminent skill in hydraulic engineering, is not surpassed in this or in any other country.

35. Mr. Thom estimates a discharge of 1200 cubic feet per minute on a fall of 30 feet as equal to a Boulton and Watt steam engine of 54 horse power.* For, by repeated experiments, he found that 1666 cubic feet of water on a fall of 20 feet was equal to an engine of 50 horse power; whence, the following proportion :—

$$\left\{ \begin{array}{rr} 1666\tfrac{2}{3} : & 1200 \\ 20 : & 30 \end{array} \right\} :: 50 : 54 \text{ horse power.}$$

Adopting Mr. Thom's estimate as the most correct, the power of a Water fall may therefore be easily found by proportion, or by adding $\frac{1}{17}$ part to the result found by the above rule.

36. *Shaws Water.* The achievements of Mr. Thom in the production and regulation of Water Power are so great as to deserve particular mention here; more particularly as the system may be carried on to an indefinite extent in this country, to the immense advantage of the working population, the landed proprietors, and the whole mercantile community. The whole fall of the water from the Whin Hill Reservoir above Greenock to the level of the Clyde at high water is about 512 feet; there are at present two lines of Mills on this fall; the first, extending the whole length, and having sites for 19 mills each of about 27 feet fall on an average; the second, extending 368 feet and having sites for 13 mills each of about 28 feet on an average. The Grand Reservoir situated at the back of the Shaws Hills, is capable of supplying, by means of the Shaws Water Aqueduct, which is 6½ miles

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* See "Brief Account of the Shaws Water Scheme," p. 61.

long, 2400 cubic feet of water per minute; hence, if all the mills were in operation, the amount of the power employed would be at least equivalent to that of 2000 horses. The utility of such an immense power as this in the immediate vicinity of so flourishing a port as Greenock, is one that cannot be too highly estimated by a mercantile community; and when the cheapness of the power as compared with that of steam is considered, its value is still more enhanced. The average rent of the water is £2 15 per horse power, and the average rent of the ground or feu-duty for erections, &c., is only £7 per acre! We are much mistaken, if 10 times, ay 20 times as much be not paid for steam-power in Glasgow and its neighbourhood.

37. To show that the Shaws Water Works are capable of supplying this quantity of water and of power at all times and seasons, throughout the year, it may be proper to state that the embankment of the great Reservoir is 60 feet high, that the water in it covers about three hundred imperial acres, and that it contains nearly 285 millions of cubic feet of water; that along with the compensation and auxiliary reservoirs, it will contain above 310 millions of cubic feet of water, which will cover nearly 400 imperial acres, and that it is capable of supplying annually according to Mr. Thom's estimate, no less than 600 millions of cubic feet of water. The whole of the ground whose waters are drained into the Reservoirs and Aqueduct, is nearly 5 thousand Imperial acres.

38. When "Loch Thom," which is the name of the Grand Reservoir, was opened on the 16th of April, 1827, a memorable day in the history of

Greenock and of Scotland, by the chief Magistrate W. Leitch, Esq., who first raised the sluices, he sailed along the whole length of the aqueduct in the space of about 3 hours.* Taking the mean velocity of the stream, therefore, at $2\frac{1}{3}$ miles per hour, the mean breadth of the aqueduct at 6 feet, and the mean depth of the water at 2 feet, it is evident that its regular discharge into the Whin Hill Reservoir is 2464 cubic feet per minute; for $2 \times 6 \times 205\frac{1}{3} = 2464$. The declivity of the aqueduct is about 5 feet per mile; hence, the mean hydraulic depth is $1\frac{1}{5}$ feet; therefore, by the rule in art. 28 the mean velocity is 2·3 or nearly $2\frac{1}{3}$ feet, a result that agrees remarkably well with observation, and confirms the accuracy of the preceding computation. The force of this stream previous to its arrival at the falls which render it so powerful, is barely equal to that of a single horse, on the lowest practical estimate. For the height due to the velocity is ·183 of a foot, by the rule in art. 25; hence, $2464 \times 62\frac{1}{2} \times \cdot 183 = 28182$. Nothing demonstrates more plainly than this, the immense utility of falls, and the advantage of collecting water in elevated situations.

39. That rain could easily be collected to a very great extent, not only in this country but in almost every country in the world, for the purpose of driving machinery, will be rendered evident from the following considerations. Sir John Leslie estimates the quantity of moisture exhaled in a year over the surface of the globe, as sufficient to form a shell or covering of 5 feet deep;† hence, taking the mean height of the atmosphere at 18 thousand feet, he

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* See Weir's History of Greenock, p. 104.

† Natural Philosophy, p. 429.

finds that the power exerted in the formation of clouds, exceeds by *two hundred thousand times* the accumulated toil of the whole population of the earth. He then states that if half of the falls in the rivers and streams of the habitable parts of the globe were detained at an elevation of 600 feet, there would be drawn from these sources a power *eleven* times greater than the whole amount of human labour. He next shows that taking the surface of this island at upwards of 67 thousand square miles, and reckoning that only 3 inches of the rain that falls annually are caught at an elevation of 100 feet, the power it would produce is equivalent to that of 6703 steam-engines of 20 horse power, or not inferior to the ordinary labour of the whole of the male population.

40. There are many natural situations in this island, however, far surpassing the above estimate in point of elevation and supply, and consequently of power. We have seen that the Shaws Water at Greenock alone furnishes a power of 2000 horses, and we believe that this power could easily be doubled. The water of Leven which issues from a lake of the same name in Fifeshire, has been calculated as capable of producing by means of a fall of 300 feet, a power equivalent to that of 2000 horses; and the water of Leith, according to a Report by Professors Leslie and Jamieson, by means of a fall of 884 feet, is capable of furnishing a power of even more than this, being equivalent to that of 106 steam engines of 20 horse power. These are a few examples in our own neighbourhood; but it is manifest that they might be multiplied to a great extent, by making a proper hydraulic survey of the island.

41. In estimating the power of the ocean itself, Sir John Leslie states that the force of the moon and sun in raising the tides is only about $\frac{1}{80}$ of the action of the atmosphere in the formation of clouds; and that therefore it is still *two thousand five hundred* times greater than the labour of the whole population of the globe.* But the rise and fall of the tide along our shores is capable of driving numerous mills. He finds that estimating the circuit of this island at 1750 miles, there might be formed no fewer than 14 thousand mills, by drawing a sea-wall or dam 66 feet from the shore; thus a power would be created equivalent to that of 350 thousand men, or 50 thousand horses.

42. *River or Tide Mills.*] The float boards of river or tide mills are not impelled by the whole velocity of the stream or tide, but only by its excess above that of the wheel, which is technically called *undershot*. The pressure which turns the wheel is found thus: *Square the difference between the velocity of the current and the velocity of the middle of the float; multiply this square by twice the area of the surface immersed in the water, and the product will be the force required in lbs.* Such is the theoretical rule, but in practice, the results vary considerably according to circumstances. In general, a great loss of power is occasioned by the accumulation of *dead water*, that is, the water which after impinging against a float-board, remains nearly stagnant, and consequently impedes the advance of the next float-board. Friction, the obliquity of impulse, and confinement of the stream to a narrow channel, all contribute to render the practical effect greatly

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* Natural Philosophy, p. 431.

different from the theoretical. The maximum effect is produced according to theory when the velocity of the middle of the float is $\frac{1}{3}$ of the velocity of the current; that is when the power communicated to the wheel is $\frac{4}{27}$ of the whole power of the stream, (art. 7). In ordinary cases, it would be more advantageous to make the float-boards turn slower, and to increase the communicated velocity afterwards, by a train of internal machinery. By this means, the whole velocity and impulse of the current might be rendered available. When the float-boards move in a circular sweep close fitted to them, or in general, when the stream cannot escape without acquiring the same velocity as the wheel, the effect is a maximum when the velocity of the wheel is $\frac{1}{2}$ of the velocity of the current, being then equal to $\frac{1}{4}$ of the moving power.* Hence, the utility of confining the stream to a narrow channel is manifest.

43. *Overshot Wheels.*] This is the technical term employed in the case of mills driven by a fall of water discharged on or near the top of the wheel. For the *mechanical effect* of an overshot wheel in the most favourable circumstances, Dr. Gregory has given a very simple algebraical expression from which the following rule is derived by a slight modification: *Raise the radius of the wheel to the cube or third power, and extract the square root of this power; multiply this root by the area of the transverse section of the stream that supplies the buckets; divide the product by 6·5, and the quotient will be the mechanical effect in horse powers.* According to this rule, the power of an overshot wheel of

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* Gregory's Mathematics for Practical Men, p. 318.

30 feet in diameter with a stream of 6 square feet in area, falling on it, is equivalent to 54 horses' power; for $15 \times 15 \times 15 = 3375$, and $\sqrt{3375} = 58{\cdot}095$; now $58{\cdot}095 \times 6 = 348{\cdot}57$ and $348{\cdot}57 \div 6{\cdot}5 = 53{\cdot}6$ or 54 nearly. This rule gives a result almost the same as that of Mr. Thom's experiments, see art. 35. The maxims for the practical construction of the different kinds of mill-wheels, and for estimating their comparative mechanical effects, according to the experiments of Smeaton, Bossut, and others, will be found in vol. 51, Philosophical Transactions, vol. ii, Bossut's Hydrodynamique, Buchanan's Essays on Mill-work, and Banks on Mills.

CHAP. IV.

STEAM-POWER.

44. The elastic force of steam is one of the most powerful prime-movers of machinery at present known. Water under the ordinary pressure of the atmosphere in this country, generates steam at the temperature of 212° Fahrenheit's thermometer; and the temperature continues at this point, whatever quantity of heat be applied, till the water be entirely converted into steam, its elastic force at this temperature being equivalent to a force of about 15 lbs. on the square inch of the resisting surface, that is, an exact balance to the pressure of the atmosphere. Under this pressure, a cubic *inch* of water produces about a cubic *foot*, or nearly 1728 cubic inches of steam. If the pressure of the atmosphere be diminished or removed, steam will

be generated at a lower temperature: thus, in a vacuum water boils at 70° instead of 212°. The boiling point varies by 1·76 of a degree for every inch of variation in the atmospheric pressure, between the limits of 26 inches, and 31 inches of the barometer, as noted in the following tablet of boiling points corresponding to the height of the mercury in the barometer.

Barometer,	26	27	28	29	30	31
Thermometer,	204·91	206·67	208·43	210·19	212	213·76

On the other hand, if the atmospheric pressure be increased or supplanted by a greater force, water will not boil at the ordinary temperature; thus in a diving bell immersed in water 68 feet below the surface, the boiling point is raised to 272° instead of 212°. Dr. Gregory says that when pressed by a column of mercury 5 inches in height, water does not boil till heated to 217°; each inch of mercury producing by its pressure, a rise of about 1° in the thermometer.

45. *Force of Steam.*] The determination of the elastic force of steam at different degrees of temperature being a subject of the greatest importance to the practical engineer, it has undergone much investigation by experimental philosophers, such as Watt, Southern, Creighton, Young and Tredgold. The following rule given by Mr. Tredgold, has the merit of simplicity when compared with others, and of near coincidence with the results of actual experiment. *To find the elastic force of vapour of water or of steam in inches of mercury of the barometer, at a given temperature of Fahrenheit's thermometer :— Add* 100 *to the given temperature, and divide the*

sum by 177 ; *raise the quotient to the sixth power, and it will be the force required.* Thus, if the temperature of steam be raised to 307°, its force in inches of mercury will be 148 nearly; for $307 + 100 = 407$; and $407 \div 177 = 2{\cdot}3$, the sixth power of which is about 148; consequently, steam at 307° has an elastic force of nearly 5 atmospheres, for $148 \div 30 = 5$ nearly. Among the tables at the end of this book, will be found a table showing the elastic force of the vapour of water from 32° to 212°, according to the experiments of Mr. Dalton, and of steam from 212° to 320°, according to those of Mr. Taylor. The results given in this table may be compared with the corresponding results given by the above rule. As this rule and table apply only when pure water is used, corrections must be employed to determine the elastic force of steam generated from salt water. The proportion of salt in the water of a boiler supplied with sea water, will continue to increase during the evaporation, till the water becomes saturated and contains $\frac{12}{33}$ of salt; the elastic force of the steam at the temperature of 307° will then be about 113 inches which is less by 35 inches, than that of the steam of pure water at the same temperature. To facilitate the computation of the force of steam generated from salt water of different degrees of saltness at different temperatures, the following table of the boiling temperatures and constant numbers to be used as divisors instead of 177 in the above rule, is here subjoined. The specific gravity of the water will in all cases determine the proportion of salt it contains.

Proportions of Salt.	Boiling Points.	Divisors.
Common water, 0	212°	177·0
Sea water, $\frac{1}{33}$	213·2	177·6
Boiler water $\frac{2}{33}$	214·4	178·3
do. $\frac{3}{33}$	215·5	179·0
do. $\frac{4}{33}$	216·7	179·7
do. $\frac{5}{33}$	217·9	180·4
do. $\frac{6}{33}$	219·0	181·0
do. $\frac{7}{33}$	220·2	181·6
do. $\frac{8}{33}$	221·4	182·3
do. $\frac{9}{33}$	222·5	183·0
do. $\frac{10}{33}$	223·7	183·6
do. $\frac{11}{33}$	224·9	184·3
Saturated water, $\frac{12}{33}$	226·0	185·0

46. *Force of Steam in Atmospheres.*] When steam by continual accessions of heat acquires an elastic force capable of supporting a column of 60 inches of mercury, or twice the height of the barometric column, it is then said to possess a force of 2 atmospheres; and so on, in proportion to the height of the column of mercury it can support. By the experiments of Taylor, the force of steam was determined as far as 180 inches of mercury, or a pressure equivalent to 6 atmospheres. Beyond this point, the determination of the force of steam is due to the labours of MM. Dulong and Arago, members of a committee appointed to investigate the subject, by the Academy of Sciences at Paris. The temperatures and pressures were experimentally ascertained up to 24 or 25 atmospheres and thence extended to 50 atmospheres by calcula-

tion.[*] The following rule is derived from the formula elicited by these philosophers from their experiments on the subject. *To find the elasticity of steam in atmospheres, at very high temperatures:—Subtract* 212° *from the given temperature, multiply the remainder by* ·003974 *and add* 1 *to the product; then, raise the sum to the 5th power, and it will give the elastic force required.* As this operation is best performed by logarithms, the rule may be thus expressed: Subtract 212° from the given temperature, to the logarithm of the remainder, add the constant logarithm $\bar{3}{\cdot}599228$; then to the number indicated by the result, add 1, and multiply the logarithm of the sum by 5; the product will be the logarithm of the elasticity in atmospheres.[†] Thus, to find the elasticity of steam at 307°, the operation is as follows:

$$\begin{array}{rl}
307^{\circ} & \\
\underline{212} & \\
\text{log. } 95 = & 1{\cdot}977724 \\
\text{log. } {\cdot}003974 = & \underline{\bar{3}{\cdot}599228} \\
\text{log. } {\cdot}37753 = & \underline{\bar{1}{\cdot}576952} \\
\text{log. } 1{\cdot}37753 = & 0{\cdot}139101 \\
 & \underline{\phantom{0{\cdot}13910}5} \\
\text{log. } 4{\cdot}96 = & 0{\cdot}695505
\end{array}$$

Hence, the elasticity of steam at 307°, is nearly

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[*] Galloway's History of the Steam Engine, p. 835.

[†] Professor Robinson says, that "tables of common logarithms are, or should be, in the hands of every person who is much engaged in mechanical calculations." A small pocket volume of Logarithmic Tables, entitled "The Practical Mathematician's Pocket Guide," may be had of the publisher of this work.

equal to the pressure of 5 atmospheres, as formerly found by Tredgold's rule, art. 45. The following table is the result of the experiments and calculations above-mentioned. The columns marked *At.* contain the *elasticity or force of steam in atmospheres,* and the columns marked *Temp.* on the right, contain the *corresponding temperatures in degrees* of Fahrenheit's thermometer.

At.	Temp.	At.	Temp.	At.	Temp.	At.	Temp.	At.	Temp.
1	212°·00	7	331°·70	18	408°·92	30	457°·16	42	491°·76
1½	233 ·96	7½	336 ·86	19	413 ·96	31	460 ·45	43	494 ·27
2	250 ·52	8	341 ·96	20	418 ·46	32	463 ·64	44	496 ·72
2½	263 ·84	9	350 ·78	21	422 ·96	33	466 ·74	45	499 ·14
3	275 ·18	10	358 ·88	22	427 ·28	34	469 ·78	46	501 ·50
3½	285 ·08	11	367 ·34	23	431 ·42	35	472 ·73	47	503 ·85
4	293 ·72	12	374 ·00	24	435 ·56	36	475 ·64	48	506 ·16
4½	301 ·28	13	380 ·66	25	439 ·34	37	478 ·46	49	508 ·40
5	308 ·84	14	386 ·94	26	443 ·16	38	481 ·24	50	510 ·60
5½	314 ·24	15	392 ·86	27	446 ·82	39	483 ·95	51	512 ·80
6	320 ·36	16	398 ·48	28	450 ·38	40	486 ·59	52	514 ·82
6½	326 ·26	17	403 ·82	29	453 ·82	41	489 ·21	53	517 ·08

47. At very high temperatures, there is a great discrepancy between the results obtained by the French and English experimenters. According to Mr. Perkins, the force of steam at 419° F. is 35 atmospheres, whereas, by the above experiments, it is only 20 atmospheres. Mr. Perkins in his specification of his high-pressure engine, states also that if the steam-generator be made strong enough, to withstand 60,000 lbs. load on the escape valve, the water would not boil although it would exert an expansive force equal to 56,000 lbs. on the square inch, and be at about 1170° of heat or cherry red; and Mr. Galloway asserts that "recent experiments have proved that steam when heated to 1170° will act with a force of 56,000 lbs. on the square inch,"

or about 4000 atmospheres. It is natural for the advocates of high-pressure steam to magnify the power of the agent which they wish to employ, but the accuracy of these statements is, at least, questionable. The force of steam at 1170°, when calculated by Tredgold's rule, is no doubt, even greater than this, being upwards of 4500 atmospheres; but when calculated by the French rule, it is only about 2567 atmospheres, or nearly 38000 lbs., instead of 56000 lbs. on the square inch. Recent experiments, therefore, instead of confirming Mr. Perkins' statement, have rather lowered it considerably. The fact is, the law of the elastic force of steam varies considerably between high and low temperatures; Mr. Tredgold's rule being pretty correct as far as 6 atmospheres, and the French rule being more correct beyond this pressure, at least as far as 50 atmospheres.

48. *Expansion of Steam.*] Like air and other elastic fluids, steam loses its elastic force or pressure directly in proportion as it is allowed to expand. Thus, if it be allowed to expand into *twice* or *thrice* its volume, it will have only *a half* or *a third* of its original pressure, supposing that its temperature is preserved while it expands. Hence, it follows that the expansion of steam is exactly proportional to its elastic force expressed in atmospheres, according to the preceding article. The following table exhibits the results of this law, at different temperatures with their corresponding pressures and expansions. The first column marked *Temperature*, contains the degrees of heat of Fahrenheit's thermometer at which the steam must be maintained, the second, marked *Pressure*, contains the number

of pounds *per square inch* with which the safety-valve must be loaded to resist its escape; and the third, marked *Expansion*, contains the number of times its volume, to which the steam would expand if relieved from the pressure, and still maintain an elasticity equivalent to the pressure of the atmosphere.

Temperature.	Pressure.	Expansion.
212°·00	0 lbs.	1 time
250 ·52	15	2 times.
275 ·18	30	3
293 ·72	45	4
308 ·84	60	5
320 ·36	75	6
331 ·70	90	7
341 ·96	105	8
350 ·78	120	9
358 ·88	135	10
367 ·34	150	11
374 ·00	165	12

49. A table similar to the preceding might be constructed from the Table of the experiments of Dalton and Taylor referred to in art. 45, and it might be extended to a greater length by the table in art. 46 or by the rules in both articles. Thus, *To determine the pressure on the safety-valve, subtract* 30 *from the elastic force in inches of mercury, and half the remainder will be the pressure required in lbs.* Or, *subtract unity from the elastic force in atmospheres, and multiply the remainder by* 15, *the product will be the pressure required in lbs. on the square inch.*

Either of these rules will give results corresponding to these in the preceding table, and probably superior in point of accuracy. The following table extracted from "Brunton's Compendium," is one of the same description.

Temp.	Pr.	Temp.	Pr.	Temp.	Pr.	Temp.	Pr.	Temp.	Pr.
	lbs.		lbs.		lbs.		lbs.		lbs.
216°	1	252°	15	275°	29	293°	43	307°	57
219	2	254	16	277	30	294	44	308	58
222	3	256	17	278	31	295	45	309	59
225	4	258	18	279	32	296	46	310	60
229	5	260	19	281	33	297	47	311	61
232	6	261	20	282	34	298	48	312	62
234	7	263	21	283	35	299	49	313	63
236	8	265	22	285	36	300	50	314	65
239	9	267	23	286	37	301	51	315	66
241	10	268	24	287	38	302	52	316	67
244	11	270	25	288	39	303	53	317	68
246	12	271	26	289	40	304	54	318	69
248	13	273	27	290	41	305	55	319	70
250	14	274	28	291	42	806	56	320	71

50. Mr. Tredgold has given the following rule for finding the volume of a cubic foot of water when converted into steam of a given elastic force and temperature: *Multiply the sum of the given temperature in degrees and* 459, *by* 76·5, *and divide the product by the force of the steam in inches of mercury; the quotient will be the number of cubic feet occupied by the steam of one cubic foot of water.* From this, the weight of a cubic foot of steam, and its specific gravity at different temperatures, may easily be found by proportion. The velocity with which the steam rushes into a vacuum is found by art. 20, modified by art. 32. Thus, to find the volume of a cubic foot of water when converted into steam of atmospheric pressure (at 30 inches, and temperature 212°,) we have $212 + 459 = 671$; then

$671 \times 76{\cdot}5 = 51331{\cdot}5$; and $51331{\cdot}5 \div 30 = 1711$ cubic feet. Again, to find the weight of a cubic foot of this steam, we have $1711 : 1 :: 62{\cdot}3$ lbs. or 436100 grains : 254·8 grains; and, to find its specific gravity, air being 1, we have $1{\cdot}2 \times 437{\cdot}5$ grains, or $525 : 254{\cdot}8 :: 1 : {\cdot}485$; where we have taken the weight of a cubic foot of water at 62·3 lbs. and the weight of a cubic foot of air 1·2 ounces at the temperature of 60°.

51. To find the velocity of steam at 212° rushing into a vacuum, we have $1711 \times 34 = 58174$ feet, the height of an atmosphere of this fluid; then $8\sqrt{58174} = 1928$; and $1928 \times {\cdot}81 = 1562$ feet nearly; where the height of a column of water at 60° equivalent to the atmospheric pressure is taken at 34 feet, and the contraction of the jet that of a tube two diameters long, its discharge being to the natural discharge nearly as 6·5 to 8.

52. *Latent heat of steam.* The remarkable fact established by undoubted experiment, that the sum of the latent and sensible heats of steam is a constant quantity, leads to several valuable practical results. It follows from this law; 1. That the same quantity of heat is necessary to convert a given weight of water into steam, at whatever temperature, or under whatever pressure, the water may be boiled; 2. That in the steam-engine, equal weights of high-pressure and low-pressure steam are produced by the same consumption of fuel; and 3. That, in general, the consumption of fuel is proportional to the quantity of water converted into steam, whatever may be the pressure of the steam. It may likewise be remarked that the variation of the density or specific gravity of steam is only

strictly proportional to its pressure or elasticity, when the temperatures are the same; and no part of steam can be reduced to the liquid state by mechanical force or compression alone, without diminishing the sum of the latent and sensible heats.

It has been pretty accurately ascertained that the latent heat of steam generated under the mean pressure of the atmosphere is 1000°, its sensible heat being 212°; the sum of these is 1212°, a constant quantity for all temperatures and pressures. Thus, between 32° and 1212°, the sum of the latent and sensible heat of steam is 1180°; for, under the ordinary atmospheric pressure, the first 180° of heat would raise water at 32° to 212° or the boiling point; and the next 1000° of heat, would convert the water into steam; but this accession of heat not being indicated by the thermometer, is termed *latent*. Hence, to find the latent heat of steam, *Subtract its sensible heat, expressed in degrees of Fahrenheit, from* 1212°, *and the remainder will be its latent heat.* Thus the latent heat of steam at 500°, is 712°.

53. On the preceding principle, it will be easy to find the heat requisite to convert water of any given temperature into vapour or steam of any required temperature: thus, *Add* 1000° *to the temperature of the vapour or steam, and from the sum, subtract the temperature of the water, the remainder will be the heat of conversion required.* Thus, the heat required to convert water at 52° into steam at 220°, the usual temperature of low-pressure steam, is $1000 + 220 - 52 = 1168°$. Among the tables at the end of this work, there is

an abstract of Mr. Tredgold's Table of the "Properties of Steam" in which will be found many examples of the application of the principles and rules contained in the ten preceding articles.

54. *Steam Engine.* The great change of volume which steam undergoes when it is condensed by being suddenly cooled, renders it a most efficient means of producing a vacuum, without the application of mechanical force. This is in fact the principle of the construction of all condensing steam engines whether operating by atmospheric pressure or by steam-pressure, with single or double action. Since a cubic inch of water expands into a cubic foot of steam at the boiling temperature, it is evident that, conversely, steam when suddenly condensed by being cooled to a low temperature will be reduced to about one 1700th part of its bulk; and if it be confined in an air-tight vessel, a vacuum will be formed in proportion to the quantity of steam condensed. Again, as steam at the temperature of 212° balances the pressure of the atmosphere, it is evident that, conversely, when it is condensed, this pressure will operate with all its force against the sides of the vessel in which the vacuum is formed. This force is well known to be equivalent to about 15 lbs. on the square inch; but from the quantity of uncondensed steam, the friction of the parts, and other sources of resistance in steam engines, it is generally reduced about one-half in its effective operation as a moving power.

55. *Low Pressure Engines.* The most improved and most generally used form of the steam engine is the *Double Acting Engine* of Watt. The moving power in this machine is rendered operative by

means of a piston placed in a cylinder, closed at top and bottom, in which it moves steam-tight. The piston is connected with the end of the working beam by a rod moving in an air-tight collar or stuffing-box in one end of the cylinder. The beam is supported on its axis, and has a connecting rod to convey motion to the crank and shaft. When the engine is to be put in motion, the atmospheric air and other gases are expelled from the cylinder and the tubes which communicate between it and the boiler, by steam, which is allowed to pass freely through them, and escape through a valve or cock provided for the purpose, until all the air be blown out of the engine. The cock is then closed, and pure steam fills every part of the engine. A vessel or chamber called a *condenser*, which is maintained at a low temperature, by being immersed in cold water, is made to communicate with both ends of the cylinder by means of proper tubes and valves worked by the engine. When the piston is required to descend, the communication between this chamber and the bottom of the cylinder is opened, while a communication is at the same time opened between the boiler and the top of the cylinder. The steam which fills the cylinder below the piston rushes towards the condenser by its elastic force, and is there immediately converted into water by the cold medium with which it is surrounded, a jet of water being allowed to play into the condenser. The space of the cylinder below the piston is thus rendered a vacuum; instantly the steam rushing from the boiler on the top of the piston forces it downwards, till it reaches the bottom of the cylinder. The communication between the boiler and the top of the cylinder is now closed, and a communication opened between the boiler and the bottom of the cylinder; and at the same time the communication between the condenser and the bottom of the cylinder is closed, and a communication is opened between the condenser and the top of the cylinder. Under these circumstances, the steam above the piston rushes by its elastic force towards the condenser as before, where it is immediately condensed, and the space of the cylinder above the piston is made a vacuum. The steam from the boiler then instantly rushes into the cylinder below the piston, and forces it upwards to the top of the cylinder. In this manner, the alternate motion of the piston upwards and downwards is continued, this motion is communicated to the beam by the piston-rod, and from the beam to the crank by the connecting rod. All the communications are effected by valves which are opened and closed by apparatus attached either to the working beam or the crank shaft. The air pump which clears the condenser of air and water, the cold water pump which supplies the cistern, and the hot water pump which supplies the boiler, are all worked by connecting rods attached to the working beam.

56. *Single Acting Engine.* This engine which is also the invention of Watt, differs from the preceding in this principal respect, that the force of steam is employed only to produce the downward motion of the piston the reverse motion being effected by a counter-weight attached to the other end of the working beam. When the piston by the operation of the moving power reaches the bottom of the cylinder, a communication is opened between tho

boiler and the bottom of the cylinder, and steam is admitted below the piston as well as above: the communication between the cylinder and condenser being then closed, the piston is raised by the counterweight; but as soon as it reaches the top of the cylinder, the communication between the cylinder and condenser is opened, the steam is condensed, the piston descends, and the operation is continued as above described. The other parts of this engine are similar to those of the double acting engine.

57. *Atmospheric Engine.* The principal difference between an atmospheric engine *with a condenser*, and a single acting steam engine, consists in the steam being admitted both into and out of the cylinder by communications at the bottom, and the descent of the piston is effected by the pressure of the atmosphere on its upper surface, the cylinder being open at the top. In the atmospheric engine, as it existed before Watt's invention of the separate condenser, the jet of cold water was thrown into the cylinder itself, at every stroke of the piston; consequently, the cylinder was alternately heated and cooled at each stroke, at a great expense of fuel and cold water, and a corresponding loss of steam. It is only by taking a retrospective glance at the early history and progress of the steam-engine towards its present improved state, that we can duly appreciate the gratitude we owe to the genius who so greatly increased its power and facility of operation, as to create a new era in the annals of his country, and in the history of the world.

58. *Proportion of the Parts of a Steam Engine.* In all kinds of steam engines, the length of the cylinder should be about twice its diameter, so that

the steam may be bounded by the least possible quantity of surface. According to Tredgold, the velocity of the piston in feet per minute should be 98 times the square root of the length of the stroke, in an engine for raising water ; and 103 times that length, in one for driving machinery. Also, the *area* of a transverse section of the steam passages, should be the 4800th part of the *product* of the velocity of the piston in feet per minute, and the *area* (in feet) of a section of the cylinder parallel to its base.

59. In the *common* atmospheric engine, if this area be multiplied by half the velocity, and the product, by 1·23 added to 1·4 divided by the diameter, the result divided by 1480 gives the number of cubic feet of water required for steam per minute. If the difference between 1220° and the temperature of condensation, be divided by the difference between that temperature and the temperature of the cold water, the quotient will be the number of times the quantity of water required for injection must exceed that required for steam, which is generally about twelve times. The aperture for injection must be such as to admit that quantity during the time of the stroke. The head of water should be about 3 times the height of the cylinder. When the jet apertures are square, the area of a section should be the 850th part of the area of a section of the cylinder. The diameter of the conducting pipe should be about40 times that of the jet.

60. In the atmospheric engine with a separate *condenser*, the capacity of the air-pump should be one 14th part of that of the cylinder, or making

the stroke of the air-pump half that of the steam piston, its diameter should be $\frac{3}{8}$ of the diameter of the cylinder. If the area of a section of the cylinder be multiplied by half the velocity, and to the product $\frac{1}{5}$ part be added, for loss by cooling, &c. the sum divided by 1480, gives the quantity of water in cubic feet per minute required for the boiler; and 24 times this quantity is necessary, for injection. The diameter of the injection aperture should be one 36th part of the diameter of the cylinder, and that of the injection pipe one 9th part.

61. In a *Single Acting* engine on Watt's principle, the capacity of the air-pump and condenser should each be $\frac{1}{8}$ of that of the cylinder, or their dimensions should each be half the diameter and half the length of stroke of those of the cylinder. By multiplying the area of a section of the cylinder by half the velocity, adding $\frac{1}{10}$ for cooling, &c. and dividing the sum by the volume of the steam corresponding to its force in the boiler, the quotient is the quantity of water required for steam per minute. The quantity of injection water should be 24 times this quantity, and the diameter of the injection pipe one 36th part of that of the cylinder.

62. In a *Double Acting* engine the proportions of the air-pump, condenser, and cylinder, should be the same as above; the quantity of water required for steam and injection *double*, and the proportions of the injection pipe and cylinder the *same*. At the ordinary pressure of 2 pounds per circular inch on the valve, in both engines, the divisor for the volume of steam, is 1497. The proportions of the dimensions of boilers are commonly stated to be, for width

1, for depth 1·1, and for length 2·5; otherwise, 5 square feet of surface of water is allowed for each horse power. Boulton and Watt allowed 25 cubic feet of space in the boiler for each horse power.

63. *Effective Pressure of Steam in Engines.* Mr. Tredgold estimates the loss of motive force in the *common* atmospheric engine due to the uncondensed steam (temp. 160°), to the force requisite to expel it and the air from the cylinder, to the friction of the piston and axes, and to the force required to open and close the valves and raise the injection water —at ·49 of the atmospheric pressure; hence, the effective pressure is only ·51 of this pressure or 5·9 lbs. per circular inch. In the atmospheric engine with a *condenser*, the loss of motive force due to the same causes, with the addition of the force requisite to work the air-pump, is only ·458 of the atmospheric pressure; hence, the effective pressure is ·542 of this pressure, or 6·25 lbs. per circular inch.

64. In the *Single Acting* engine, the loss of motive force due to the same causes, is ·402 of the pressure of one atmosphere: hence, the effective pressure is ·598 of this pressure. To determine the mean effective pressure when the force of the steam in the boiler is different from that of the atmosphere; *Multiply the given pressure in inches of mercury by* ·598, *and from the product subtract the pressure due to the temperature of the uncondensed steam, the remainder is the pressure required, in inches of mercury; multiply this pressure by* $14\frac{3}{4}$ lbs. *the atmospheric pressure on a square inch, and divide the product by* 30, *the quotient is the mean effective pressure on a square inch of the piston, which multiplied by* ·7854 *gives the pressure per circular inch.*

65. In the Double Acting Engine, the loss of motive force due to the causes above mentioned, is estimated by Mr. Tredgold at ·368 of the pressure of one atmosphere; hence, the effective pressure is ·632 of this pressure. Consequently the mean effective pressure on the piston, when the force of the steam in the boiler is different from that of the atmosphere, is found by the rule in the preceding article. The force of low pressure steam in the boiler, is generally equivalent to that of 35 inches of mercury, the temperature being 220°; and the temperature of the uncondensed steam 120°, its force being equivalent to that of 3·7 inches. Hence, for the Single Engine, we have $35 \times {\cdot}598 = 20{\cdot}93$ inches, and $20{\cdot}93 - 3{\cdot}7 = 17{\cdot}23$ inches; whence $17{\cdot}23 \times 14{\cdot}75 = 254{\cdot}1425$, and $254{\cdot}1425 \div 30 = 8{\cdot}47142$ lbs. nearly, per square inch; consequently $8{\cdot}47142 \times {\cdot}7854 = 6{\cdot}66$ lbs. nearly, per circular inch. For the Double Engine, we have $35 \times {\cdot}632 = 22{\cdot}12$ inches and $22{\cdot}12 - 3{\cdot}7 = 18{\cdot}42$ inches; whence $18{\cdot}42 \times 14{\cdot}75 = 271{\cdot}695$, and $271{\cdot}695 \div 30 = 9{\cdot}0565$ lbs. per square inch; consequently $9{\cdot}0565 \times {\cdot}7854 = 7{\cdot}1$ lbs. per circular inch.

66. *To Calculate the Power of a Steam Engine.* 1. *The Common Atmospheric Engine.* Multiply 5·9 times the square of the diameter of the cylinder in inches (see art. 63), by half the velocity of the piston in feet per minute, and the product is the effective power in lbs. raised 1 foot high per minute. Divide this product by 33000, and the quotient is the number of horses' power (see art. 11). 2. *The Atmospheric Engine with Condenser.* Apply the above rule, but instead of 5·9, use $6\frac{1}{4}$ for the multiplier (see art. 63). 3. *Single Acting Engine.*

Multiply the mean effective pressure on the piston (see arts. 64, 65) by the square of its diameter in inches and by half the velocity in feet per minute, and the product is the effective power in lbs. raised 1 foot high per minute. The number of horses' power is found as above. 4. *Double Acting Engine.* Apply the preceding rule, but instead of half the velocity, use the whole of it, for a multiplier (see arts. 64, 65).

67. *To Calculate the Power of an Engine, when the Steam acts Expansively.* 1. In the *Single Acting Engine.* Multiply 2·3 times the common logarithm of the reciprocal of the fraction denoting the portion of the stroke made when the steam is cut off, and to the product add ·3; then, multiply the sum by that fraction and by the whole force of the steam in the boiler, in lbs. per circular inch; the product is the mean effective pressure on the piston, with which proceed as directed in art. 66. 2. In the *Double Acting Engine.* Divide 2·3 times the common logarithm of the reciprocal of the fraction denoting the portion of stroke made when the steam is cut off, by the reciprocal itself, and multiply the quotient by the whole force of the steam in the boiler, in lbs. per circular inch; the product is the mean effective pressure on the piston, with which proceed as directed in art. 66.

68. *High Pressure Engines.* Those engines in which the steam, after having performed its work, instead of being condensed, is allowed to escape into the atmosphere, are generally called *high pressure*, but more properly *non-condensing* engines. The steam which constitutes the moving power, is generated under a great pressure, and its excess above

that of the atmosphere, which is generally from 30 to 40 lbs. per circular inch, is the effective pressure. The working parts of a non-condensing engine, are the cylinder having steam passages furnished with cocks or valves to admit the steam either at top or bottom, and similar apparatus for its escape; with the air-tight piston, piston-rod, working-beam, crank, and shaft, as before. When the piston is at the bottom of the cylinder, and the steam passage open below, and the communication with the atmosphere open above, the rest being closed, the steam rushing from the boiler will press on the bottom of the piston and cause it to ascend. By the time it has reached the top, the steam communication below, and the atmospheric communication above are both shut, and the opposite communications above and below are opened: the steam then rushing from the boiler on the top of the piston will cause it to descend, while the steam that was below will escape into the atmosphere; in this manner, the alternate motion is continued. The passages are closed a little before the end of the stroke, to prevent concussion against the ends of the cylinder, or strain on the crank shaft; when properly managed, the elasticity of the steam destroys the momentum of the piston, and causes it to recoil without loss of force.

69. *To calculate the Power of a High Pressure Engine.* The excess of the force of steam in the boiler above the pressure of the atmosphere, as shown by the steam gauge, is the motive force; but the loss of force due to friction, waste, cooling, opening of valves, cutting off steam before the end of the stroke, &c. is estimated by Mr. Tredgold

at ·4 of the force of the steam in the boiler, consequently the effective pressure is only ·6 of this force diminished by the pressure of the atmosphere. Hence, *When the engine is working at full pressure,* multiply the difference between six-tenths of the excess of the force of the steam in the boiler above the pressure of the atmosphere, and four-tenths of that pressure, in pounds per circular inch, by the square of the diameter of the cylinder in inches, and by the velocity of the piston in feet per minute, and the product is the number of lbs. raised 1 foot high per minute, from which the number of horses' power may be found as before (see art. 65). If the area of the piston in feet be multiplied by the velocity per minute in feet, the product will be the volume of steam when of the same density as that in the boiler; if this product be divided by the volume of steam which a cubic foot of water forms at the temperature or force in the boiler, the quotient is the cubic feet of water consumed per minute.

70. *When the engine is working expansively.* 1. *To find the mean effective pressure on the piston*; add 1 to 2·3 times the logarithm of the reciprocal of the fraction denoting the part of the stroke at which the steam is cut off, divide the sum by that reciprocal, and subtract ·4 from the quotient; multiply the remainder by the whole force of the steam in the boiler per circular inch, and from the product subtract 11·55 for the pressure of the atmosphere; the remainder is the mean effective pressure in lbs. per circular inch. 2. *To find the Power.* Multiply the mean effective pressure by the square of the diameter of the piston in inches and by the velocity in feet per minute; and from

the product, find the number of horses' power, as before (see art. 65). If the area of the piston be multiplied by the velocity in feet per minute, and the product increased by $\frac{1}{10}$ part, be divided by the reciprocal of the fraction above mentioned, the quotient is the quantity of steam in cubic feet consumed per minute; from this quantity the number of cubic feet of water required may be found as before (see art. 70).

71. *Length of Stroke and Velocity of an Engine* The stroke of an engine is equal to one revolution of the crank shaft, and consequently to double the length of the cylinder. In common parlance however, the length of stroke and the length of the cylinder are synonymous; in this sense, it is to be understood, in the following rules by Tredgold, for finding the proper velocity of the piston: 1. If the engine be regulated by a fly, and the pressure on the piston be the same throughout the stroke, the best velocity is 120 times the square root of the length of the stroke in feet. 2. If the steam act expansively, the velocity is found by multiplying the logarithm of the reciprocal of the fraction denoting the part of the stroke where the steam is cut off, by 2·3, adding ·7 to the product, and multiplying the sum by that fraction; then taking 120 times the square root of the product. 3. If the steam does not act expansively, the velocity is equal to 108 times the square root of the length of the stroke. 4. If the steam act expansively at the ordinary pressure of about 8 lbs. per circular inch of the safety valve, and the steam is cut off at half the stroke, the velocity is 100 times the square root of the length of the stroke. In the following table exemplifying the application

of the preceding rules, the diameter of the cylinder is supposed to be 30 inches, the depth 60 inches or 5 feet, and the velocity 22 double strokes per minute, or 220 feet per minute, the usual rate of the piston in steam engines.

Comparative Table of the Power of the Different kinds of Steam Engines.

Kind of Engine.	Stroke.	Velocity.	Diameter	Temperature.	Pressure of Steam.	Horse Power.
		ft.	in.		in.	
Common Atmospheric,	full	220	30	212°	30	18
Do. with Condenser,	full	220	30	212°	30	19
Single acting Low Pressure,	full	220	30	220°	35	20
Do. Expansive,	¾	220	30	220°	35	18
Double acting Low Pressure,	full	220	30	220°	35	43
Do. Expansive,	¼	220	30	220°	35	28
High Pressure,	full	220	30	277°	45	58
Do. Expansive,	¾	220	30	277°	45	51

72. *Steam Gauge, Condenser Gauge, Indicator and Governor.* The most important apparatus for ascertaining the state of an engine is the *Steam Gauge;* this is a short bent tube of iron nearly half an inch in diameter open at both ends, one of which is fixed in the boiler, or steam pipe, and the other is open to the atmosphere; in the bent part of the tube there is placed a quantity of mercury, and the steam pressing on its surface at the one end, raises it in the other leg of the tube; the height to which it is raised, is measured on a scale, by the slender stem of a float on the surface of the mercury. This apparatus shows the excess of the elastic force of the steam above the pressure of the atmosphere. In some engines, the gauge pipe is made of glass ter-

minating in a cistern of mercury inclosed in an iron box. The steam has free access to the surface of the mercury, and the action of the apparatus is like that of a common barometer.

The *Condenser gauge*, or barometer gauge as it is sometimes called, is an iron tube in the form of an inverted syphon, having one leg about half the length of the other. The end of the longer leg communicates with the condenser by means of a pipe furnished with a stop cock. Mercury being poured into the short leg, it rises in the other to the same level, when the tube is open to the atmosphere at both ends; in the short leg is placed a float with a stem and scale, which indicates by the sinking of the mercury in this leg, and its consequent rising in the longer one, the degree of exhaustion in the condenser. The difference between the elastic force of the vapour in the condenser and that of the steam in the boiler, as shown by the gauge, plus the height of the barometer at the time, gives the relative motive force of the steam, independent of deductions (see arts. 64, 65).

The *Indicator* is an apparatus for showing the force of the steam and the state of exhaustion in the cylinder, at the different periods of the stroke of the engine. It consists of a small cylinder about $1\frac{3}{4}$ inch diameter and 8 inches long furnished with a piston and a direct communication with the cylinder of the engine. When the force of the steam in the cylinder is greater than the pressure of the atmosphere the piston of the indicator rises, and when less it sinks. The indicator is furnished with a tracer for drawing a curve on paper, showing the variation in the pressure of the steam.

The *Governor*, though not necessarily peculiar to the steam engine, is a very useful apparatus for regulating the admission of the steam, by its operation on the *throttle-valve*. It consists of two heavy balls so suspended from an axis made to revolve by the operation of the engine, that they rise when the velocity is increased, and fall when it is diminished. To the rods by which these balls are suspended, arms are so connected that the rising or falling of the balls moves a lever which shuts or opens the valve, according as the velocity of the engine exceeds or falls below a certain point. The vertical distance between the point of suspension and the plane in which the centre of the balls revolve, is the same as the length of a pendulum, which makes one vibration during one revolution. The usual velocity for the axis is 30 revolutions per minute, hence the height should be the same as the length of the second's pendulum or 39·139 inches. To find the height for any other number of revolutions per minute, divide 35225 by the square of that number. For, since the lengths of pendulums are to one another, inversely as the squares of their numbers of revolutions made in the same time; and $30 \times 30 = 900$; we have $39{\cdot}139 \times 900 = 35225{\cdot}1$ the number in the rule.

73. *Safety Valve.* A common form of this apparatus is that of a lever of the third order, where the fulcrum is a joint at one end of the lever, the resistance, a moveable weight at the other end; and the power, the pressure of the steam upon the valve, which acts upon the lever somewhere between its extremities. From similarity of form, this apparatus is called the *steelyard safety* valve. The

pressure of the steam is increased or diminished either by the motion of the weight, along the arm of the lever or by altering the weight itself; this is consequently a very dangerous form of the apparatus, as was unfortunately exemplified in the case of the explosion of the Earl Grey. A more usual and safer form is the valve with spindle loaded with circular weights, until the whole weight per inch exceeds, just a little, the force of steam per inch required to work the engine, the orifice being so large as to permit the steam to escape faster than it is generated. To prevent accidents similar to that above mentioned, the valve should be enclosed in a box communicating with the chimney, or perforated with holes, so that the steam when forced through the valve, may escape into the atmosphere. This box, of course, should be kept locked, and the key placed in the proprietor's or captain's charge, so that the valve could never be overloaded without his cognizance. To prevent oversight, a number of such valves might be constructed, so that the probability of accidents would be greatly diminished; they might also be placed in steam boats so as to communicate with the atmosphere by the sides of the vessel, or with the sea by the bottom; in the former case, besides being out of the reach of danger, they would give proper warning of the excess of steam pressure.

For other interesting particulars respecting the Steam Engine, we must refer the reader to Tredgold's work on that subject, to which we are mainly indebted for several of the preceding articles, and to the tables in the third section of this book.

THE

PRACTICAL MECHANIC'S

POCKET GUIDE.

SECT. II.—WEIGHT, STRENGTH, AND STRAIN OF MATERIALS.

CHAP. I.

WEIGHT OF MATERIALS.

74. *Definitions.* The *weight* of a body is the quantity of matter it contains, independently of its magnitude or volume. The *density* of a body is the ratio of its weight to its volume. The *specific gravity* of a body is the ratio of its density to the density of another body assumed as a standard.

75. *Corollaries.* 1. The specific gravities of bodies are directly as their weights, when the volumes are equal. 2. The specific gravities of bodies are inversely as their volumes, when their weights are equal. 3. The weights of bodies are directly as their volumes, when the specific gravities are equal. 4. The weights of bodies are directly as the products of their volumes and specific gravities.

76. *Standard of Weight.* That body which is most universally diffused in nature, which is most easily obtained, and which is most uniform in all circumstances, ought to be selected as the standard of comparison with other bodies in point of weight

and specific gravity. Such a body is *water*, according to the universal opinion of philosophers; and by a remarkably fortunate coincidence, it is found that a cubic foot of water at a mean temperature of the air, weighs *almost* exactly 1000 ounces *Avoirdupois.* Indeed, this fact was so generally known and understood not only in this country, but on the continent, that it was considered a fixed and established point in our system of weights and measures, until the experiments of the Royal Commissioners on this subject, as referred to in the Act of Parliament "for establishing uniformity" in 1826, shewed that at the temperature of 62° Fahrenheit, the atmospheric pressure being 30 inches of the barometer, a cubic inch of distilled water weighs 252·458 grains, and at the maximum density 253 grains; consequently, a cubic foot of distilled water at these temperatures, weighs respectively 997·137 ounces, and 999·278 ounces avoirdupois.* As water, therefore, weighs very nearly 1000 ounces at 40°, and in common experiments holds foreign matter in solution which increases its weight, the ordinary estimate may be taken as the true one, except in cases where extreme delicacy is required.

77. *Specific Gravities and Weights.* From the preceding remarks, it is evident, that in a table of the specific gravities of bodies, where that of water is assumed as unity, the weight of a cubic foot of each body will be expressed in thousands of ounces or parts of a thousand ounces avoirdupois; and, if the specific gravity of water be taken at 1000, then

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* A detailed account of the Imperial Weights & Measures, with Tables of Comparison and Conversion between the Old and New Standards, may be had of the Publisher, price 4d.

the table will show the weight of a cubic foot of each body in ounces; hence the weight of a cubic foot in lbs., and the weight of a cubic inch in ounces may very easily be found. Some useful tables of this description will be found in Sect. III. Moreover, as an Imperial gallon of water weighs 10 lbs. avoirdupois, according to the new act, a table showing the specific gravities of bodies, where water is assumed as 10, will show the number of lbs. of each body, which fills an imperial gallon, or constitutes a cylinder whose diameter is one inch and altitude is 352 inches; hence, when the specific gravity of water is 1000, the number of lbs. of a body, whose capacity is that of an imperial gallon, is found by cutting off two figures from the number expressing the specific gravity. Thus, the specific gravity of melted lead is, 11·352, water being 1, or 11352 water being 1000; hence a cubic foot of lead weighs 11352 ozs. or 709½ lbs. and a cubic inch weighs 6·569 ozs. Moreover, an imperial gallon of lead weighs 113·52 lbs., which is also the weight of a solid cylinder 1 inch in diameter and 352 inches high.

78. By means of these tables, *the weight of a body may be found from its capacity, and conversely, its capacity from its weight,* by a very simple proportion. To render even a proportion in numerous cases unnecessary, very extensive tables of the weight of metal (particularly iron) bars, rods, plates, balls, cylinders, and pipes, have been introduced at the beginning of Sect. III. In all questions regarding the capacity and weight of bodies, it will be useful to remember that the *cubic foot* which contains *exactly* 1728 cubic inches, contains *very nearly* 2200

cylindric inches, 3300 *spherical inches,* and 6600 *conical inches.* Thus the capacity of a box, 60 inches long and 30 inches square, is $60 \times 30 \times 30 = 54000$ cubic inches, and $54000 \div 1728 = 31\frac{1}{4}$ cubic feet. The capacity of a cylinder, 60 in. long and 30 in. diameter, is $54000 \div 2200 = 24\frac{6}{11}$ cubic feet. The capacity of a prolate spheroid, whose axes are 60 in. and 30 in., is $54000 \div 3300 = 16\frac{4}{11}$ cubic feet. And the capacity of a cone whose altitude is 60 in. and diameter of base 30 in., is $54000 \div 6600 = 8\frac{2}{11}$ cubic feet.

79. *Weight of a Fly Wheel.* This is usually found by multiplying the number of horses' power of the engine to which it is to be applied, by 2000, and dividing the product by the square of the velocity of the circumference of the wheel, in feet per second; the quotient is the weight of the fly in cwts. Thus, the weight of a fly-wheel, for an engine of 20 horses' power, is 90·4 cwts., supposing it to be 18 feet in diameter, and to revolve 22 times in a minute.

80. *To find the specific gravity of a solid body.* This problem is founded on the principle, first observed by Archimedes, that *the apparent loss of weight which a body sustains by immersion in a fluid is equal to that of the volume of fluid which it displaces.* 1. When the body is insoluble in, and heavier than water. Weigh it in water, by means of a hydrostatic balance, or some contrivance of the same kind; then, divide its weight in air (or more correctly *in vacuo*) by the difference between its weight in air and its weight in water, and the quotient will be the specific gravity of the body, that of water being unity. 2. When the body is

insoluble in, and lighter than water, attach it to a heavier body the difference of whose weight in air and in water is known, provided it be sufficient to sink the compound mass in water; then, divide the weight of the lighter body in air, by the difference between the losses of weight which the heavier body and the compound mass apparently sustain in water, and the quotient will be the specific gravity of the lighter body.

81. *To find the specific gravity of a fluid body.* Weigh a solid which is insoluble in water and in the given fluid, in both fluids and in air; then divide its apparent loss of weight in the given fluid by its apparent loss of weight in water, and the quotient is the specific gravity of the given fluid. *Otherwise:* Fill a small glass measure having a very short narrow neck, and adjusted to hold exactly a thousand grains of water, with the given fluid; then divide the weight of the fluid it contains, in grains, by 1000, and the quotient will be its specific gravity.

82. When the specific gravities of bodies soluble in water are to be determined, other means must be employed; but as this subject belongs more particularly to Chemistry, we refer to the treatises on that science. The construction and use of the Hydrometer, Areometer, and other instruments for ascertaining specific gravities, will be found in Gregory's Mechanics, arts. 401—409, Vol. I. and p. 211, Vol. II.; Leslie's Natural Philosophy, p. 306, and Nicholson's Natural Philosophy, p. 16, Vol. II.

83. *To find the weights of two different ingredients in a given compound mass,* the specific gravities of all three being known. Multiply the weight of the

compound mass, the specific gravity of the heavier ingredient, and the difference between the specific gravities of the lighter ingredient and the mass, continuously together; divide the product by the specific gravity of the mass, and then the quotient by the difference between the specific gravities of the two ingredients; the result will be the weight of the heavier ingredient contained in the mass; of course, the weight of the lighter ingredient will be the difference between this weight and the weight of the mass. Thus, suppose a mass composed of gold and silver weighed 100 lbs. the specific gravity of the mass being 15·920, the weight of the gold would be found as follows:

$$\frac{100 \times 19{\cdot}258 \times (15{\cdot}920 - 10{\cdot}474)}{15{\cdot}920 \times (19{\cdot}258 - 10{\cdot}474)} = 75 \text{ lbs.}$$

whence, the weight of the silver is 25 lbs.*

CHAP. II.

STRENGTH AND STRAIN OF MATERIALS.

84. The Materials employed in machinery are subjected to four different kinds of stress or strain, by which the force of cohesion may be ultimately overcome and fracture ensue. These are, 1. *Tension* or any *stretching* force by which they may be torn asunder, as in the case of ropes, tie-beams, king-posts, &c. 2. *Transverse pressure*, or any *breaking* force acting perpendicularly or obliquely to the

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* The diameter of any small sphere or globule of a given material may be found by dividing its weight in grains by the number expressing its specific gravity, extracting the cube root of the quotient, and multiplying this root by 1·9612.

direction of their length, as in the case of levers, joists, &c. 3. *Vertical pressure*, or any *crushing* force acting in the direction of their length; as in the case of pillars, posts, &c. 5. *Torsion*, or any *twisting* force acting at either or both extremities of a beam or rod, such as the axle of a wheel, a screw, &c.

85. The natural forces, inherent in materials, which oppose the preceding forces, are, *Direct Cohesion* and *Elasticity*. Numerous experiments have been made on the direct cohesion of different substances, particularly woods and metals—on their resistance to transverse pressure, and their amount of deflection under a given pressure—on the *modulus* or measure of their elasticity—and lastly, though neither to so great nor so satisfactory an extent, on their resistance to vertical pressure or crushing weight.

86. The following Table contains the *Mean Strength and Elasticity of various Materials, as deduced from the most accurate Experiments;* it is the latest that has been published, and it was presented by Mr. Barlow, to the "British Association for the Advancement of Science," at their Third Meeting, which took place at Cambridge in 1833.

The first column of figures marked C, contains the mean strength of cohesion on an inch section of the material; the second, marked S, the constant for transverse strains; the third marked E, the constant for deflections; and the fourth, marked M, the modulus of elasticity. The specific gravity of the different kinds of wood in this table will be found in Sect. III.; that of iron varies from 7200 to 7760.

MATERIALS.	C	S	E	M
Woods.	lbs.			
† Acacia		1800	4609000	3739000
† Ash	17000	2026	6580000	4988000
Beech	11500	1560	5417000	4457000
† Birch, common		1900	6570000	5406000
* ——— American black		1500	5700000	3388000
Box	20000			
¶ Bullet-tree		2650	10512000	5878000
¶ Cabacully		2500	7437000	4759000
Deal, Christiana	11000	1550	6350000	5378000
——— Memel	11000	1730	6420000	6268000
† Elm	5780	1030	2803000	3007000
Fir, New England	12000	1100	5967000	6249000
—— Riga	12600	1130	5314000	4080000
§ — Mar Forest	12000	1140	3400000	2797000
¶ Green heart		2700	10620000	6118000
Larch, Scotch	7000	1120	4200000	4480000
† Locust-tree	20580	3400	767000	4649000
Mahogany	8000			
Norway spars	12000	1470	5830000	5789000
Oak, English from	9000	1200	3490000	2872000
Oak, English to	15000	2260	7000000	47020000
——— African	14400	2000	9500000	55830000
——— Adriatic	14000	1380	3880000	2257000
——— Canadian	12000	1760	8950000	5674000
——— Dantzic	14500	1450	4760000	3607000
Pear-tree	9800			
‖ Poon	14000	2200	6760000	6488000
Pine, Pitch	10500	1630	5000000	4364000
——— Red	10000	1310	7360000	6423000
‖ Teak	15000	2460	9660000	7417000
¶ Tonquin bean		2700	10620000	5826000
Iron.				
Iron, cast from	16300	8100	69120000	5530000 ‡
Iron, cast to	36000			
——— Malleable	60000	9000	91440000	6770000
——— Wire	80000			

The use of this table will be exemplified in the following problems, for the demonstration of the principles of which, we must refer the reader to the scientific treatises on Natural Philosophy.

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† Of English growth. * American. ¶ Berbice. § Scotland ‖ East Indies. ‡ Mean of English and Foreign.

87. *Force of Direct Cohesion or Tenacity of Materials.* The resistance of a homogeneous body to longitudinal tension or a stretching force is proportional to the area of a transverse section; hence, the centre of tenacity is the same as the centre of gravity of the section. The absolute strength of rods or beams is estimated by the cohesive power of the material of which they are composed. The preceding table exhibits in column C, the force of direct cohesion in lbs. avoirdupois for every square inch of area in the transverse section of a beam or rod of the materials enumerated in the first column.

88. *To find the absolute strength or force of direct cohesion of beams or rods of given materials,* that is, their absolute resistance to longitudinal tension or strain in lbs. Rule.—*Multiply the area of the transverse section of the rod or beam in inches by the tabular number, in the column marked* C, *opposite the name of the material, and the product will be the strength or resistance required. Note.* 1. In practice the weight or strain should not exceed $\frac{1}{3}$ of the absolute strength according to Barlow, or $\frac{1}{4}$ according to Tredgold. Thus; the force which would tear asunder a piece of teak $4\frac{1}{2}$ inches broad and 2 inches thick, is $2 \times 4\frac{1}{2} \times 15000 = 135000$ lbs. Hence a longitudinal strain of more than 45000 lbs. would be unsafe in practice. *Note.* 2. The tenacity of materials of the same kind is proportional to their specific gravity. Hence, a piece of teak whose specific gravity was $\frac{1}{20}$ part less than that of the preceding, would have $\frac{1}{20}$ part less of cohesive power.

89. When the direction of the straining force does not coincide with the perpendicular to the centre of tenacity or centre of gravity of the trans-

verse section, the Rule is modified as follows: Multiply the tabular number in col. C, by the breadth and the square of the thickness of the beam, both in inches, and divide the product by the sum of the thickness and 6 times the distance of the line of direction from the centre of the section, in inches; the quotient will be the absolute strength required, of which take $\frac{1}{3}$ as before, for the practical load. *Note.* In actual constructions an allowance of $\frac{1}{3}$ of the thickness should be made for the probable deviation of the direction of the stretching force. The absolute strength will then be $\frac{1}{3}$ of that found by the Rule in the preceding article; and the practical load $\frac{1}{9}$ of the same quantity, or $\frac{1}{12}$ according to Tredgold.

90. *To find the dimensions of a rod or beam to resist a given longitudinal strain,* that is, to sustain a given weight without fracture in the direction of its fibres. *Rule.—Multiply the tabular number in col.* C, *by the number denoting the ratio of the breadth to the thickness, and divide* 9 (*or* 12) *times the given weight in lbs. by the product; the square root of the quotient will be the required thickness in inches, and the thickness multiplied by the number of the ratio will give the breadth required.* Thus, the dimensions of a beam of the strongest English oak to sustain a load of 20 tons in the direction of its fibres, supposing the breadth to be 3 times its thickness is $\sqrt{\{(9\times 44800)\div(3\times 15000)\}}=3$ inches nearly, the thickness required; whence $3\times 3=9$ inches, the breadth required. *Note.* If the beam be cylindrical, divide 9 times the given weight by ·7854 times the tabular number, and the square root of the quotient will be the diameter.

91. *Force of the Transverse Resistance of Materials.* This force is proportional to the product of the breadth and the square of the depth in rectangular beams (more properly parallelopipedal beams), and to the cube of the diameter in cylindric beams; but it is in the inverse ratio of the length, modified by the cosine or square of the secant of the angle of deflection immediately before fracture, and by the manner in which the beam is supported. In ordinary practice, the consideration of the angle of deflection may be omitted.

92. *To find the relative strength or force of resistance of rectangular beams or rods of given materials, to transverse strain or pressure in lbs.* 1. When the beam is *fixed* at one end and *loaded at the other*. Rule. Multiply the tabular number, in the column marked S, opposite the name of the given material, by the breadth of the beam in inches, and this product by the square of its depth in inches, and divide the result by the length of the beam in inches, the quotient will be the strength or resistance required. 2. When the beam is *fixed* at the one end and *uniformly loaded*, the strength or resistance will be *double* the preceding resistance, which for brevity we shall call the *prime* resistance. 3. When the beam is *supported* at both ends and *loaded in the middle*, the strength will be *four times* the prime resistance. 4. When the beam is *supported* at both ends and *uniformly loaded*, the strength will be *eight times* the prime resistance. 5. When the beam is *fixed* at both ends and *loaded in the middle*, the strength is *six times* the prime resistance. 6. When the beam is *fixed* at both ends, and *uniformly loaded*, the strength is *twelve times* the prime resistance.

7. When the beam is *supported* at both ends and *loaded at a point not in the middle*, the strength is found by multiplying the prime resistance by the square of the length, and dividing the result by the product of the lengths of the segments into which the beam is divided at the point of application of the load.

93. In all the preceding cases, it must be remembered that not more than *one-third* of the ultimate strength found by the rule, ought to be depended upon for any permanent construction, according to Barlow, and only *one-fourth* according to Tredgold, who adds that if the beam be not horizontal, the distance between the supports must be the horizontal distance. As an example, the weight which a beam of Riga fir, 20 feet long, 12 inches broad and 12 inches deep, supported at both ends, would sustain in the middle, is $(1130 \times 12 \times 144) \times 4 \div 240 = 32544$ lbs. and the practical load is $32544 \div 3 = 10848$ lbs. or $32544 \div 4 = 8136$ lbs.

94. When beams are cylindrical, their resistance to transverse pressure is only two-thirds of that of a square prism of the same thickness. In the case of a hollow cylinder, the resistance will be found by multiplying the difference of the cubes of the interior and exterior diameters by 8 times the modulus of elasticity and dividing the product by 9 times the length. If the hollow part be $\frac{9}{10}$ of the diameter of the cylinder, its strength will be reduced to about $\frac{1}{12}$ more than $\frac{1}{4}$ of that of the solid cylinder; but if the tube were formed into a solid rod its strength would be only about $\frac{1}{12}$ part of that of the solid cylinder. A cylinder having half its core hollowed out should be rendered only $\frac{1}{8}$ part weaker, which

agrees with an experiment made by Barlow. We see here the divine process of nature in making the bones of animals hollow, and the imitative ingenuity of man in making cast metal pillars tubular, thus combining lightness with strength in their structures.

95. The *lateral* or transverse strength of any beam thus depends mainly on the distance and cohesion of the upper and under surfaces. Whatever stiffens the exterior layers contributes greatly to strengthen the whole. A small incision drawn across the under side weakens a bar essentially; while a notch cut near the middle of the upper side will not impair the strength, but if filled up with a harder material will even sensibly augment it. Thus Duhamel found that a bar of willow cut through $\frac{1}{3}$ of its depth, the cut being filled up with a thin slip of hard wood, was thereby rendered $\frac{1}{6}$ part stronger than before. It was even remarked that the incision could be carried much farther without injuring the strength of the bar.*

96. *To find the breadth and depth of a beam of given length and material, so that it may, in practice support a given load*, in the case of prime resistance (art. 92). Rule. Multiply the given weight in lbs. by the length in inches, and divide this product by 4 times the product of the tabular number in col. S, and the number denoting the ratio of the breadth to the depth; then, the cube root of the quotient will be the required depth in inches, from which the breadth is found as before (art. 90). In all other cases, the tabular number in col. S, must be multiplied by the number denoting the increase of

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* Leslie's Natural Philosophy, p. 271.

strength or resistance arising from the mode of fixing the beam (art. 92), before the above rule be applied. Thus, the depth of a beam of Scotch Fir, 18 feet long, to bear a load of 20 tons at the middle, when supported at both ends, the breadth being half of the depth, is $\sqrt{\{(4 \times 44800 \times 216) \div (1140 \times \frac{1}{2} \times 4)\}} = 20{\cdot}4$ inches nearly; whence the breadth is 10·2 inches. When the breadth or depth is given, the calculation is easy, as the rule in art. 92, requires only to be reversed.

97. *Deflection of Beams under Transverse Strains.* The deflection of beams under given weights is proportional to the product of the weight and cube of the length directly, and to the product of the breadth and the cube of the depth inversely; whence the elasticity is deduced, being proportional to the deflection. Consequently, beams will be of the same stiffness, when the depth is increased in the same proportion as the length, the breadth remaining the same; and the deflection of beams arising from their own weight, having their several dimensions proportional, will be as the square of either of their like lineal dimensions. The same will apply to beams loaded throughout proportionally to the dimensions; this ought to be kept constantly in view in the construction of models, on a small scale, of works intended to be executed on a large one.

98. *To find the Deflection of a Beam:* 1. *When supported at both ends and loaded in the middle.* For brevity's sake, we shall call this the *prime* deflection. *Rule. Multiply the given weight in lbs. by the cube of the length of the beam in inches, and divide this product by the continuous product of the tabular*

number, in the column marked E, *opposite the name of the given material, the breadth, and the cube of the depth, the quotient will be the required deflection in inches.* 2. When the beam is fixed at one end and loaded at the other, multiply the prime deflection by 32. 3. When it is fixed the same, but uniformly loaded, multiply the prime deflection by 12. 4. When it is supported at both ends and uniformly loaded, take $\frac{5}{8}$ of the prime deflection. 5. When it is fixed at both ends and loaded in the middle, take $\frac{2}{3}$ of the prime deflection. 6. When it is fixed the same, but uniformly loaded, take $\frac{5}{12}$ of the prime deflection. Thus, the prime deflection of a beam of Pitch Pine, 30 feet long, 6 inches broad, and 10 inches deep, supported at both ends, and loaded in the middle with a weight of 1000 lbs. is $(1000 \times 27000 \times 1728) \div (5000000 \times 6 \times 1000) = 1\frac{5}{9}$ inches nearly; whence the deflections due to other modes of fixing and supporting, may easily be found. *Note.* If the beam be a cylinder, the deflection will be 1·7 times that of a square beam in similar circumstances.

99. *To find the weight which will produce a given prime deflection, on a beam of given material and dimensions.* Rule.—Find the continuous product of the tabular number in col. E, the breadth, the cube of the depth, and the given deflection, and divide this product by the cube of the length, the quotient will be the weight required. Thus, the weight which will produce a deflection of $1\frac{1}{2}$ inch on a wrought iron beam, 20 feet long, 3 inches broad and 9 inches deep, supported at both ends, and loaded in the middle, is $(91440000 \times 3 \times 729 \times 1\frac{1}{2}) \div (8000 \times 1728) = 21699$ lbs or nearly 10 tons;

whence, the weight for other deflections, may easily be found.

100. *To find the depth requisite for a beam of given material, length and breadth, to bear a given load with a given prime deflection.* Rule.—Divide the given load in lbs. by the continuous product of the tabular number in col. E, the breadth and the deflection, and multiply the cube root of the quotient by the length, the product is the depth required. Thus the depth of a wrought iron beam, 20 feet long, 3 inches broad, requisite to support a load of 10 tons with a prime deflection of $1\frac{1}{2}$ inch, is $240 \times \sqrt[3]{\{(10 \times 2240) \div (91440000 \times 3 \times 1\frac{1}{2})\}} = 9{\cdot}1$ inches nearly. When the breadth is not given, multiply the given weight by the cube of the length, and divide this product, by the product of the tabular number in col. E, and the given deflection, the quotient is the product of the breadth and cube of the depth. Hence, when the beam is to be square, the fourth root of the quotient is the breadth or depth required; and when it is to be cylindric multiply the quotient by 1·7, and the fourth root of the product will be the diameter.

101. *Practical Remarks.* Shafts which are to be cut for inserting arms, &c., should be made longer in proportion to the quantity removed by cutting. The deflection for shafts should not exceed $\frac{1}{100}$ of an inch for every foot of length, this being considered the limit; they ought also to be made always as short as possible, to avoid flexure. The deflection of $\frac{1}{40}$ of an inch for each foot of length is not injurious to ceilings; the usual allowance being double this quantity. Ceilings have been found to settle about 4 times as much without causing cracks,

and have been raised again without injury. The variable load on a floor can seldom exceed half the maximum or 120 lbs. for a square foot, except in public rooms; hence, the allowance may be taken from 60 to 120 lbs. according to circumstances. This rule applies to joists for floors.

102. The *modulus of Elasticity* is the measure of the elastic force of any material. It is found by the following proportion: As the portion of the length of a column of the material, which it loses by compression, is to the whole length before compression, so is the force which produced that compression, to the modulus of elasticity. Sir John Leslie has shown that the modulus of elasticity is found by dividing 5 times the fourth power of the length of a beam, by 32 times the product of its spontaneous depression and the square of its depth. In his work on *Heat*, he observes that a white deal 138 inches long and $\frac{9}{20}$ of an inch deep, suffered a depression of $2\frac{1}{2}$ inches by its own weight; hence $(5 \times 138 \times 138 \times 138 \times 138) \div (32 \times \cdot 45 \times \cdot 45 \times 2 \cdot 5) = 111936000$ inches, or 9328000 feet, in round numbers. The numbers in col. M, may be found from those in col. E, by multiplying the latter by 576, and dividing the product by the corresponding specific gravity.

103. *The Resistance of Materials to a crushing force*, appears to be directly proportional to the fourth power of the diameter in cylinders, or of the side in square prisms, and inversely proportional to the square of the height.

104. *To find the weight which a column of given material will support before flexure.* Multiply the tabular number in col. E, by ·121 times the fourth

power of the diameter in inches, in cylindric columns, or ·2056 times the side in inches, in square prismatic columns, and divide the product by the square of the length in inches, the quotient is the weight required in lbs. *Note.* When the base of the column is rectangular, multiply the tabular number by ·2056 times the area multiplied by the square of its breadth, and divide as before. Only $\frac{1}{3}$ or $\frac{1}{4}$ of this weight ought to be depended upon, in practice; for when once the column begins to bend, the consequences are inevitable. Thus, the weight under which a pillar of New England fir would begin to bend, supposing its length 20 feet and its diameter 12 inches, is $(5967000 \times {\cdot}121 \times 12 \times 12 \times 12 \times 12) \div (20 \times 20 \times 12 \times 12) = 259922{\cdot}52$ lbs. or nearly 116 tons, a most enormous load, according to theory; but 29 tons could only be trusted in practice.

105. *The Resistance of Materials to the force of Torsion, or Twisting,* is directly proportional to the angle of torsion and the fourth power of the diameter in cylindric shafts, and inversely as their length, according to Sir John Leslie; other writers say, that it is directly proportional to the cubes of the diameters. According to the Professor's law, the power of an iron cylinder to resist the torsion of a weight in lbs. acting at a distance of a foot, is found by dividing 600 times the fourth power of the diameter by the length. The preceding principle is employed in the construction of the *Balance of Torsion,* invented by Coulomb, for which see an account in Hebert's "Engineer's and Mechanic's Cyclopædia," a highly useful and ingenious work at present publishing in monthly parts.

THE

PRACTICAL MECHANIC'S

POCKET GUIDE.

SECT. III.—PRACTICAL TABLES.

I.—WEIGHT OF METALS.

MALLEABLE IRON, SQUARE, ROUND, AND FLAT.

Table I. contains the weight of Square Iron in sizes, from ¼ inch to 6 inches square, advancing by ⅛ inch; and from 6 to 12 inches square, advancing by ¼ inch; and in lengths, from 1 foot to 18 feet. The sizes are arranged in the first column of each page, and the lengths along the top; the weights in lbs. immediately under the lengths and in a line with the sizes.

Table II. contains the weight of Rounn Iron in sizes from ¼ inch to 6 inches diameter, advancing by ⅛ inch; and from 6 to 12 inches diameter, advancing by ¼ inch; and in lengths from 1 foot to 18 feet. The sizes, lengths, and weights are arranged as in Table I.

Table III. contains the weight of Flat Iron in widths, from ¼ inch to 6 inches, advancing by ¼ inch; in thicknesses from ¼ inch to 1 inch, advancing by ⅛ inch; and in lengths, from 1 to 18 feet. The widths, lengths, and weights, are arranged as in the preceding tables, and the thicknesses alongside of the widths.

TABLE I.—SQUARE IRON.

size.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.
ins.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
¼	0·2	0·4	0·6	0·8	1·1	1·3	1·5	1·7	1·9
⅜	0·5	1·0	1·4	1·9	2·4	2·9	3·3	3·8	4·3
½	0·8	1·7	2·5	3·4	4·2	5·1	5·9	6·8	7·6
⅝	1·3	2·6	4·0	5·3	6·6	7·9	9·2	10·6	11·9
¾	1·9	3·8	5·7	7·6	9·5	11·4	13·3	15·2	17·1
⅞	2·6	5·2	7·8	10·4	12·9	15·5	18·1	20·7	23·3
1	3·4	6·8	10·1	13·5	16·9	20·3	23·7	27·0	30.4
1⅛	4·3	8·6	12·8	17·1	21·4	25·7	29·9	34·2	38·5
1¼	5·3	10·6	15·8	21·1	26·4	31·7	37·0	42·2	47·5
1⅜	6·4	12·8	19·2	25·6	32·0	38·3	44·7	51·1	57·5
1½	7·6	15·2	22·8	30·4	38·0	45·6	53·2	60·8	68·4
1⅝	8·9	17·9	26·8	35·7	44·6	53·6	62·5	71·4	80·3
1¾	10·4	20·7	31·1	41·4	51·8	62·1	72·5	82·8	93·2
1⅞	11·9	23·8	35·6	47·5	59·4	71·3	83·2	95·1	106·9
2	13·5	27·0	40·6	54·1	67·6	81·1	94·6	108·2	121·7
2⅛	15·3	30·5	45·8	61·1	76·3	91·6	106·8	122·1	137·4
2¼	17·1	34·2	51·3	68·4	85·6	102·7	119·8	136·9	154·0
2⅜	19·1	38·1	57·2	76·3	95·3	114·4	133·5	152·5	171·6
2½	21·1	42·2	63·4	84·5	105·6	126·7	147·8	169·0	190·1
2⅝	23·3	46·6	69·9	93·2	116·5	139·8	163·0	186·3	209·6
2¾	25·6	51·1	76·7	102·2	127·8	153·4	178·9	204·5	230·0
2⅞	27·9	55·9	83·8	111·8	139·7	167·6	195·7	223·5	251·5
3	30·4	60·8	91·2	121·7	152·1	182·5	212·9	243·3	273·7
3⅛	33·0	66·0	99·0	132·0	165·1	198·1	231·1	264·1	297·1
3¼	35·7	71·4	107·1	142·8	178·5	214·2	249·9	285·6	321·3
3⅜	38·5	77·0	115·5	154·0	192·5	231·0	269·5	308·0	346·5
3½	41·4	82·8	124·2	165·6	207·0	248·4	289·8	331·3	372·7
3⅝	44·4	88·8	133·3	177·7	222·1	266·5	310·9	355·3	399·8
3¾	47·5	95·1	142·6	190·1	237·7	285·2	332·7	380·3	427·8
3⅞	50·8	101·5	152·3	203·0	253·8	304·5	355·3	406·0	456·8
4	54·1	108·2	162·3	216·3	270·4	324·5	378·6	432·7	486·8
4⅛	57·5	115·0	172·6	230·1	287·6	345·1	402·6	460·1	517·7
4¼	61·1	122·1	183·2	244·2	305·3	366·3	427·4	488·4	549·5
4⅜	64·7	129·4	194·1	258·8	323·5	388·2	452·9	517·6	582·3
4½	68·4	136·9	205·3	273·8	342·2	410·7	479·1	547·6	616·0
4⅝	72·3	144·6	216·9	289·2	361·5	433·8	506·1	578·4	650·7
4¾	76·3	152·5	228·8	305·1	381·3	457·6	533·8	610·1	686·4
4⅞	80·3	160·7	241·0	321·3	401·7	482·0	562·3	642·7	723·0

TABLE I.—SQUARE IRON.

size.	10 ft.	11 ft.	12 ft.	13 ft.	14 ft.	15 ft.	16 ft.	17 ft.	18 ft.
ins.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
¼	2·1	2·3	2·5	2·7	3·0	3·2	3·4	3·6	3·8
⅜	4·8	5·2	5·7	6·2	6·7	7·1	7·6	8·1	8·6
½	8·5	9·3	10·1	11·0	11·8	12·	13·5	14·4	15·2
⅝	13·2	14·5	15·8	17·2	18·5	19·8	21·1	22·4	23·8
¾	19·0	20·9	22·8	24·7	26·6	28·5	30·4	32·3	34·2
⅞	25·9	28·5	31·1	33·6	36·2	38·8	41·4	44·0	46·6
1	33·8	37·2	40·6	43·9	47·3	50·7	54·1	57·5	60·8
1⅛	42·8	47·1	51·3	55·6	59·9	64·2	68·4	72·7	77·0
1¼	52·8	58·1	63·4	68·6	73·9	79·2	84·5	89·8	95·0
1⅜	63·9	70·3	76·7	83·1	89·5	95·9	102·2	108·6	115·0
1½	76·0	83·6	91·2	98·9	106·5	114·1	121·7	129·3	136·9
1⅝	89·3	98·2	107·1	116·0	125·0	133·9	142·8	151·7	160·7
1¾	103·5	113·9	124·2	134·6	144·9	155·3	165·6	176·0	186·3
1⅞	118·8	130·7	142·6	154·5	166·4	178·2	190·1	202·0	213·9
2	135·2	148·7	162·2	175·8	189·3	202·8	216·3	229·8	243·4
2⅛	152·6	167·9	183·2	198·4	213·7	228·9	244·2	259·5	274·7
2¼	171·1	188·2	205·3	222·5	239·6	256·7	273·8	290·9	308·0
2⅜	190·7	209·7	228·8	247·9	266·9	286·0	305·1	324·1	343·2
2½	211·2	232·3	253·4	274·6	295·7	316·8	337·9	359·0	380·2
2⅝	232·9	256·2	279·5	302·8	326·1	349·4	372·7	396·0	419·3
2¾	255·6	281·2	306·7	332·3	357·8	383·4	409·0	434·5	460·1
2⅞	279·4	307·3	335·3	363·2	391·4	419·1	447·0	475·0	502·9
3	304·2	334·6	365·0	395·4	425·8	456·2	486·7	517·1	547·5
3⅛	330·1	363·1	396·1	429·1	462·1	495·2	528·2	561·2	594·2
3¼	357·0	392·7	428·4	464·2	499·9	535·6	571·3	607·0	642·7
3⅜	385·0	423·5	462·0	500·5	539·0	577·5	616·0	654·6	693·1
3½	414·1	455·5	496·9	538·3	579·7	621·1	662·5	703·9	745·3
3⅝	444·2	488·6	533·0	577·4	621·9	666·3	710·7	755·1	799·5
3¾	475·3	522·9	570·4	617·9	665·5	713·0	760·5	808·1	855·6
3⅞	507·6	558·3	609·1	659·8	710·6	761·3	812·1	862·9	913·6
4	540·8	594·9	649·0	703·1	757·2	811·3	865·3	919·4	973·5
4⅛	575·2	632·7	690·2	747·7	805·2	862·8	920·3	977·8	1035·3
4¼	610·6	671·6	732·7	793·7	854·8	915·8	976·9	1037·9	1099·0
4⅜	647·0	711·7	776·4	841·1	905·8	970·5	1035·2	1099·9	1164·6
4½	684·5	752·9	821·4	889·8	958·3	1026·7	1095·2	1163·6	1232·1
4⅝	723·1	795·4	867·7	940·0	1012·3	1084·6	1156·9	1229·2	1301·5
4¾	762·6	838·9	915·2	991·4	1067·7	1144·0	1220·2	1296·5	1372·8
4⅞	803·3	883·7	964·0	1044·3	1124·7	1205·0	1285·3	1365·7	1446·0

TABLE I.—SQUARE IRON.

size.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.
ins.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
5	84·5	169·0	253·4	337·9	422·4	506·9	591·4	675·8	760·3
5⅛	88·8	177·6	266·4	355·1	443·9	532·7	621·5	710·3	799·1
5¼	93·2	186·3	279·5	372·7	465·8	559·0	652·2	745·3	838·5
5⅜	97·7	195·3	293·0	390·6	488·3	585·9	683·6	781·3	878·9
5½	102·2	204·5	306·7	409·0	511·2	613·4	715·7	817·9	920·2
5⅝	107·0	213·5	320·9	427·8	534·8	641·7	748·7	855·6	962·6
5¾	111·8	223·5	335·3	447·0	558·8	670·5	782·3	894·0	1005·8
5⅞	116·7	233·3	350·0	466·7	583·4	700·0	816·7	933·4	1050·0
6	121·7	243·3	365·0	486·7	608·3	730·0	841·6	973·3	1095·0
6¼	132·0	264·1	396·1	528·2	660·2	792·2	924·3	1056·3	1188·4
6½	142·8	285·6	428·4	571·3	714·1	856·9	999·7	1142·5	1285·3
6¾	154·0	308·0	462·0	616·0	770·1	924·1	1078·1	1232·1	1386·1
7	165·6	331·2	496·9	662·5	828·2	993·8	1159·4	1325·1	1490·7
7¼	177·7	355·3	533·0	710·7	888·4	1066·0	1243·7	1421·4	1599·0
7½	190·1	380·3	570·4	760·5	950·7	1140·8	1331·0	1521·1	1711·2
7¾	203·0	406·0	609·1	812·1	1015·1	1218·1	1421·2	1624·2	1827·2
8	216·3	432·7	649·0	865·3	1081·7	1298·0	1514·4	1730·7	1947·0
8¼	230·1	460·1	690·2	920·3	1150·3	1380·4	1610·5	1840·5	2070·6
8½	244·2	488·4	732·7	976·9	1221·1	1465·3	1709·5	1953·8	2198·0
8¾	258·8	517·6	776·4	1035·2	1294·0	1552·8	1811·6	2070·4	2329·2
9	273·8	547·6	821·4	1095·2	1369·0	1642·8	1916·5	2190·3	2464·1
9¼	289·2	578·4	867·7	1156·9	1446·1	1735·3	2024·5	2313·8	2603·0
9½	305·1	610·1	915·2	1220·2	1525·3	1830·3	2135·4	2440·4	2745·5
9¾	321·3	642·7	964·0	1285·3	1606·7	1928·0	2249·3	2570·7	2892·3
10	337·9	675·8	1013·8	1351·7	1689·6	2027·5	2365·4	2703·4	3041·0
10¼	355·1	710·3	1065·4	1420·5	1775·7	2130·8	2486·0	2841·1	3196·2
10½	372·7	745·3	1118·0	1490·7	1863·4	2236·0	2608·7	2981·4	3354·0
10¾	390·6	781·3	1171·9	1562·5	1953·1	2343·8	2734·4	3125·0	3515·7
11	409·0	817·9	1226·9	1635·8	2044·8	2453·8	2862·7	3271·7	3680·6
11¼	427·8	855·6	1283·4	1711·2	2139·1	2566·9	2994·7	3422·5	3850·3
11½	447·0	894·0	1341·1	1788·1	2235·1	2682·1	3129·2	3576·2	4023·2
11¾	466·7	933·4	1400·1	1866·7	2333·4	2800·1	3266·8	3733·5	4200·2
12	486·7	973·3	1460·0	1946·6	2433·3	2919·9	3406·6	3893·2	4379·9

TABLE I.—SQUARE IRON.

size.	10 ft.	11 ft.	12 ft.	13 ft.	14 ft.	15 ft.	16 ft.	17 ft.	18 ft.
ins.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
5	844·8	929·3	1013·8	1098·2	1182·7	1267·2	1351·7	1436·2	1520·6
5⅛	887·8	976·6	1065·4	1154·2	1243·0	1331·8	1420·5	1509·3	1598·1
5¼	931·7	1024·8	1118·0	1211·2	1304·4	1397·5	1490·7	1583·9	1677·0
5⅜	976·6	1074·2	1171·9	1269·5	1367·2	1464·9	1562·5	1660·2	1757·8
5½	1022·4	1124·6	1226·9	1329·1	1431·4	1533·6	1635·8	1738·1	1840·3
5⅝	1069·5	1176·5	1283·4	1390·4	1497·3	1604·3	1711·2	1818·2	1925·2
5¾	1117·6	1229·3	1341·1	1452·8	1564·6	1676·3	1788·1	1899·9	2011·6
5⅞	1166·7	1283·4	1400·1	1516·7	1633·4	1750·1	1866·7	1983·4	2100·1
6	1216·6	1338·3	1460·0	1581·6	1703·3	1825·0	1946·6	2068·3	2190·0
6¼	1320·4	1452·4	1584·4	1716·5	1848·6	1980·6	2112·6	2244·7	2376·7
6½	1428·2	1571·0	1713·8	1856·6	1999·4	2142·2	2285·1	2427·9	2570·7
6¾	1540·1	1694·1	1848·1	2002·2	2156·2	2310·2	2464·2	2618·2	2772·2
7	1656·3	1822·0	1987·6	2153·2	2318·8	2484·5	2650·1	2815·7	2981·4
7¼	1776·7	1954·4	2132·1	2309·7	2487·4	2665·1	2842·8	3020·4	3198·1
7½	1901·4	2091·5	2281·6	2471·8	2661·9	2852·0	3042·2	3232·3	3422·4
7¾	2030·2	2233·3	2436·3	2639·3	2842·3	3045·4	3248·4	3451·4	3654·4
8	2163·4	2379·7	2596·0	2812·4	3028·7	3245·0	3461·4	3677·7	3894·0
8¼	2300·7	2530·7	2760·8	2990·9	3220·9	3451·0	3681·1	3911·1	4141·2
8½	2442·2	2686·4	2930·6	3174·9	3419·1	3663·3	3907·5	4151·7	4396·0
8¾	2588·0	2846·8	3105·6	3364·4	3623·2	3882·0	4140·8	4399·6	4658·4
9	2737·9	3011·7	3285·5	3559·3	3833·1	4106·9	4380·7	4654·5	4928·3
9¼	2892·2	3181·4	3470·6	3759·9	4049·1	4338·3	4627·5	4916·7	5206·0
9½	3050·6	3355·6	3660·7	3965·7	4270·8	4575·8	4880·9	5186·0	5491·0
9¾	3213·3	3534·7	3856·0	4177·3	4498·6	4820·0	5141·3	5462·6	5784·0
10	3379·2	3717·1	4055·0	4393·0	4730·9	5068·8	5406·7	5744·6	6082·6
10¼	3551·4	3906·5	4261·6	4616·8	4971·9	5327·0	5682·2	6037·3	6392·4
10½	3726·7	4099·4	4472·1	4844·7	5217·4	5590·1	5962·8	6335·4	6708·1
10¾	3906·3	4297·0	4687·5	5078·2	5468·8	5859·4	6250·0	6644·7	7031·3
11	4089·6	4498·6	4907·5	5316·5	5725·4	6134·4	6543·4	6952·3	7361·3
11¼	4278·1	4705·9	5133·7	5561·6	5989·4	6417·2	6845·0	7272·8	7700·6
11½	4470·2	4917·3	5364·3	5811·3	6258·3	6705·4	7152·4	7599·4	8046·4
11¾	4666·8	5133·5	5600·2	6066·9	6533·6	7000·3	7466·9	7933·6	8400·3
12	4866·6	5353·2	5839·9	6326·5	6813·2	7299·8	7786·5	8273·2	8759·8

TABLE II.—ROUND IRON.

size.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.
ins.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
¼	0·2	0·3	0·5	0·7	0·8	1·0	1·2	1·3	1·5
⅜	0·4	0·7	1·1	1·5	1·9	2·2	2·6	3·0	3.4
½	0·7	1·3	2·0	2·7	3·3	4·0	4·6	5·3	6·0
⅝	1·0	2·1	3·1	4·2	5·2	6·3	7·3	8·3	9·4
¾	1·5	3·0	4·5	6·0	7·5	9·0	10·5	11·9	13·4
⅞	2·0	4·1	6·1	8·1	10·2	12·2	14·2	16·3	18·3
1	2·7	5·3	8·0	10·6	13·3	15·9	18·6	21·2	23·9
1⅛	3·4	6·7	10·1	13·4	16·8	20·2	23·5	26·9	30·2
1¼	4·2	8·3	12·5	16·7	20·9	25·0	29·2	33·4	37·5
1⅜	5·0	10·0	15·1	20·1	25·1	30·1	35·1	40·2	45·2
1½	6·0	11·9	17·9	23·9	29·9	35·8	41·8	47·8	53·7
1⅝	7·0	14·0	21·0	28·0	35·1	42·1	49·1	56·1	63·1
1¾	8·1	16·3	24·4	32·5	40·6	48·8	56·9	65·0	73·2
1⅞	9·3	18·7	28·0	37·3	46·7	56·0	65·3	74·7	84·0
2	10·6	21·2	31·8	42·5	53·1	63·7	74·3	84·9	95·5
2⅛	12·0	24·0	36·0	48·0	59·9	71·9	83·9	95·9	107·9
2¼	13·4	26·9	40·3	53·8	67·2	80·6	94·1	107·5	121·0
2⅜	15·0	30·0	44·9	60·0	74·9	89·9	104·8	119·8	134·8
2½	16·7	33·4	50·1	66·8	83·4	100·1	116·8	133·5	150·2
2⅝	18·3	36·6	54·9	73·2	91·5	109·8	128·1	146·3	164·6
2¾	20·1	40·2	60·2	80·3	100·4	120·5	140·5	160·6	180·7
2⅞	21·9	43·9	65·8	87·8	109·7	131·7	153·6	175·6	197·5
3	23·9	47·8	71·7	95·6	119·4	143·3	167·2	191·1	215·0
3⅛	25·9	51·9	77·8	103·7	129·6	155·6	181·5	207·4	233·3
3¼	28·0	56·1	84·1	112·2	140·2	168·2	196·3	224·3	253·4
3⅜	30·2	60·5	90·7	121·0	151·2	181·4	211·7	341·9	272·2
3½	32·5	65·0	97·5	130·0	162·6	195·1	227·6	260·1	292·6
3⅝	34·9	69·8	104·7	139·5	174·4	209·3	244·2	279·1	314·0
3¾	37·3	74·7	112·0	149·3	186·7	224·0	261·3	298·7	336·0
3⅞	39·9	79·7	119·6	159·5	199·3	239·2	279·0	318·9	358·8
4	42·5	84·9	127·4	169·9	212·3	254·8	297·2	339·7	382·2
4⅛	45·2	90·3	135·5	180·7	225·9	271·0	316·2	361·4	406·6
4¼	48·0	95·9	143·9	191·8	239·8	287·7	335·7	383·6	431·6
4⅜	50·8	101·6	152·4	203·3	254·1	304·9	355·7	406·5	457·3
4½	53·8	107·5	171·3	215·0	268·8	322·6	376·3	430·1	483·8
4⅝	56·8	113·6	170·4	227·2	283·9	340·7	397·5	454·3	511·1
4¾	60·0	119·8	179·7	239·6	299·5	359·4	419·3	479·2	539·1
4⅞	63·1	126·2	189·3	252·4	315·5	378·6	441·7	504·8	567·8

TABLE II.—ROUND IRON.

size.	10 ft.	11 ft.	12 ft.	13 ft.	14 ft.	15 ft.	16 ft.	17 ft.	8 ft.
ins.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
¼	1·7	1·8	2·0	2·1	2·3	2·5	2·6	2·8	3·0
⅜	3·7	4·1	4·5	4·8	5·2	5·6	6·0	6·3	6·7
½	6·6	7·3	8·0	8·6	9·3	9·9	10·6	11·3	11·9
⅝	10·4	11·5	12·5	13·6	14·6	15·6	16·7	17·3	18·8
¾	14·9	16·4	17·9	19·4	20·9	22·4	23·9	25·4	26·9
⅞	20·3	22·4	24·4	26·4	28·4	30·5	32·5	34·5	36·6
1	26·5	29·2	31·8	34·5	37·2	39·8	42·5	45·1	47·8
1⅛	33·6	37·0	40·3	43·7	47·0	50·4	53·8	57·1	60·5
1¼	41·7	45·9	50·1	54·2	58·4	62·6	66·8	70·9	75·1
1⅜	50·2	55·2	60·2	65·2	70·3	75·3	80·3	85·3	90·3
1½	59·7	65·7	71·7	77·6	83·6	89·6	95·6	101·5	107·5
1⅝	70·1	77·1	84·1	91·1	98·1	105·2	112·2	119·2	126·2
1¾	81·3	89·4	97·5	105·7	113·8	121·9	130·0	138·2	146·3
1⅞	93·3	102·7	112·0	121·3	130·7	140·0	149·3	158·7	168·0
2	106·2	116·8	127·4	138·0	148·6	159·2	169·9	180·5	192·1
2⅛	119·9	131·9	143·9	155·8	167·8	179·8	181·8	193·8	205·8
2¼	134·4	147·8	161·3	174·7	188·2	201·6	215·0	228·5	241·9
2⅜	149·8	164·7	179·7	194·7	209·7	224·6	239·6	254·6	269·6
2½	166·9	183·6	200·3	216·9	233·6	250·3	267·0	283·7	300·4
2⅝	182·9	201·2	219·5	237·8	256·1	274·4	292·7	311·0	329·3
2¾	200·8	220·8	240·9	261·0	281·1	301·1	321·2	341·3	361·4
2⅞	219·4	241·4	263·3	285·3	307·2	329·2	351·1	373·0	395·0
3	238·9	262·8	286·7	310·5	334·4	358·3	382·2	406·1	430·0
3⅛	259·3	285·2	311·1	337·0	363·0	388·9	414·8	440·7	466·7
3¼	280·4	308·4	336·5	364·5	392·6	420·6	448·6	476·7	504·7
3⅜	302·4	332·6	362·9	393·1	423·4	453·6	483·8	514·1	544·3
3½	325·1	357·6	390·1	422·7	455·2	487·7	520·2	552·7	585·2
3⅝	348·9	383·7	418·6	453·5	488·4	523·3	558·2	593·1	627·9
3¾	373·3	410·7	448·0	485·3	522·6	560·0	597·3	634·6	672·0
3⅞	398·6	438·5	478·4	518·2	558·1	598·0	637·8	677·7	717·6
4	424·6	467·1	509·6	552·0	594·5	637·0	676·4	721·9	764·4
4⅛	451·7	496·9	542·1	587·3	632·4	677·6	722·8	761·0	813·1
4¼	479·5	527·5	575·4	623·4	671·3	719·3	767·2	815·2	863·1
4⅜	508·2	559·0	609·8	660·6	711·4	762·2	813·0	863·9	914·7
4½	537·6	591·4	645·1	698·9	752·6	806·4	860·2	913·9	967·7
4⅝	567·9	624·7	681·5	738·2	795·0	851·8	908·6	965·4	1022·2
4¾	599·0	658·9	718·8	778·7	838·6	898·5	958·4	1018·3	1078·2
4⅞	630·9	694·0	757·1	820·2	883·3	946·4	1009·5	1072·6	1135·7

TABLE II.—ROUND IRON.

size.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.
ins.	lbs.	lbs	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
5	66·8	133·5	200·3	267·0	333·8	400·5	467·3	534·0	600·8
5⅛	69·7	139·5	209·2	278·9	348·7	418·4	488·1	557·8	627·6
5¼	73·2	146·3	219·5	292·7	365·9	439·0	512·2	585·4	658·5
5⅜	76·7	153·4	230·1	306·8	383·5	460·2	536·9	613·6	690·3
5½	80·3	160·6	240·9	321·2	401·5	481·8	562·1	642·4	722·7
5⅝	84·0	168·0	252·0	336·0	420·0	504·0	588·0	672·0	756·0
5¾	87·8	175·6	263·3	351·1	438·9	526·7	614·4	702·2	790·0
5⅞	91·6	183·3	274·9	366·5	458·2	549·8	641·4	733·1	824·7
6	95·6	191·1	286·7	382·2	477·8	573·3	668·9	764·4	860·0
6¼	103·7	207·4	311·1	414·8	518·5	622·2	725·9	829·6	933·3
6½	112·2	224·3	336·5	448·6	560·8	673·0	785·1	897·3	1009·4
6¾	121·0	241·9	362·9	483·8	604·8	725·8	846·7	967·6	1088·6
7	130·0	260·1	390·1	520·2	650·2	780·3	910·3	1040·4	1170·4
7¼	139·5	279·1	418·6	558·2	697·7	837·3	976·8	1116·4	1255·9
7½	149·3	298·7	448·0	597·3	741·6	896·0	1045·3	1194·6	1344·0
7¾	159·5	318·9	478·4	637·8	797·3	956·7	1116·2	1275·6	1435·1
8	169·9	339·7	509·6	679·4	849·3	1019·1	1189·0	1358·8	1528·7
8¼	180·7	361·4	542·1	722·8	903·5	1084·2	1264·9	1445·6	1626·3
8½	191·8	383·6	595·4	767·2	959·0	1150·8	1342·6	1534·5	1726·3
8¾	203·3	406·5	609·8	813·0	1016·3	1219·6	1422·8	1626·1	1829·3
9	215·0	430·1	645·1	860·2	1075·2	1290·2	1505·3	1720·3	1935·4
9¼	227·2	454·3	681·5	908·6	1135·8	1362·9	1590·1	1817·2	2044·4
9½	239·6	479·2	718·8	958·4	1198·0	1437·6	1677·2	1916·8	2156·4
9¾	252·4	505·8	757·1	1009·5	1261·9	1514·3	1766·6	2019·0	2291·4
10	266·3	532·6	798·9	1065·2	1331·4	1597·7	1864·0	2130·3	2396·6
10¼	278·9	557·8	836·8	1115·7	1394·6	1673·5	1952·5	2231·4	2510·3
10½	292·7	585·4	878·1	1170·8	1463·4	1756·1	2048·8	2341·5	2634·2
10¾	306·8	603·6	920·4	1227·2	1534·0	1840·8	2147·6	2454·4	2161·2
11	321·2	642·4	963·6	1284·9	1606·1	1927·3	2248·5	2569·7	2890·9
11¼	336·0	672·0	1008·0	1344·0	1680·0	2016·0	2352·0	2688·0	3024·0
11½	351·1	702·2	1053·3	1404·4	1755·5	2106·6	2457·7	2808·8	3159·9
11¾	366·5	733·1	1099·6	1466·1	1832·7	2199·2	2565·8	2932·3	3298·8
12	382·2	764·4	1146·6	1528·8	1911·0	2293·2	2675·5	3057·7	3439·9

TABLE II.—ROUND IRON.

size.	10 ft.	11 ft.	12 ft.	13 ft.	14 ft.	15 ft.	16 ft.	17 ft.	18 ft.
ins.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
5	667·5	734·3	801·0	867·8	934·5	1001·3	1068·0	1134·8	1201·5
5⅛	697·3	767·0	836·8	906·5	976·2	1046·0	1115·7	1185·4	1255·2
5¼	731·7	804·9	878·1	951·2	1024·4	1097·6	1170·8	1243·9	1317·1
5⅜	767·0	843·7	920·4	997·1	1073·8	1150·5	1227·2	1303·9	1380·6
5½	803·0	883·3	963·6	1044·0	1124·3	1204·6	1284·9	1365·2	1445·5
5⅝	840·0	924·0	1008·0	1092·0	1176·0	1260·0	1344·0	1428·0	1512·0
¼	877·8	965·5	1053·3	1141·1	1228·9	1316·6	1404·4	1492·2	1580·0
5⅞	916·3	1008·0	1099·6	1191·2	1282·9	1374·5	1466·1	1557·8	1649·4
6	955·5	1051·1	1146·6	1242·2	1337·7	1433·3	1528·8	1624·4	1719·9
6¼	1037·0	1140·7	1244·4	1348·2	1451·9	1555·6	1659·3	1763·0	1866·7
6½	1121·6	1233·8	1345·9	1458·1	1570·2	1682·4	1794·6	1906·7	2018·9
6¾	1209·6	1330·6	1451·5	1572·5	1693·4	1814·4	1935·4	2056·3	2177·3
7	1300·5	1430·5	1560·6	1690·6	1820·7	1950·7	2080·8	2210·8	2340·9
7¼	1395·4	1535·0	1674·5	1814·1	1953·6	2093·2	2232·7	2372·2	2511·8
7½	1493·3	1642·6	1791·9	1941·3	2090·6	2239·9	2389·2	2538·6	2687·9
7¾	1594·6	1754·0	1913·5	2072·9	2232·4	2391·8	2551·3	2710·8	2870·2
8	1698·6	1868·4	2038·3	2208·1	2378·0	2547·8	2717·7	2887·6	3057·4
8¼	1809·0	1987·7	2168·4	2349·0	2529·7	2710·4	2891·1	3071·8	3252·5
8½	1918·1	2109·9	2301·7	2493·5	2685·3	2879·1	3068·9	3260·7	3452·5
8¾	2032·6	2235·9	2439·1	2642·4	2845·6	3048·9	3252·2	3455·4	3658·7
9	2150·4	2365·4	2580·5	2795·5	3010·6	3225·6	3440·6	3655·7	3870·7
9¼	2271·5	2498·7	2725·8	2953·0	3180·1	3407·3	3634·4	3861·6	4088·7
9½	2396·0	2635·6	2875·2	3114·8	3354·4	3594·0	3833·6	4073·2	4312·8
9¾	2523·8	2776·1	3028·5	3280·9	3533·3	3785·6	4038·0	4290·4	4542·8
10	2662·9	2929·2	3195·5	3461·7	3728·0	3994·3	4260·6	4526·9	4793·2
10¼	2789·2	3068·2	3347·1	3626·0	3904·9	4183·9	4462·8	4741·7	5020·6
10½	2926·9	3219·6	3512·3	3804·9	4097·6	4390·3	4683·0	4975·7	5268·4
10¾	3068·0	3374·8	3681·6	3988·4	4295·2	4602·0	4908·8	5215·6	5522·4
11	3212·2	3533·4	3854·6	4175·8	4497·0	4818·2	5139·5	5460·7	5781·3
11¼	3360·0	3696·0	4032·0	4368·1	4704·1	5040·1	5376·1	5712·1	6048·1
11½	3511·0	3862·1	4213·2	4564·4	4915·5	5266·6	5619·7	5968·8	6319·9
11¾	3665·4	4031·9	4398·4	4765·0	5131·5	5498·0	5864·6	6231·1	6597·6
12	3822·1	4204·3	4586·5	4968·7	5350·9	5733·1	6115·3	6497·5	6879·7

TABLE III.—FLAT IRON.

Thick.	Width.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.
ins.	ins.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
¼	1	0·8	1·7	2·5	3·4	4·2	5·1	5·9	6·8	7·6
„	1¼	1·1	2·1	3·2	4·2	5·3	6·3	7·4	8·4	9·5
„	1½	1·3	2·5	3·8	5·1	6·3	7·6	8·9	10·1	11·4
„	1¾	1·5	3·0	4·4	5·9	7·4	8·9	10·4	11·8	13·3
„	2	1·7	3·4	5·1	6·8	8·5	10·1	11·8	13·5	15·2
„	2¼	1·9	3·8	5·7	7·6	9·5	11·4	13·3	15·2	17·1
„	2½	2·1	4·2	6·3	8·4	10·6	12·7	14·8	16·9	19·0
„	2¾	2·3	4·6	7·0	9·3	11·6	13·9	16·3	18·6	20·9
„	3	2·5	5·1	7·6	10·1	12·7	15·2	17·7	20·3	22·8
„	3¼	2·7	5·5	8·2	11·0	13·7	16·5	19·2	22·0	24·7
„	3½	3·0	5·9	8·9	11·8	14·8	17·7	20·7	23·7	26·6
„	3¾	3·2	6·3	9·5	12·7	15·8	19·0	22·2	25·4	28·5
„	4	3·4	6·8	10·1	13·5	16·9	20·3	23·7	27·0	30·4
„	4¼	3·6	7·2	10·8	14·4	18·0	21·5	25·1	28·7	32·3
„	4½	3·8	7·6	11·4	15·2	19·0	22·8	26·6	30·4	34·2
„	4¾	4·0	8·0	12·0	16·1	20·1	24·1	28·1	32·1	36·1
„	5	4·2	8·4	12·7	16·9	21·1	25·3	29·6	33·8	38·0
„	5¼	4·4	8 9	13·3	17·7	22·2	26·6	31·1	35·5	39·9
„	5½	4·6	9·3	13·9	18·6	23·2	27·9	32·5	37·2	41·8
„	5¾	4·9	9·7	14·6	19·4	24·3	29·2	34·0	38·9	43·7
„	6	5·1	10·1	15·2	20·3	25·3	30·4	35·5	40 6	45·6
⅜	1	1·3	2·5	3·8	5·1	6·3	7·6	8·9	10·1	11·4
„	1¼	1·6	3·2	4·8	6·3	7·9	9·5	11·1	12·7	14·3
„	1½	1·9	3·8	5·7	7·6	9·5	11·4	13·3	15·2	17·1
„	1¾	2·2	4·4	6·7	8·9	11·1	13·3	15·5	17·7	20·0
„	2	2·5	5·1	7·6	10·1	12·7	15·2	17·7	20·3	22·8
„	2¼	2·9	5·7	8·3	11·4	14·3	17·1	20·0	22·8	25·7
„	2½	3·2	6·3	9·5	12·7	15·8	19·0	22·2	25·4	28·5
„	2¾	3·5	7·0	10·5	13·9	17·4	20·9	24·4	27·9	31·4
„	3	3·8	7·6	11·4	15·2	19·0	22·8	26·6	30·4	34·2
„	3¼	4·1	8·2	12·4	16·5	20·6	24·7	28·8	33·0	37·1
„	3½	4·4	8·9	13·3	17·7	22·2	26·6	31·1	35·5	39·9
„	3¾	4·8	9 5	14·3	19·0	23·8	28·5	33·3	38·0	42·8
„	4	5·1	10·1	15·2	20·3	25·3	30·4	35·5	40·6	45·6
„	4¼	5·4	10·8	16·1	21·5	26·9	32·3	37·7	43·1	48·5
„	4½	5·7	11·4	17·1	22·8	28·5	34·2	39·9	45·6	51·3
„	4¾	6·0	12·0	18·1	24·1	30·1	36·1	42·1	48·2	54·2

TABLE III.—FLAT IRON.

Thick-	Width.	10ft.	11ft.	12ft.	13ft.	14ft.	15ft.	16ft.	17ft.	18 ft.
ins.	ins.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
¼	1	8·5	9·3	10·1	11·0	11·8	12·7	13·5	14·4	15·2
,,	1¼	10·6	11·6	12·7	13·7	14·8	15·8	16·9	17·9	19·0
,,	1½	12·7	13·9	15·2	16·5	17·7	19·0	20·3	21·5	22·8
,,	1¾	14·8	16·3	17·7	19·2	20·7	22·2	23·7	25·1	26·6
,,	2	16·9	18·6	20·3	22·0	23·7	25·4	27·0	28·7	30·4
,,	2¼	19·0	20·9	22·8	24·7	26·6	28·5	30·4	32·3	34·2
,,	2½	21·1	23·2	25·3	27·5	29·6	31·7	33·8	35·9	38·0
,,	2¾	23·2	25·6	27·9	30·2	32·5	34·9	37·2	39·5	41·8
,,	3	25·3	27·9	30·4	33·0	35·5	38·0	40·6	43·1	45·6
,,	3¼	27·5	30·2	33·0	35·7	38·5	41·3	43·9	46·7	49·4
,,	3½	29·6	32·5	35·5	38·5	41·4	44·4	47·3	50·3	53·2
,,	3¾	31·7	34·9	38·0	41·2	44·4	47·5	50·7	53·9	57·0
,,	4	33·8	37·2	40·6	43·9	47·3	50·7	54·1	57·5	60·8
,,	4¼	35·9	39·5	43·1	46·7	50·3	53·9	57·5	61·0	64·6
,,	4½	38·0	41·8	45·6	49·4	53·2	57·0	60·8	64·6	68·4
,,	4¾	40·1	44·1	48·2	52·2	56·2	60·2	64·2	68·2	72·2
,,	5	42·2	46·5	50·7	54·9	59·1	63·4	65·6	71·8	76·0
,,	5¼	44·4	48·8	53·2	57·7	62·1	66·5	71·0	75·4	79·9
,,	5½	46·5	51·1	55·8	60·4	65·1	69·7	74·4	79·0	83·6
,,	5¾	48·6	53·4	58·3	63·2	68·0	72·9	77·7	82·6	87·5
,,	6	50·7	55·8	60·8	65·9	70·9	76·0	81·1	86·2	91·2
⅜	1	12·7	13·9	15·2	16·5	17·7	19·0	20·3	21·5	22·8
,,	1¼	15·8	17·4	19·0	20·6	22·2	23·8	25·3	26·9	28·5
,,	1½	19·0	20·9	22·8	24·7	26·6	28·5	30·4	32·3	34·2
,,	1¾	22·2	24·4	26·6	28·8	31·1	33·3	35·5	37·7	39·9
,,	2	25·3	27·9	30·4	33·0	35·5	38·0	40·6	43·1	45·6
,,	2¼	28·5	31·4	34·2	37·1	39·9	42·8	45·6	48·5	51·3
,,	2½	31·7	34·9	38·0	41·2	44·4	47·5	50·7	53·9	57·0
,,	2¾	34·9	36·3	41·8	45·3	48·8	52·3	55·8	59·3	62·7
,,	3	38·0	41·8	45·6	49·4	53·2	57·0	60·8	64·6	68·4
,,	3¼	41·2	45·3	49·4	53·6	57·7	61·8	65·9	70·0	74·2
,,	3½	44·4	48·8	53·2	57·7	62·1	66·5	71·0	75·4	79·9
,,	3¾	47·5	52·3	57·0	61·8	66·5	71·3	76·0	80·8	85·5
,,	4	50·7	55·8	60·8	65·9	70·9	76·0	81·1	86·2	91·2
,,	4¼	53·9	59·3	64·7	70·0	75·4	80·8	86·2	91·6	97·0
,,	4½	57·0	62·7	68·4	74·2	79·9	85·6	91·3	97·0	102·7
,,	4¾	60·2	66·2	72·2	78·3	84·3	90·3	96·3	102·3	108·4

TABLE III.—FLAT IRON.

Thick.	Width.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.
in.	ins.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
⅜	5	6·3	12·7	19·0	25·3	31·7	38·0	44·4	50·7	57·0
,,	5¼	6·7	13·3	20·0	26·6	33·3	39·9	46·6	53·2	59·9
,,	5½	7·0	13·9	20·9	27·9	34·9	41·8	48·8	55·8	62·7
,,	5¾	7·3	14·6	21·9	29·2	36·4	43·7	51·0	58·3	65·6
,,	6	7·6	15·2	22·8	30·4	38·0	45·6	53·2	60·8	68·4
½	1	1·7	3·4	5·1	6·8	8·5	10·1	11·8	13·5	15·2
,,	1¼	2·1	4·2	6·3	8·4	10·6	12·7	14·8	16·9	19·0
,,	1½	2·5	5·1	7·6	10·1	12·7	15·2	17·7	20·3	22·8
,,	1¾	3·0	5·9	8·9	11·8	14·8	17·7	20·7	23·7	26·6
,,	2	3·4	6·8	10·1	13·5	16·9	20·3	23·7	27·0	30·4
,,	2¼	3·8	7·6	11·4	15·2	19·0	22·8	26·6	30·4	34·2
,,	2½	4·2	8·4	12·7	16·9	21·1	25·3	29·6	33·8	38·0
,,	2¾	4·6	9·3	13·9	18·6	23·2	27·9	32·5	37·2	41·8
,,	3	5·1	10·1	15·2	20·3	25·3	30·4	35·5	40·6	45·6
,,	3¼	5·5	11·0	16·5	22·0	27·5	32·9	38·4	43·9	49·4
,,	3½	5·9	11·8	17·7	23·7	29·6	35·5	41·4	47·3	53·2
,,	3¾	6·3	12·7	19·0	25·3	31·7	38·0	44·4	50·7	57·0
,,	4	6·8	13·5	20·3	27·0	33·8	40·6	47·3	54·1	60·8
,,	4¼	7·2	14·4	21·5	28·7	35·9	43·1	50·3	57·4	64·6
,,	4½	7·6	15·2	22·8	30·4	38·0	45·6	53·2	60·8	68·4
,,	4¾	8·0	16·1	24·1	32·1	40·1	48·2	56·2	64·2	72·2
,,	5	8·4	16·9	25·3	33·8	42·2	50·7	59·1	67·6	76·0
,,	5¼	8·9	17·7	26·6	35·5	44·4	53·2	62·1	71·0	79·9
,,	5½	9·3	18·6	27·9	37·2	46·5	55·8	65·1	74·4	83·7
,,	5¾	9·7	19·4	29·2	38·9	48·6	58·3	68·0	77·7	87·5
,,	6	10·1	20·3	30·4	40·6	50·7	60·8	70·9	81·1	91·2
⅝	1	2·1	4·2	6·3	8·4	10·6	12·7	14·8	16·9	19·0
,,	1¼	2·6	5·3	7·9	10·6	13·2	15·8	18·5	21·1	23·8
,,	1½	3·2	6·3	9·5	12·7	15·8	19·0	22·2	25·4	28·5
,,	1¾	3·7	7·4	11·1	14·8	18·5	22·2	25·9	29·6	33·3
,,	2	4·2	8·4	12·7	16·9	21·1	25·3	29·6	33·8	38·0
,,	2¼	4·8	9·5	14·3	19·0	23·8	28·5	33·3	38·0	42·8
,,	2½	5·3	10·6	15·8	21·1	26·4	31·7	37·0	42·2	47·5
,,	2¾	5·8	11·6	17·4	23·2	29·0	34·8	40·7	46·5	52·3
,,	3	6·3	12·7	19·0	25·3	31·7	38·0	44·4	50·7	57·0
,,	3¼	6·9	13·7	20·6	27·5	34·3	41·2	48·1	54·9	61·8
,,	3½	7·4	14·8	22·2	29·6	37·0	44·4	51·8	59·2	66·5

TABLE III.—FLAT IRON.

Thick.	Width.	10 ft.	11 ft.	12 ft	13ft.	14 ft.	15 ft.	16 ft.	17 ft.	18 ft.
in.	ins.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
⅜	5	63·3	69·7	76·0	82·4	88·7	95·0	101·4	107·7	114·0
,,	5¼	66·5	73·2	79·8	86·5	93·1	99·8	106·5	113·1	119·8
,,	5½	69·7	76·7	83·7	90·6	97·6	104·5	111·5	118·5	125·5
,,	5¾	72·9	80·2	87·5	94·7	102·0	109·3	116·6	123·9	131·2
,,	6	76·0	83·6	91·2	98·9	106·5	114·1	121·7	129·3	136·9
½	1	16·9	18·6	20·3	22·0	23·7	25·4	27·0	28·7	30·4
,,	1¼	21·1	23·2	25·3	27·5	29·6	31·7	33·8	35·9	38·0
,,	1½	25·3	27·9	30·4	33·0	35·5	38·0	40·6	43·1	45·6
,,	1¾	29·6	32·5	35·5	38·5	41·4	44·4	47·3	50·3	53·2
,,	2	33·8	37·2	40·6	43·9	47·3	50·7	54·1	57·5	60·8
,,	2¼	38·0	41·8	45·6	49·4	53·2	57·0	60·8	64·6	68·4
,,	2½	42·2	46·5	50·7	54·9	59·1	63·4	65·6	71·8	76·0
,,	2¾	46·5	51·1	55·8	60·4	65·1	69·7	74·4	79·0	83·6
,,	3	50·7	55·8	60·8	65·9	70·9	76·0	81·1	86·2	91·2
,,	3¼	54·9	60·4	65·9	71·4	76·9	82·4	87·9	93·3	98·8
,,	3½	59·2	65·1	71·0	76·9	82·8	88·7	94·6	100·6	106·5
,,	3¾	63·3	69·7	76·0	82·4	88·7	95·0	101·4	107·7	114·0
,,	4	67·6	74·4	81·1	87·9	94·6	101·4	108·2	114·9	121·7
,,	4¼	71·8	79·0	86·2	93·4	100·5	107·7	114·9	122·1	129·3
,,	4½	76·0	83·6	91·2	98·9	106·5	114·1	121·7	129·3	136·9
,,	4¾	80·3	88·3	96·3	104·3	112·4	120·4	128·4	136·4	144·5
,,	5	84·5	92·9	101·4	109·8	118·3	126·7	135·2	143·6	152·1
,,	5¼	88·7	97·6	106·5	115·4	124·2	133·1	142·0	150·8	159·7
,,	5½	93·0	102·2	111·5	120·8	130·1	139·4	148·7	158·0	167·3
,,	5¾	97·2	106·9	116·6	126·3	136·0	145·8	155·5	165·2	174·9
,,	6	101·4	111·5	121·7	131·8	141·9	152·1	162·2	172·4	182·5
⅝	1	21·1	23·2	25·3	27·5	29·6	31·7	33·8	35·9	38·0
,,	1¼	26·4	29·0	31·7	34·3	37·0	39·6	42·2	44·9	47·5
,,	1½	31·7	34·8	38·0	41·2	44·4	47·5	50·7	53·9	57·0
,,	1¼	37·0	40·7	44·4	48·1	51·8	55·5	59·2	62·8	66·5
,,	2	42·2	46·5	50·7	54·9	59·1	63·4	67·6	71·8	76·0
,,	2¼	47·5	52·3	57·0	61·8	66·5	71·3	76·0	80·8	85·5
,,	2½	52·8	58·1	63·4	68·6	73·9	79·2	84·5	89·8	95·0
,,	2¾	58·1	63·9	69·7	75·5	81·3	87·1	92·9	98·7	104·5
,,	3	63·3	69·7	76·0	82·4	88·7	95·0	101·4	107·7	114·0
,,	3¼	68·7	75·5	82·4	89·3	96·1	103·0	109·9	116·7	123·6
,,	3½	73·9	81·3	88·7	96·1	103·5	110·9	118·3	125·7	133·1

TABLE III.—FLAT IRON.

Thick.	Width.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.
ins.	ins.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
⅝	3¾	7·9	15·8	23·8	31·7	39·6	47·5	55·5	63·4	71·3
"	4	8·4	16·9	25·3	33·8	42·2	50·7	59·1	67·6	76·0
"	4¼	9·0	18·0	26·9	35·9	44·9	53·9	62·9	71·8	80·8
"	4½	9·5	19·0	28·5	38·0	47·5	57·0	66·5	76·1	85·6
"	4¾	10·0	20·1	30·1	40·1	50·2	60·2	70·2	80·3	90·3
"	5	10·6	21·1	31·7	42·3	52·8	63·4	73·9	84·5	95·1
"	5¼	11·1	22·2	33·3	44·4	55·5	66·5	77·6	88·7	99·8
"	5½	11·6	23·2	34·9	46·5	58·1	69·7	81·3	92·9	104·6
"	5¾	12·1	24·3	36·4	48·6	60·7	72·9	85·0	97.2	109·3
"	6	12·7	25·3	38·0	50·7	63·4	76·0	88·7	101·4	114·1
¾	1	2·5	5·1	7·6	10·1	12·7	15·2	17·7	20·3	22·8
"	1¼	3·2	6·3	9·5	12·7	15·8	19·0	22·2	25·4	28·5
"	1½	3·8	7·6	11·4	15·2	19·0	22·8	26·6	30·4	34·2
"	1¾	4·4	8·9	13·3	17·7	22·2	26·6	31·1	35·5	39·9
"	2	5·1	10·1	15·2	20·3	25·3	30·4	35·5	40·6	45·6
"	2¼	5·7	11·4	17·1	22·8	28·5	34·2	39·9	45·6	51·3
"	2½	6·3	12·7	19·0	25·3	31·7	38·0	44·4	50·7	57·0
"	2¾	7·0	13·9	20·9	27·9	34·9	41·8	48·8	55·8	62·7
"	3	7·6	15·2	22·8	30·4	38·0	45·6	53·2	70·9	68·4
"	3¼	8·2	16·5	24·7	33·0	41·2	49·4	57·7	65·9	74·2
"	3½	8·9	17·7	26·6	35·5	44·4	53·2	62·1	71·0	79 9
"	3¾	9·5	19·0	28·5	38·0	47·5	57·0	66·5	76·1	85·6
"	4	10·1	20·3	30·4	40·6	50·7	60·8	70·9	81·1	91·2
"	4¼	10·8	21·5	32·3	43·1	53·9	64·6	75·4	86·2	97·0
"	4½	11·4	22·8	34·2	45·6	57·0	68·4	79·9	91·3	102·7
"	4¾	12·0	24·1	36·1	48·2	60·2	72·2	84·3	96·3	108·4
"	5	12·7	25·3	38·0	50·7	63·4	76·0	88·7	101·4	114·0
"	5¼	13·3	26·6	39·9	53·2	66·5	79·8	93·1	106·5	119·8
"	5½	13·9	27·9	41·8	55·8	69·7	83·7	97·6	111·5	125·5
"	5¾	14·6	29·1	43·7	58·3	72·9	87·4	102·0	116·6	131·2
"	6	15·2	30·4	45·6	60·8	76·0	91·2	106·5	121·7	136·9
1	1½	5·1	10·1	15·2	20·3	25·3	30·4	35·5	40·6	45·6
"	2	6·8	13·5	20·3	27·0	33·8	40·6	47·8	54·1	60·8
"	3	10·1	20·3	30·4	40·6	50·7	60·8	70·9	81·1	91·2
"	4	13·5	27·0	40·6	54·1	67·6	81·1	94·6	108·1	121·7
"	5	16·9	33·8	50·7	67·6	84·5	101·4	118·3	135·2	152·1
"	6	20·3	40·6	60·8	81·1	101·4	121·7	141·9	162·2	182·5

TABLE III.—FLAT IRON.

Thick.	Width.	10 ft.	11 ft.	12 ft.	13 ft.	14 ft.	15 ft.	16 ft.	17 ft.	18 ft.
ins.	ins.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
⅝	3¾	79·2	87·1	95·1	103·0	110·9	118·8	126·8	134·7	142·6
,,	4	84·5	92·9	101·4	109·8	118·3	126·7	135·2	143.6	152·1
,,	4¼	89·8	98·8	107·8	116·7	125·7	134·7	143·7	152·6	161·6
,,	4½	95·1	104·6	114·1	123·6	133·1	142·6	152·1	161·6	171·1
,,	4¾	100·3	110·4	120·4	130·4	140·5	150·5	160·5	170·6	180·6
,,	5	105·6	116·2	126·8	137·3	147·9	158·4	169·0	179·6	190·1
,,	5¼	110·9	122·0	133·1	144·2	155·3	166·4	177·5	188·5	199·6
,,	5½	116·2	127·8	139·4	151·0	162·6	174·3	185·9	197·5	209·1
,,	5¾	121·5	133·6	145·7	157·9	170·0	182·2	194·3	206·5	218·6
,,	6	126·7	139·4	152·1	164·8	177·4	190·1	202·8	215·4	228·1
¾	1	25·3	27·9	30·4	33·0	35·5	38·0	40·6	43·1	45·6
,,	1¼	31·7	34·9	38·0	41·2	44·4	47·5	50·7	53·9	57·0
,,	1½	38·0	41·8	45·6	49·4	53·2	57·0	60·8	64·6	68·4
,,	1¾	44·4	48·8	53·2	57·7	62·1	66·5	71·0	75·4	79·9
,,	2	50·7	55·8	69·8	65·9	70·9	76·0	81·1	86·2	91·2
,,	2¼	57·0	62·7	68·4	74·2	79·9	85·6	91·3	97·0	102·7
,,	2½	63·3	69·7	76·0	82·4	88·7	95·0	101·4	107·7	114·0
,,	2¾	69·7	76·7	83·7	90·6	97·6	104·5	111·5	118·5	125·5
,,	3	76·0	83·6	91·2	98·9	106·5	114·1	121·7	129·3	136·9
,,	3¼	82·4	90·6	98·9	107·1	115·3	123·6	131·8	140·0	148·3
,,	3½	88·7	97·6	106·5	115·4	124·2	133·1	142·0	150·8	159·7
,,	3¾	95·1	104·6	114·1	123·6	133·1	142·6	152·1	161·6	171·1
,,	4	101·4	111·5	121·7	131·8	141·9	152·1	162·2	172·4	182·5
,,	4¼	107·7	118·5	129·3	140·1	150·8	161·6	172·4	183·2	193·9
,,	4½	114·1	125·5	136·9	148·3	159·7	171·1	182·5	193·9	205·3
,,	4¾	120·4	132·4	144·5	156·5	168·6	180·6	192·6	204·7	216·7
,,	5	126·7	139·4	152·1	164·8	177·4	190·1	202·8	215·4	228·1
,,	5¼	133·1	146·4	159·7	173·0	186·3	199·6	212·9	226·2	239·5
,,	5½	139·4	153·3	167·3	181·2	195·2	209·2	223·1	237·0	250·9
,,	5¾	145·7	160·3	174·9	189·5	204·0	218·6	233·2	247·8	262·3
,,	6	152·1	167·3	182·5	197·7	212·9	228·1	243·3	258·5	273·7
1	1½	50·7	55·8	60·8	65·9	70·9	76·0	81·1	86·2	91·2
,,	2	67·6	74·4	81·1	87·9	94·6	101·4	108·1	114·9	121·7
,,	3	101·4	111·5	121·7	131·8	141·9	152·1	162·2	172·4	182·5
,,	4	135·2	148·7	162·2	175·7	189·3	202·8	216·3	229·8	243·3
,,	5	169·0	185·9	202·8	219·7	236·6	253·5	270·4	287·3	304·2
,,	6	202·8	223·1	243·3	263·6	283·9	304·2	324·4	344·7	365·0

The tables are all calculated to the nearest tenth of a lb. To the weights of bars of wrought iron, *add* $\frac{1}{100}$ part for bars of *soft steel;* and from the same weights, *subtract* $\frac{1}{14}$ part for bars of *cast iron.* In order to render these tables applicable to bars of other metals, of the same dimensions, the following *tablet of multipliers* is added.

Metals.	Multipliers.	Metals.	Multipliers.
Iron, cast	·926	Brass, cast	1·078
Steel, soft	1·006	Do. wire	1·098
Do. hardened	1·007	Tin, cast	·936
Do. tempered	1·004	Zinc, do.	·923
Copper, cast	1·129	Silver, do.	1·345
Do. wire	1·140	Gold, do.	2·473
Lead, molten	1·458	Platinum, do.	2·504

TABLE IV.—METAL PLATES.

This table shows the weight of a square foot of different metal plates, of thicknesses from one sixteenth of an inch to one inch, advancing by a sixteenth.

Sixteenths.	Wrought Iron.	Cast Iron.	Cast Copper.	Cast Brass.	Cast Lead.	Cast Zinc.	Cast Tin.	Cast Silver.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1	2·5	2·3	2·9	2·7	3·7	2·3	2·4	3·4
2	5·1	4·7	5·7	5·5	7·4	4·7	4·7	6·8
3	7·6	7·0	8·6	8·2	11·1	7·0	7·1	10·2
4	10·1	9·4	11·4	11·0	14·8	9·4	9·5	13·6
5	12·7	11·7	14·3	13·7	18·5	11·7	11·9	17·0
6	15·2	14·0	17·2	16·4	22·2	14·0	14·2	20·5
7	17·9	16·4	20·0	19·2	25·9	16·4	16·6	23·9
8	20·3	18·8	22·9	21·9	29·5	18·7	19·0	27·3
9	22·8	21·1	25·7	24·6	33·2	21·1	21·4	30·7
10	25·4	23·5	28·6	27·4	36·9	23·4	23·7	34·1
11	27·9	25·8	31·4	30·1	40·6	25·7	26·1	37·5
12	30·4	28·1	34·3	32·9	44·3	28·1	28·5	40·9
13	32·9	30·5	37·2	35·6	48·0	30·4	30·9	44·3
14	35·5	32·9	40·0	38·3	51·7	32·8	33·2	47·7
15	38·0	35·2	42·9	41·2	55·4	35·1	35·6	51·1
16	40·6	37·6	45·8	43·9	59·1	37·5	38·0	54·6

TABLE V.—CAST METAL BALLS.

Diam.	Iron.	Copper.	Brass.	Lead.
ins.	lbs.	lbs.	lbs.	lbs.
1	$\frac{3}{22}$	$\frac{1}{6}$	$\frac{3}{19}$	$\frac{3}{14}$
2	1·1	1·3	1·3	1·7
3	3·7	4·5	4·3	5·8
4	8·7	10·7	10·2	13·8
5	17·0	20·8	19·9	26·9
6	29·5	35·9	34·3	46·4
7	46·8	57·1	54·5	73·7
8	69·8	85·2	81·4	110·1
9	99·4	121·3	115·9	156·7
10	136·4	166·4	159·0	215·0

TABLE VI.—CAST METAL CYLINDERS.

The cylinders are solid, each one foot in length.

Diam.	Iron.	Copper.	Brass.	Lead.
ins.	lbs.	lbs.	lbs.	lbs.
1	2·5	3·0	2·9	3·9
2	9·8	12·0	11·4	15·5
3	22·1	27·0	25·8	34·8
4	39·3	47·9	45·8	61·9
5	61·4	74·9	71·6	96·7
6	88·4	107·8	103·0	139·3
7	120·3	146·8	140·2	189·6
8	157·1	191·7	183·2	247·7
9	198·8	242·7	231·8	313·4
10	245·4	299·5	286·2	387·0

TABLE VII.—CAST IRON PIPES.

This table shows the weight of pipes one foot long, of bores from 1 in. to 12 in. diameter, advancing by $\frac{1}{4}$ in.; and of thicknesses from $\frac{1}{4}$ in. to $1\frac{1}{4}$ in., advancing by $\frac{1}{8}$ in.

TABLE VII.—CAST IRON PIPES.

Bore.	¼	⅜	½	⅝	¾	⅞	1	1⅛	1¼
In.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1	3·1	5·1	7·4	10·0	12·9	16·1	19·6	23·5	27·6
1¼	3·7	6·0	8·6	11·5	14·7	18·3	22·1	26·2	30·7
1½	4·3	6·9	9·8	13·0	16·6	20·4	24·5	29·0	33·7
1¾	4·9	7·8	11·1	14·6	18·4	22·6	27·0	31·8	36·8
2	5·5	8·8	12·3	16·1	20·3	24·7	29·5	34·5	39·9
2¼	6·1	9·7	13·5	17·6	22·1	26·8	31·9	37·3	43·0
2½	6·7	10·6	14·7	19·2	23·9	28·9	34·4	40·0	46·0
2¾	7·4	11·5	16·0	20·7	25·7	31·1	36·8	42·8	49·1
3	8·0	12·4	17·2	22·2	27·6	33·3	39·3	45·6	52·2
3¼	8·6	13·3	18·4	23·8	29·5	35·4	41·7	48·3	55·2
3½	9·2	14·2	19·6	25·3	31·3	37·6	44·2	51·1	58·3
3¾	9·8	15·2	20·9	26·9	33·1	39·7	46·6	53·8	61·4
4	10·4	16·1	22·1	28·4	35·0	41·9	49·1	56·6	64·4
4¼	11·1	17·1	23·4	30·0	36·9	44·1	51·6	59·4	67·6
4½	11·7	18·0	24·5	31·4	38·7	46·2	54·0	62·1	70·6
4¾	12·3	18·9	25·8	33·0	40·5	48·3	56·5	64·9	73·6
5	12·9	19·8	27·0	34·5	42·3	50·5	58·9	67·6	76·7
5¼	13·5	20·7	28·2	36·1	44·2	52·6	61·4	70·4	79·8
5½	14·1	21·6	29·5	37·6	46·0	54·8	63·8	73·2	82·8
5¾	14·7	22·6	30·7	39·1	47·9	56·9	66·3	76·0	85·9
6	15·3	23·5	31·9	40·7	49·7	59·1	68·7	78·7	88·8
6¼	16·0	24·4	33·1	42·2	51·5	61·2	71·2	81·2	92·0
6½	16·6	25·3	34·4	43·7	53·4	63·4	73·4	84·2	95·1
6¾	17·2	26·2	35·6	45·3	55·2	65·3	76·1	87·0	98·2
7	17·8	27·2	36·8	46·8	56·8	67·7	78·5	89·7	101·2
7¼	18·4	28·1	38·1	48·1	58·9	69·8	81·0	92·5	104·3
7½	19·0	29·0	39·1	49·9	60·7	72·0	83·5	95·3	107·4
7¾	19·6	29·7	40·5	51·4	62·6	74·1	85·9	98·0	110·5
8	20·0	30·8	41·7	52·9	64·4	76·2	88·4	100·8	113·5
8¼	20·9	31·7	43·0	54·5	66·3	78·4	90·8	103·5	116·6
8½	21·7	32·9	44·4	56·2	68·3	80·8	93·5	106·5	119·9
8¾	22·1	33·6	45·4	57·5	70·0	82·7	95·7	109·1	122·7
9	22·7	34·5	46·6	59·1	71·8	84·8	98·2	111·8	125·8
9¼	23·3	35·4	47·9	60·6	73·6	87·0	100·6	114·6	128·9
9½	23·9	36·4	49·1	62·1	75·5	89·1	103·1	117·4	131·9
9¾	24·6	37·3	50·3	63·7	77·3	91·3	105·5	120·1	135·0
10	25·2	38·2	51·5	65·2	79·2	93·4	108·0	122·8	138·1
10¼	25·8	39·1	52·8	66·7	81·0	95·6	110·4	125·6	141·1
10½	26·4	40·0	51·0	68·3	82·8	97·7	112·9	128·4	144·2
10¾	27·0	41·0	55·2	69·8	84·7	99·9	115·4	131·2	147·3
11	27·6	41·9	56·5	71·3	86·5	102·0	117·8	133·9	150·3
11¼	28·2	42·8	57·7	72·9	88·4	104·2	120·3	136·7	153·4
11½	28·8	43·7	58·9	74·4	90·2	106·3	122·7	139·4	156·4
11¾	29·5	44·6	60·1	75·9	92·0	108·5	125·2	142·2	159·5
12	30·1	45·6	61·4	77·5	93·6	110·6	127·6	145·0	162·6

II.—SPECIFIC GRAVITY AND WEIGHT OF MATERIALS.

TABLE I.—METALS.	Specific Gravity.	Wt. of 1 cub. ft.	Wt. of 1 cub. in.
	ozs.	lbs.	oz.
Antimony, cast	6702	418·9	3·878
Arsenic,	5763	360·2	3·335
Bismuth, cast	9822	613·9	5·684
Brass, cast	8396	524·8	4·859
Brass, wire	8544	534·0	4·944
Bronze,	8222	513·4	4·753
Cobalt, cast	7811	488·2	4·520
Copper, cast	8788	549·3	5·086
Copper, sheet	8915	557·2	5·159
Copper, wire	8878	554·9	5·136
Gold, pure	19258	1203·6	11·161
Gold, hammered	19362	1210·1	11·205
Gold, standard	17647	1102·9	10·213
Gun, metal	8784	549·0	5·083
Iron, bars wrought	7786	486·6	4·506
Iron, cast	7207	450·4	4·171
Lead, cast	11352	709·5	6·569
Mercury, solid	15632	977·0	9·046
Mercury, fluid	13568	848·0	7·852
Nickel, cast	7807	487·9	4·518
Platinum, pure	19500	1218·8	11·285
Platinum, hammered	20336	1271·0	11·767
Silver, pure	10474	654·6	6·061
Silver, hammered	10511	656·9	6·083
Silver, standard	10534	658·4	6·096
Steel, tempered	7818	488·6	4·524
Steel, soft	7833	489·6	4·533
Tin, cast	7291	455·7	4·244
Type metal	10450	653·1	6·047
Zinc, cast	7190	449·4	4·161

TABLE II.—STONES, EARTHS, &C.	Specific Gravity.	Wt. of 1 cub. ft.	Wt. of 1 cub. in.
	ozs.	lbs.	oz.
Basaltes (Giant's causeway)	2864	179·0	1·657
Basaltes, prismatic	2722	170·1	1·575
Borax	1714	107·1	0·992
Brick	2000	125·0	1·157
Chalk, mean of 3 sorts	2767	172·9	1·601
Coal, mean of 4 sorts	1270	79·4	0·735
Cutler's stone	2111	131·9	1·220
Emery,	4000	250·0	2·315
Flint, mean of 4 sorts	2588	161·8	1·498
Freestone, mean of 5 sorts	2452	153·3	1·419
Gypsum, opaque	2168	135·5	1·255
Granite, mean of 14 sorts	2698	168·6	1·561
Grindstone	2143	133·9	1·240
Hone, white	2876	179·8	1·664
Jet,	1259	78·7	0·729
Limestone, mean of 7 sorts	2945	184·1	1·278
Marble, mean of 19 sorts	2720	170·0	1·574
Millstone,	2484	155·3	1·438
Pavingstone	2416	151·0	1·398
Peat, hard	1329	83·1	0·764
Portland stone	2570	160·1	1·487
Porphyry, mean of 5 sorts	2723	170·2	1·575
Pumice stone	915	57·2	0·530
Purbeck stone	2601	162·6	1·505
Rag stone	2470	154·4	1·429
Rotten stone	1981	123·8	1·146
Salt,	2130	133·1	1·233
Sand,	1520	95·0	0·880
Slate, mean of 4 sorts	2620	163·8	1·516
Stone, common	2520	157·5	1·458
Sulphur, native	2033	127·1	1·176
Sulphur, melted	1991	124·4	1·152

TABLE III.—WOODS.	Specific Gravity.	Wt. of 1 cub. ft.	Wt. of 1 cub in.
	ozs.	lbs.	oz.
Acacia and orange tree	710	44·4	0·411
Ash and Dantzic oak	760	47·5	0·440
Beech and English oak	700	43·8	0·405
Birch, common	700	43·8	0·405
Birch, American black	750	46·9	0·434
Box and green heart	1000	62·5	0·579
Cedar, mean of 4 sorts	771	48·2	0·446
Cherry tree	715	44·7	0·414
Cork	240	15·0	0·139
Deal, Christiana	681	42·5	0·394
Deal, Memel	390	36·9	0·341
Ebony, mean of 2 sorts	1270	79·4	0·735
Elm and larch	540	33·8	0·313
Fir, New England	550	34·4	0·318
Fir Riga, and maple	750	46·9	0·434
Fir, Mar Forest	700	43·8	0·405
Lignum vitae	1333	83·3	0·771
Logwood	913	57·1	0·528
Mahogany	637	39·8	0·369
Norway spars	580	36·3	0·336
Oak, English	900	56·3	0·521
Oak, African	980	61·3	0·567
Oak, Adriatic	990	61·9	0·573
Oak, Canadian	872	54·5	0·505
Pear tree	646	40·4	0·374
Pine, pitch and red	660	41·3	0·382
Poon and hazel	600	37·5	0·347
Poplar, mean of 2 sorts	456	28·5	0·264
Teak and plum tree	750	46·9	0·434
Walnut	671	41·9	0·386
Willow	585	36·6	0·339
Yew, mean of 2 sorts	798	49·9	0·462

TABLE IV.—RESINS, GUMS, &c.	Specific Gravity.	Wt. of 1 cub. ft.	Wt. of 1 cub in.
	ozs.	lbs.	oz.
Assafoetida	1328	83·0	0·769
Bee's wax	967	60·4	0·560
Bone of an ox	1656	103·5	0·958
Butter	942	58·9	0·545
Caoutchouc	934	58·4	0·541
Camphor	989	61·8	0·572
Copal, mean of 4 sorts	1077	67·3	0·623
Fat, do.	930	58·1	0·538
Gamboge	1222	76·4	0·707
Gum Arabic	1452	90·8	0·040
Gum Ammoniac	1207	75·4	0·699
Gum lac	1139	71·2	0·659
Gunpowder, shaken	932	58·3	0·539
Do. solid	1745	109·1	1·010
Honey	1450	90·6	0·839
Indigo	769	48·1	0·445
Ivory, dry	1825	114·1	1·056
Lard	948	59·3	0·549
Madder root	765	47·8	0·443
Opium	1336	83·5	0·773
Sandarac	1092	63·3	0·586
Spermaceti	943	58·9	0·547
Sugar, white	1606	100·4	0·929
Tallow	942	58·9	0·545
Tar	1015	63·4	0·587
Wax, shoemakers	897	56·1	0·519
Atmospheric air	1·200	·075	·0007
Azotic Gas	1·182	·074	·0007
Carbonic acid do.	1·824	·114	·0011
Muriatic acid do.	1·534	·096	·0009
Nitrous acid do.	2·912	·182	·0017
Sulphurous acid do.	2·761	·173	·0016

TABLE V.—LIQUIDS, &c.	Specific Gravity.	Wt. of 1 cub. ft.	Wt. of 1 cub. in.
	ozs.	lbs.	oz.
Hydrogen Gas	0·100	·006	·0001
Oxygen do.	1·435	·090	·0008
Acid, acetic	1063	66·4	0·615
Do. muriatic	1200	75·0	0·694
Do. nitric	1271	79·4	0·736
Do. phosphoric	1558	97·4	0·902
Do. sulphuric	1850	115·6	1·071
Alcohol, absolute	797	49·8	0·461
Do. highly rectified	829	51·8	0·480
Do. of commerce	837	52·3	0·484
Ammoniac, liquid	897	56·1	0·519
Beer, mean of 2 sorts	1028	64·3	0·595
Cyder	1018	63·6	0·589
Ether, acetic	866	54·1	0·501
Do. muriatic	730	45·6	0·422
Do. sulphuric	740	46·3	0·428
Milk	1032	64·5	0·597
Oil of Anise seed	987	61·6	0·570
Do. Caraway seed	905	56·6	0·524
Do. Cinnamon	1044	65·3	0·604
Do. Lavender	894	55·9	0·517
Do. Linseed	940	58·8	0·544
Do. Mint	898	56·1	0·520
Do. Olives	915	57·2	0·530
Do. Turpentine	870	54·9	0·508
Do. Whale	923	57·7	0·534
Vinegar	1010	63·1	0·585
Water, distilled	1000	62·5	0·579
Do. sea	1026	64·1	0·594
Wine, Champaigne	998	62·4	0·578
Do. Madeira	1038	64·9	0·601
Do. Port	997	62·3	0·577

TABLE VI.—WATER IN PIPES.

This table shows the quantity and weight of water contained in one fathom of length of pipes of different bores from 1 in. to 12 inches in diameter, advancing by ½ inch. The weight of a cubic foot of water is taken at 1000 ounces avoirdupois, and the imperial gallon at 10 lbs.

Diameter in inches.	Quantity in Cubic inches.	Quantity in Imperial gallons.	Weight in lbs. Avoird.
½	14·14	0·051	0·51
1	56·55	0·205	2·05
1½	127·23	0·460	4·60
2	226·19	0·818	8·18
2½	353·43	1·278	12·78
3	508·94	1·841	18·41
3½	692·72	2·506	25·06
4	904·78	3·272	32·72
4½	1145·11	4·142	41·42
5	1413·72	5·113	51·13
5½	1710·60	6·187	61·87
6	2035·75	7·363	73·63
6½	2389·18	8·641	86·41
7	2770·88	10·022	100·22
7½	3180·86	11·505	115·05
8	3619·11	13·090	130·90
8½	4085·64	14·777	147·77
9	4580·44	16·567	165·67
9½	5103·52	18·459	184·59
10	5654·87	20·453	204·53
10½	6234·49	22·550	225·50
11	6842·39	24·748	247·48
11½	7478·56	27·049	270·49
12	8143·01	29·452	294·52

III.—STEAM AND STEAM ENGINES.

TABLE I.—PROPERTIES OF STEAM.

Column A, contains the total force of steam in atmospheres; Column B, in inches of mercury; and Column C, in lbs. per circular inch. Column D, contains the excess of force above the atmosphere, in lbs. per circular inch; Column E, in lbs. per square inch. Column F, contains the temperature, Fahrenheit; Column G, the volume in cubic feet, the water being 1; Column H, the weight of a cubic foot in grains; Column I, the specific gravity, air being 1; Column K, the velocity into a vacuum in feet per second; Column L, the heat of conversion from water of 52°, to steam.

A	B	C	D	E	F	G	H	I	K	L
ats.	ins.	lbs.	lbs.	lbs.		cu. ft	grs.	s. g.	vel.	
·018	0·6	·2	-11·3	-14·4	60°	72190	6	·012	1377	1009°
·033	1	·4	-11·2	-14·2	77	41010	11	·020	1400	1025
·067	2	·8	-10·8	-13·7	98·7	21400	21	·039	1427	1047
·1	3	1·2	-10·4	-13·2	112·5	14570	30	·057	1445	1061
·133	4	1·5	-10·0	-12·7	123	11130	39	·074	1458	1071
·25	7·5	2·9	-8·7	-11·0	147·6	6187	71	·134	1499	1096
·5	15	5·8	-5·8	-7·3	178	3249	135	·255	1526	1126
·75	22·5	8·7	-2·9	-3·7	197·4	2232	196	·371	1549	1146
1·00	30	11·5	0·0	0·0	212	1711	255	·484	1566	1160
1·17	35	13·5	1·9	2·4	220	1497	292	·553	1575	1168
1·5	45	17·3	5·8	7·3	233·8	1178	363	·687	1591	1182
1·75	52·5	20·2	8·7	11·0	242·5	1022	427	·810	1601	1191
2·0	60	23·1	11·5	14·7	250·2	905	483	·915	1610	1199
2·5	75	28·9	17·3	22·0	263·5	737	593	1·123	1625	1212
3·0	90	34·6	23·1	29·3	274·7	623	700	1·330	1638	1223
3·5	105	40·4	28·9	36·6	284·5	542	810	1·530	1649	1233
4	120	46·2	34·6	44·0	293·1	479	910	1·728	1658	1241
5	150	57·7	46·2	58·6	308	391	1110	2·120	1674	1256
6	180	69·2	57·7	73·3	320·6	331	1317	2·500	1688	1269
7	210	80·8	69·2	87·9	331·5	288	1520	2·68	1700	1280
8	240	92·3	80·8	102·6	341·2	255	1662	3·25	1710	1289
9	270	103·9	92·3	117·2	350	229	1910	3·61	1720	1298
10	300	115·4	103·9	131·9	358	209	2100	3·97	1729	1306
20	600	230·8	219·3	278·4	414	111	3940	7·44	1786	1362
30	900	346·2	334·7	424·9	450	77	5670	10·75	1823	1398
40	1200	461·6	450·1	571·4	477	60	7350	13·88	1850	1425

TABLE II.—ELASTIC FORCE OF STEAM.

Note.—T. denotes temperature; and F, force.

T	F.	T.	F.	T.	F.	T.	F.	T.	F.	T	F.	T.	F.
°	in.	°	in.	°	in.	°	in.	°	in.	°	in.	°	in.
32	0·20	74	0·82	116	3·0	157	8·8	198	22·7	239	49·1	280	97·8
33	0·21	75	0·85	117	3·1	158	9·0	199	23·2	240	50·0	281	99·7
34	0·21	76	0·88	118	3·2	159	9·2	200	23·6	241	50·9	282	100·3
35	0·22	77	0·91	119	3·3	160	9·5	201	24·1	242	51·8	283	102·2
36	0·23	78	0·94	120	3·3	161	9·7	202	24·6	243	52·6	284	103·8
37	0·24	79	0·97	121	3·4	162	9·9	203	25·1	244	53·5	285	105·6
38	0·25	80	1·0	122	3·5	163	10·2	204	25·6	245	54·4	286	107·3
39	0·25	81	1·0	123	3·6	164	10·4	205	26·1	246	55·3	287	109·0
40	0·26	82	1·1	124	3·7	165	10·7	206	26·7	247	56·3	288	110·8
41	0·27	83	1·1	125	3·8	166	11·0	207	27·2	248	57·2	289	112·7
42	0·28	84	1·1	126	3·9	167	11·3	208	27·7	249	58·2	290	114·5
43	0·29	85	1·2	127	4·0	168	11·5	209	28·3	250	59·1	291	116·4
44	0·31	86	1·2	128	4·1	169	11·8	210	28·8	251	60·1	292	118·3
45	0·32	87	1·2	129	4·2	170	12·1	211	29·4	252	61·1	293	120·3
46	0·33	88	1·3	130	4·3	171	12·4	212	30·0	253	62·2	294	122·2
47	0·34	89	1·3	131	4·5	172	12·7	213	30·6	254	63·2	295	124·2
48	0·35	90	1·4	132	4·6	173	13·0	214	31·2	255	64·4	296	126·1
49	0·36	91	1·4	133	4·7	174	13·3	215	31·8	256	65·5	297	128·0
50	0·38	92	1·4	134	4·9	175	13·6	216	32·4	257	66·6	298	129·8
51	0·39	93	1·5	135	5·0	176	13·9	217	33·0	258	67·8	299	131·6
52	0·40	94	1·5	136	5·1	177	14·2	218	33·7	259	69·0	300	133·8
53	0·42	95	1·6	137	5·3	178	14·5	219	34·2	260	70·1	301	135·6
54	0·43	96	1·6	138	5·4	179	14·8	220	35·0	261	71·3	302	137·6
55	0·44	97	1·7	139	5·6	180	15·2	221	35·5	262	72·5	303	139·8
56	0·46	98	1·7	140	5·7	181	15·5	222	36·2	263	73·5	304	141·9
57	0·47	99	1·8	141	5·9	182	15·9	223	37·0	264	74·8	305	144·1
58	0·49	100	1·9	142	6·1	183	16·2	224	37·5	265	76·0	306	146·2
59	0·51	101	1·9	143	6·2	184	16·6	225	38·0	266	77·3	307	148·3
60	0·52	102	2·0	144	6·4	185	17·0	226	38·8	267	78·5	308	150·7
61	0·54	103	2·0	145	6·5	186	17·4	227	39·5	268	79·8	309	152·7
62	0·56	104	2·1	146	6·7	187	17·8	228	40·2	269	81·1	310	155·0
63	0·58	105	2·2	147	6·9	188	18·2	229	40·9	270	82·5	311	157·2
64	0·60	106	2·3	148	7·1	189	18·6	230	41·6	271	83·9	312	159·5
65	0·62	107	2·3	149	7·2	190	19·0	231	42·3	272	85·5	313	161·8
66	0·64	108	2·4	150	7·4	191	19·4	232	43·0	273	87·0	314	164·2
67	0·66	109	2·5	151	7·6	192	19·9	233	43·8	274	88·5	315	166·7
68	0·68	110	2·5	152	7·8	193	20·3	234	44·6	275	90·0	316	169·2
69	0·70	111	2·6	153	8·0	194	20·8	235	45·5	276	91·6	317	171·7
70	0·72	112	2·7	154	8·2	195	21·2	236	46·4	277	93·2	318	174·3
71	0·75	113	2·8	155	8·4	196	21·7	237	47·3	278	94·7	319	176·9
72	0·77	114	2·8	156	8·6	197	22·1	238	48·2	279	96·3	320	179·4
73	0·80	115	2·9										

TABLE III.—SINGLE ACTING STEAM ENGINES.

Note. The horse power is estimated at 33000 lbs. and the elastic force of the steam at 35 inches. In the first eight columns, the steam acts expansively, and in the last two columns, at full pressure.

Column A, is the number of horses' power; Col. B, the diameter of the steam piston in inches; Col. C, the mean pressure on the piston in lbs. @ 5½ lbs. per circular inch; Col. D, the velocity of the steam piston in feet per minute; Col. E, length of the stroke in feet; Col. F, number of strokes per minute; Col. G, water required per hour to supply the boiler; Col. H, coals consumed per hour in lbs. Col. I, number of horses' power; Col. K, coals consumed per hour in lbs.

A	B	C	D	E	F	G	H	I	K
10	26·4	3850	174	4·4	19¾	11·1	114	11·2	152
15	31·1	5324	187	5·2	18	16·7	164	16·8	220
20	34·9	6702	197	5·8	17	22·3	213	22·5	285
25	38·1	8012	203	6·3	16	27·7	257	28	343
30	41·1	9270	214	6·8	15¾	33·3	307	33·5	410
35	43·7	10490	221	7·3	15¼	39	356	39·2	475
40	46·1	11670	227	7·7	14¾	44·5	401	45	536
45	48·3	12820	232	8·0	14½	50	450	50·5	600
50	50·4	13950	237	8·4	14¼	55·5	500	56	670
55	52·3	15050	242	8·7	14	61·2	551	62	735
60	54·2	16140	246	9·0	13¾	66·7	600	67	800
65	56·0	17210	250	9·3	13½	72·1	649	73	865
70	57·6	18260	254	9·6	13¼	78	702	78	940
75	59·2	19290	257	9·8	13	83·3	750	84	1000
80	60·8	20310	260	10·1	13	89	801	89	1070
85	62·3	21330	264	10·4	12¾	94·5	851	95	1140
90	63·7	22320	267	10·6	12½	100	900	101	1200
100	66·5	24290	272	11·0	12¼	111	999	112	1330
120	71·5	28100	283	11·9	12	133	1197	134	1600
140	76·0	31790	291	12·6	11½	156	1404	157	1860
160	80·2	35380	299	13·3	11¼	178	1602	179	2140
180	84·1	38870	307	14·0	11	200	1800	201	2400
200	87·7	42300	313	14·6	10¾	222	1998	224	2650
213½	90	44550	318	15·0	10½	237	2133	265	2860

TABLE IV.—DOUBLE ACTING STEAM ENGINES.

Note.—The horse power and elastic force are the same as in Table III.

The Columns in this table are headed the same as in Table III, with the exception of Col. C, where the mean pressure is 4·8 lbs. per circular inch.

A	B	C	D	E	F	G	H	I	K
1	7·8	289	114	1·3	44	0·8	15	1·46	31·5
2	10·25	516	131	1·75	37½	1·57	23	2·95	48
3	12·05	697	141	2·0	35	2·36	30½	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	8·85	111
7	16·9	1373	167	2·8	29¾	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	28¼	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	26⅓	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	3431	211	4·5	23½	17·3	163	32·5	341
24	27·7	3678	213	4·6	23¼	18·8	176	35·5	370
26	28·6	3922	216	4·75	23¾	20·4	189	38·4	395
28	29·45	4161	220	4·9	22½	22·0	203	41·3	425
30	30·27	4397	222	5·04	22⅓	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	20⅔	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	38·85	7245	254	6·49	19½	44·0	396	82·2	827
58	39·4	7453	255	6·57	19½	45·4	409	85·1	850
60	39·9	7656	257	6·65	19⅓	47·0	423	88·1	887
62	40·5	7860	259	6·75	19¼	48·6	437	91·0	916

A	B	C	D	E	F	G	H	I	K
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	49·0	11520	284	8·16	17½	78·2	704	146·0	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	16¼	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	2363
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	292·0	2956

TABLE V.—HIGH PRESSURE ENGINES.

Col. A, temperature of the steam; B, elastic force in inches; C, force in lbs. per square inch above the atmosphere; D, lbs. of coal equivalent to 1 horse power, steam at full pressure; E, do. acting expansively; F, lbs. raised 1 foot high, equivalent to the power of steam from 84 lbs. of coal, at full pressure; G, do. expansively.

A	B	C	D	E	F	G
234·5	45	7·4	480		2780000	
251	60	14·8	163	143	8200000	9300000
275	90	29·7	98	77	13700000	17700000
292·8	120	44·5	82	59	16600000	22700000
307·7	150	59·3	74	51	18000000	26200000
320·2	180	74·2	70	48	19200000	28700000
343·6	240	104	65	41½	25000000	32200000

IV.—SPECIFIC COHESION AND STRENGTH OF MATERIALS.

TABLE I.—METALS.

		Specific Cohesion
Antimony, cast		0·113
Bismuth, do.	From	0·345 to 0·319
Copper, wire		6·606
—— cast, Barbary		2·396
—— do. Japan		2·152
Gold, wire		3·279
—— cast		2·171
Iron, wire	From	12·004 to 9·108
—— Bar	"	8·964 to 5·839
—— do. best quality		7·006
—— do. German, BR	From	9·880 to 6·514
—— do. Swedish L	"	9·445 to 7·296
—— do. Liege	"	8·794 to 6·621
—— do. German L	"	9·119 to 7·382
—— do. Spanish		8·685
—— do. Oosement	From	8·142 to 7·296
—— do. fine grained		5·306
—— do. medium fineness		3·618
—— do. coarse grained		2·172
—— cast, French	From	7·470 to 4·000
—— do. German		7·250
—— do. English	From	5·520 to 4·334
Lead, milled		0·354
—— wire	From	0·334 to 0·270
—— cast, English		0·094
Platinum, wire	From	5·995 to 5·625
Silver, wire		4·090
—— cast		4·342
Steel, razor temper		15·927
—— soft		12·739

Tin, wire		0·757
—— cast, English block,	From	0·706 to 0·565
—— do. Banca		0·391
—— do. Malacca		0·342
Zinc wire		2·394
—— patent sheet		1·762
—— cast, Goslar,	From	0·312 to 0·286

TABLE II.—WOODS.

Alder		1·506
Ash,	From	1·804 to 1·274
—— red, seasoned		1·899
—— white do.		1·509
Bay,	From	1·547 to 1·085
Beech		1·880
Cedar		0·528
Chestnut, a century in use		1·291
Citron	From	1·357 to 0·868
Cypress	,,	0·732 to 0·542
Elm		1·432
Elder		1·086
Fir	From	1·380 to 0·879
—— pitch pine	,,	1·398 to 0·380
—— strong red		1·172
—— Memel, seasoned		1·154
—— Russian	From	1·062 to 0·963
—— American		0·942
—— yellow deal		0·900
—— white deal		0·455
—— Scotch		0·711
Larch		1·177
—— Scotch seasoned	From	0·837 to 0·745
Lancewood		2·621
Lemon		1·004
Mahogany, Spanish		1·283

Maple, Norway - -	-	1·123
Mulberry - - -	-	1·492
Oak - - -	From	1·891 to 0·955
—— English - -	"	1·085 to 0·936
—— do. seasoned -	-	1·509
—— French - -	From	1·060 to 0·960
—— do. seasoned -	"	1·559 to 1·363
—— Baltic do. - -	-	1·211
—— American white -	-	1·009
—— Dantzic - -	-	0·818
Plum - - -	From	1·357 to 1·205
Poplar - - -	From	0·705 to 0·488
Pomegranate - -	"	1·221 to 0·882
Teak, Java seasoned -	-	1·509
—— Pegu do. - -	-	1·400
—— Malabar - -	-	1·395
Willow - - -	From	1·357 to 0·809

TABLE III.—OTHER SUBSTANCES.

Bone of an ox - -	-	0·599
Brick - - -	From	0·031 to 0·029
Hemp fibres glued -	-	9·766
Horn of an ox - -	-	0·950
Ivory - - - -	-	1·765
Marble, white - -	-	0·955
Mortar, 16 years old -	-	0·005
Paper strips glued -	-	3·184
Plaster of Paris - -	-	0·008
Plate glass - -	-	1·000
Slate, clay, Welsh -	-	1·358
Stone hard, Givry -	-	0·230
—— soft do. - -	-	0·041
—— Portland - -	-	0·083
—— white, fine -	-	0·022
Whalebone - -	-	0·814

In the preceding tables of *specific cohesion* from Tredgold, the cohesion of *plate glass* is assumed as unity. If any of the numbers in these tables be multiplied by 9240, the product will express the force in lbs. which would tear asunder a bar of the corresponding material of one inch square of transverse section. Thus, the specific cohesion of steel, razor temper, is 15·927, whence the extreme cohesion of a bar one inch square, is 15·927 × 9240= 147165·48 lbs.

TABLE IV.—DIRECT COHESION OF METALS.

The numbers in this table of Rennie's experiments express the direct cohesion of bars 1 inch square in tons.

	tons.
Iron bar, cast horizontally	8·32
Do. do. do. vertically	8·69
Cast steel previously tilted	59·93
Blistered do. reduced by hammer	59·43
Shear do. do. do.	56·97
Swedish iron do. do.	32·15
English do. do. do.	24·93
Hard gun metal	16·23
Wrought copper reduced by hammer	15·08
Cast do.	8·51
Fine yellow brass	8·01
Cast tin	2·11
Cast lead	0·81
Wrought Iron, mean of 26 experiments by Brunel	31·20
Do. mean of 9 experiments by Telford	29·25
Do. mean of 8 experiments by Brown	25·00
Iron cable, mean of 13 experiments by Do.	21·25

TABLE V.—RESISTANCE OF METALS TO TORSION.

This table of experiments by Rennie exhibits only the relative resistance to torsion, that of lead being assumed as unity.

	lbs.
Cast steel	19·56
Sheer steel	17·06
Blister steel	16·69
English iron	10·13
Swedish iron	9·50
Hard gun metal	5·00
Fine yellow brass	4·69
Copper	4·31
Tin	1·44
Lead	1·00

TABLE VI.—RESISTANCE OF METALS TO PRESSURE.

In this table of experiments by Rennie, the number of lbs. are the weights required to crush cubes of $\frac{1}{4}$ inch in the edge.

	lbs.
Iron cast vertically	11136
do. do. horizontally	10114
Copper do.	7318
do. wrought	6440
Brass	10304
Tin cast	966
Lead do.	483

TABLE VII.—RESISTANCE OF WOODS TO PRESSURE.

In this table the experiments were made with cubes of 1 inch in the edge.

	lbs.
Elm	1284
American pine	1606
White deal	1928
English oak	3860

TABLE VIII.—RESISTANCE OF STONES TO PRESSURE.

The following experiments were made with cubes of $1\frac{1}{2}$ inch in the edge, except the first two, which were made with cubes one inch in the edge.

	lbs.
Statuary marble	3216
Craigleith stone	8688
Chalk	1127
Brick pale red	1265
Roe stone Gloucestershire	1449
Red Brick do.	1817
Do. Hammersmith pavier's	2254
Burnt do.	3243
Fire Brick	3864
Derby grit	7070
Do.	9776
Killaly white freestone	10264
Portland do.	10284
Craigleith do.	12346
Yorkshire paving	12856
White statuary marble	13632
Cornish granite	14302
Dundee sandstone	14918
Devonshire red marble	16712
Compact limestone	17354
Peterhead granite	18636
Black compact limestone	19924
Purbeck	20610
Black Brabant marble	20742
Freestone very hard	21254
White Italian marble	21783
Granite Aberdeen blue	24556

TABLE IX.—MODULUS OF ELASTICITY AND COHESION OF MATERIALS.

In this table taken mostly from Sir John Leslie's work on Natural Philosophy, column A denotes the modulus of elasticity in feet; col. B, the fraction of it which constitutes the limit of extreme longitudinal cohesion; col. C, the absolute cohesion or load in lbs. that would rend a prism of an inch square; and col. D, the altitude in feet of the prism that would be torn asunder by the action of its own weight.

Materials.	A	B	C	D
Teak -	6040000	168th.	12915	36049
Oak -	4150000	144	11880	32900
Sycamore	3860000	108	9630	35800
Beech -	4180000	107	12225	38940
Ash -	4617000	109	14130	42080
Elm -	5680000	146	9720	39050
Memel fir	8292000	205	9540	40500
Christiana deal	8118000	146	12346	55500
Larch -	5096000	121	12240	42160
White marble	2150000	1394	1811	1542
Portland stone	1570000	1789	857	945
Hempen fibres	5000000	266	6400	18790
Malleable Iron	7550000	446	55872	16938
Cast Iron	5895000	965	19096	6110

TABLE X.—ADHESION OF NAILS.

In this table of experiments by Mr. Bevan, col. A contains the number of nails to the lb.; col. B, the length in inches; col. C, the depth forced into the wood in inches; and col. D, the force required to extract them in lbs.

Nails.	A	B	C	D
Fine sprigs	4560	0·44	0·40	22
do. do.	3200	0·53	0·44	37
Threepenny Brads	618	1·25	0·50	58
Cast iron nails	380	1·00	0·50	72
Sixpenny nails	73	2·50	1·00	187
do. do.	—	—	1·50	327
do. do.	—	—	2·00	530
Fivepenny nails	139	2·00	1·50	320

The preceding table exhibits the relative adhesion of nails of various kinds, when forced into dry Christiana deal, at right angles to the grain of the wood.

The percussive force required to drive the common sixpenny nail to the depth of one inch and half into *dry Christiana deal,* with a cast iron weight of 6·275 lbs. was four blows or strokes falling freely the space of 12 inches; and the steady pressure to produce the same effect was 400 lbs.

A sixpenny nail driven into *dry elm,* to the depth of one inch across the grain, required a pressure of 327 lbs. to extract it; and the same nail, driven endways, or longitudinally into the same wood, was extracted with a force of 257 pounds.

The same nail driven two inches endways into *dry Christiana deal,* was drawn by a force of 257 pounds; and to draw out one inch under like circumstances, took 87 pounds only. The relative adhesion, therefore, in the same wood, when driven transversely or longitudinally, is 100 to 78, or about 4 to 3 in dry elm; and 100 to 46, or about 2 to 1 in deal; and in like circumstances, the relative adhesion to elm and deal is as 2 or 3 to 1.

The progressive depths of a sixpenny nail driven into dry Christiana deal by simple pressure, were as follows:

One quarter of an inch, a pressure of	24 lbs.
Half an inch	76 —
One inch	235 —
One inch and half	400 —
Two inches	610 —

To extract a common sixpenny nail from a depth of one inch out of

Dry Oak, required	507 lbs.
Dry Beech	667 —
Green Sycamore	312 —

From these experiments, we may infer that a common sixpenny nail, driven two inches into dry oak, would require a force of more than half a ton to extract it by a steady force. A common screw, of one-fifth of an inch, was found to have an adhesive force of about three times that of a sixpenny nail. The force necessary to break or tear out a half inch iron pin, applied in the manner of a pin to a tenon in the mortice, the thickness of the board being 0·87 inch, and the distance of the centre of the hole from the end of the board 1·05 inch, was 976 pounds.

As the strength of a tenon from the pin hole may be considered in proportion to the distance from the end, and also as the thickness, we may, for this species of wood, obtain the breaking force in pounds nearly, by multiplying together one thousand times the distance of the hole from the end by the thickness of the tenon in inches.

FINIS.