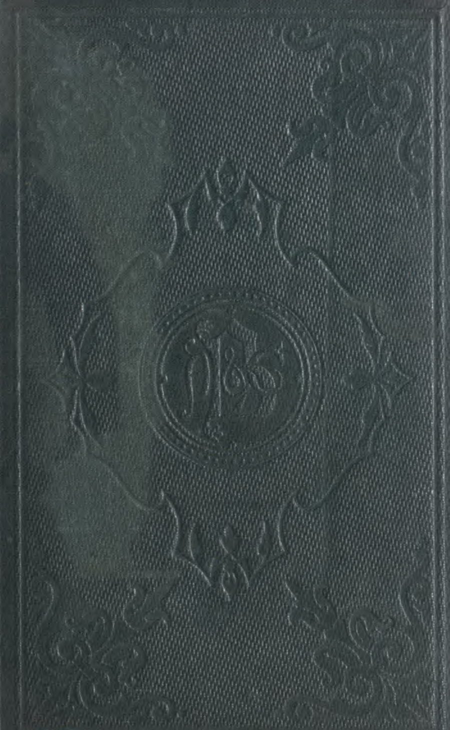

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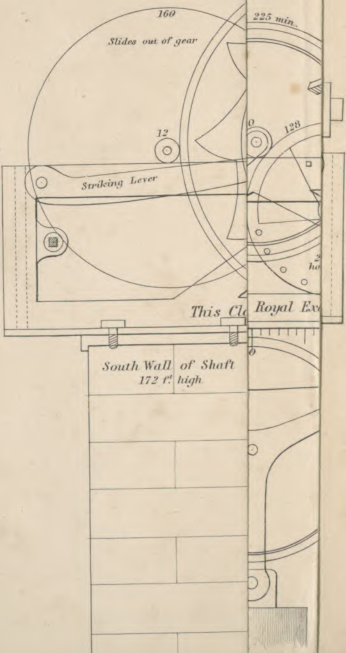

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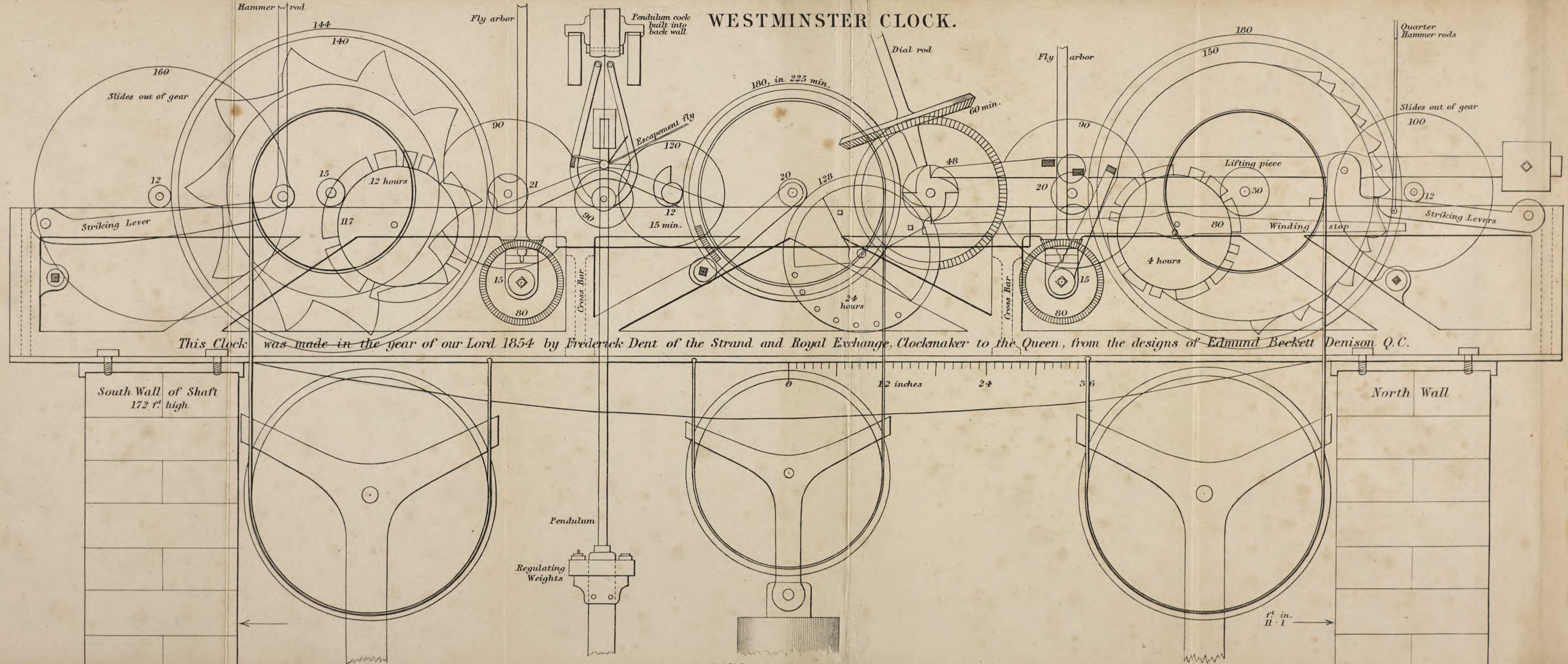
WESTMINSTER CLOCK.



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CLOCKS AND LOCKS.

FROM THE "ENCYCLOPÆDIA BRITANNICA."

SECOND EDITION;

WITH A FULL ACCOUNT OF

THE GREAT CLOCK AT WESTMINSTER.

BY

EDMUND BECKETT DENISON, M.A., Q.C.

EDINBURGH:
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ERRATA.

In the frontispiece, on the largest wheel on the right hand, *for* 180 *read* 144.

Page 11, line 1, *for* cosine *read* $\sqrt{\text{cosine}}$.

PREFACE.

THE first part of this book is a new and enlarged edition of the articles on *Clock and Watch Work*, and on the meridian instrument called the *Dipleidoscope*, which were reprinted in a small volume in 1855 from the 8th edition of the *Encyclopædia Britannica*. It may also be regarded as a third edition of the *Rudimentary Treatise* on this subject published in 1850, in Weale's Series of such treatises.

The second part is a similar reprint of the article on *Locks*, which has just been published in the 13th volume of the *Encyclopædia*. It was too short to print alone; and as it can be added with very little increase of cost, by using the Encyclopædia types before they are broken up, and both subjects are likely to be interesting to the same class of readers, it has been added to the present volume.

The reader will doubtless be struck with the frequent recurrence of my own name, and that of a single clock and chronometer maker, in the first part of the book. I can only say that I wish I had occasion to mention other names more frequently. But it was my business to give a full and true account of the present state of horological science. I have noticed everything which appeared to be worth notice; and if many of them come from the same source, that is no reason why it should not be mentioned. And so long as the English clockmakers are determined to display their spirit only in resisting and running down every invention for either improving or cheapening the manufacture of clocks, they have no business to complain or be surprised at being supplanted by the Americans and the French in their own market, and at their names being very rarely mentioned in modern treatises on horology. Some striking illustrations of the non-progressiveness of the art of clockmaking, during the time that all other branches of mechanical science have been making greater progress than in any former period of the world, will be found in the account I have given of the proceedings respecting the great clock of the Houses of Parliament, and in other parts of this book.

To save frequent repetition, and to prevent the mistakes—and something more—which, I find from people who consult me about clocks, are constantly occurring, I wish to state, once for all, that when I mention the name of Mr Dent in these pages, I mean always either the late Mr E. J. Dent, who died in 1853, or else Mr Frederick Dent, his executor and sole successor in the shops at 61 Strand and 34 Royal Exchange, and the clock factory on the banks of the Thames, and in all his patent rights, and what may be called his scientific business generally; and who, I find it also necessary to state, is the sole maker of the Westminster clock, and the inventor of the fluid compass free from bubble, now extensively used in the navy. The shop in Cockspur Street, which still has the same name, went, on old Mr Dent's death, to another member of the family, and now belongs to a lady and some children.

42 Queen Anne Street, London,
31 *July* 1857.

CLOCKS.

The origin of clock work is involved in great obscurity. Notwithstanding the statements by many writers that clocks, *horologia*, were in use so early as the ninth century, and that they were then invented by an archdeacon of Verona, named Pacificus, there appears to be no clear evidence that they were machines at all resembling those which have been in use for the last five or six centuries. But it is certain that for that period at least clocks have been made depending on the action of a weight on a train of wheels, as distinguished from the water-clocks, *clepsydræ*, which are well known to have been used many centuries before. However, we intend to confine this treatise as far as possible to matters of practical interest, as we cannot afford the space to enter into the history of horology; and we will, therefore, at once refer the reader who is curious about it to the articles on clocks, chronometers, &c., in Rees's Cyclopædia, and the various works there cited. We will only add to the information there given, that it appears from a communication of Captain Smith to the Antiquarian Society in 1851, that there is still a clock in existence at Dover Castle bearing the date 1348, earlier by 30 years than that of the clock made by De Vick for the palace of the French king Charles the Fifth, which has generally been described as the earliest clock of which the construction is known. Mr Denison and carries the long or minute hand; this wheel always turning in an hour, and the great wheel generally in 12 hours, by having 12 times as many teeth as the centre pinion. The centre wheel drives the "second wheel" D by its pinion *d*, and that again drives the scape-wheel E by its pinion *e*. If the pinions *d* and *e* have each 8 teeth or *leaves* (as the teeth of pinions are usually called), *c* will have 64 teeth and D 60, in a clock of which the scape-wheel turns in a minute, so that the seconds hand may be set on its arbor prolonged to the dial. A represents the pallets of the escapement, which will be described presently, and their arbor *a* goes through a large hole in the back plate near F, and its back pivot turns in a cock O F Q screwed on to the back plate. From the pallet arbor at F descends the *crutch* F*f*, ending in the *fork f*, which embraces the pendulum, so that as the pendulum vibrates, the crutch and the pallets necessarily vibrate with it. The pendulum is hung by a thin spring S from the cock Q, so that the bending point of the spring may be just opposite the end of the pallet arbor, and the edge of the spring as close to the end of that arbor as possible—a point too frequently neglected.

We may now go to the front (or left hand) of the clock, and describe the dial or "motion-work." The minute hand fits on to a squared end of a brass socket, which is fixed to the wheel M, and fits close, but not tight, on the prolonged arbor of the centre wheel. Behind this wheel is a bent spring which is (or ought to be) set on the same arbor with a square hole (not a round one as it sometimes is) in the middle, so that it must turn with the arbor; the wheel is pressed up against this spring, and kept there by a cap and a small pin through the end of the arbor. The consequence is, that there is friction enough between the spring and the wheel to carry the hand round, but not enough to resist a moderate push with the finger for the purpose of altering the time indicated. This wheel M, which is sometimes called the minute-wheel, but is better called the ***hour-wheel***, as it turns in an hour, drives another wheel N, of the same number of teeth, which has a pinion attached to it; and that pinion drives the twelve-hour wheel H, which is also attached to a larger socket or pipe carrying the hour hand, and riding on the former socket, or rather (in order to relieve the centre arbor of that extra weight) on an intermediate socket fixed to the *bridge* L, which is screwed to the front plate over the hour-wheel M. The weight W, which drives the train and gives the impulse to the pendulum through the escapement, is generally hung by a catgut line passing through a pulley attached to the weight, as shown in fig. 14, the other end of the cord being tied to some convenient place in the clock frame or *seat-board*, to which it is fixed by screws through the lower pillars. It has usually been the practice to make the cases of house clocks and astronomical clocks not less than 6 feet high; but that is a very unnecessary waste of space or materials; for by either diminishing the size of the barrel, or the number of its turns, by increasing the size of the great wheel by one-half, or hanging the weights by a treble instead of a double line, a case just long enough for the pendulum will also be long enough for the fall of the weights in 7 or 8 days. Of course the weights have to be increased in the same ratio, and indeed rather more, to overcome the increased friction; but that is of no consequence.

PENDULUM.

The claim to the invention of the pendulum, like the claim to most inventions, is disputed; and we have no intention of trying to settle it. It was, like many other discoveries and inventions, probably made by various persons, independently, and almost simultaneously, when the state of science had become ripe for it. That peculiarly valuable property of the pendulum called *isochronism*, or the disposition to vibrate different arcs in very nearly the same time (provided the arcs are none of them large), was known long before the time of the earliest clocks we have described; for it is said that the ancient astronomers of the East employed pendulums in measuring the times of their observations, counting their vibrations during the phases of an eclipse or transit, and renewing them by a push of the finger when they languished. This knowledge, however, appears itself to have languished before the time of Galileo, if credit is to be given to the well-known story of his being struck with the apparent isochronism of a chandelier hung by a long chain from the roof of the church at Florence. And Galileo's son appears as a rival of Avicenna, Huygens, Dr Hooke, and a London clockmaker named Harris, for the honour of having first applied the pendulum to regulate the motion of a clock train, all in the early part of the seventeenth century. Be this as it may, there seems little doubt that Huygens was the first who mathematically investigated, and therefore really knew the true nature of those properties of the pendulum, which may now be found explained in any mathematical book on mechanics. He discovered that if a *simple* pendulum (*i.e.*, a weight or *bob* consisting of a single point, and hung by a rod or string of no weight) can be made to describe, not a circle, but a cycloid of which the string would be the radius of curvature at the lowest point, all its vibrations, however large, will be performed in the same time. For a little distance near the bottom, the circle very nearly coincides with the cycloid; and hence it is, that for small arcs, a pendulum vibrating as usual in a circle, is nearly enough isochronous for the purposes of horology; more especially when contrivances are introduced either to compensate for the variations of the arc, or, better still, to destroy them altogether, by making the force on the pendulum so constant that its arc may never sensibly vary.

The difference between the time of any *small* arc of the circle and *any* arc of the cycloid varies nearly as the square of the circular arc; and again, the difference between the times of any two small and nearly equal circular arcs of the same pendulum, varies nearly as the arc itself. If a, the arc, is increased by a small amount da, the pendulum will lose $10800ada$ seconds a-day, which is rather more than 1 second, if a is 2° (from zero) and da is $10'$, since the numerical value of 2° is $\cdot 035$. If the increase of arc is considerable, it will not do to reckon thus by differentials, but we must take the difference of time for the day as $5400\ (a_{,}^2 - a^2)$, which will be just 8 seconds if $a = 2^\circ$ and $a_{,} = 3^\circ$. For many years it was thought of great importance to obtain cycloidal vibrations of clock pendulums, and it was done by making the suspension string or spring vibrate between *cycloidal cheeks*, as they were called. But it was in time discovered that all this is a delusion. First, because there is and can be no such thing in reality as a simple pendulum, and cycloidal cheeks will only make a simple pendulum vibrate isochronously; secondly, because a very slight error in the form of the cheeks (as Huygens himself discovered) would do more harm than the *circular error* uncorrected at all, even for an arc of 10°, which is much larger than the common pendulum arc; thirdly, because there was always some friction or adhesion between the cheeks and the string; and fourthly (a reason which applies equally to all the isochronous contrivances since invented), because a common clock escapement itself generally tends to produce an error exactly opposite to the circular error, or to make the pendulum vibrate quicker the farther it swings; and therefore (as was shown by Mr Denison in the Cambridge Philosophical Transactions in 1848) the circular error is actually useful for the purpose of helping to counteract the error due to the escapement, and the clock goes better than it would with a simple pendulum, describing the most perfect cycloid. At the same time, the thin spring by which pendulums are always suspended, except in some French clocks where a silk string is used (a very inferior plan), causes the pendulum to deviate a little from circular and to approximate to cycloidal motion, because the bend does not take place at one point, but is spread over some length of the spring.

The accurate performance of a clock depends so essentially on the pendulum, that we shall go somewhat into detail respecting it. First then, the time of vibration depends entirely on the length of the pendulum, the effect of the spring being too small for consideration until we come to differences of a higher order. But the time does not vary as the length, but only as the square root of the length; *i.e.*, a pendulum to vibrate two seconds must be four times as long as a seconds pendulum. The relation between the time and the length of a pendulum is expressed thus:— $t=\pi\sqrt{\frac{l}{g}}$, where t is the time in seconds, π the well-known symbol for 3·14159, the ratio of the circumference of a circle to its diameter, l the length of the pendulum, and g the force of gravity at the latitude where it is intended to vibrate. This letter g, in the latitude of London, is the symbol for 32·2 feet, that being the velocity (or number of feet per second) at which a body is found by experiment to be moving at the end of the first second of its fall, being necessarily equal to twice the actual number of feet it has fallen in that second. Consequently, the length of a pendulum to beat seconds in London is 39·14 inches. But the same pendulum carried to the equator, where the force of gravity is less, would lose $2\frac{1}{4}$ minutes a day.

The seconds we are here speaking of are the seconds of a common clock indicating *mean solar time*. But as clocks are also required for sidereal time, it may be as well to mention the proportions between a mean and a sidereal pendulum. A sidereal day is the interval between two successive transits over the meridian of a place by that imaginary point in the heavens called ♈, the first point of Aries, at the intersection of the equator and the ecliptic; and there is one more sidereal day than there are solar days in a year, since the earth has to turn more than once round in space before the sun can come a second time to the meridian, on account of the earth's own motion in its orbit during the day. A sidereal day or hour is shorter than a mean solar one in the ratio of ·99727, and consequently a sidereal pendulum must be shorter than a mean-time pendulum in the square of that ratio, or in the latitude of London the sidereal seconds pendulum is 38·87 inches. As we have mentioned what is 0 or 24 o'clock by sidereal time, we may as well add, that the mean day is also reckoned in astronomy by 24 hours, and not from midnight as in civil reckoning, but from the following noon; thus, what we call 11 A.M. May 1 in common life, is 23 h. April 30 with astronomers.

It must be remembered that the pendulums whose lengths we have been speaking of are simple pendulums; and as that is a thing which can only exist in theory, the reader may ask how the length of a real pendulum to vibrate in any required time is ascertained. In every pendulum, that is to say in every body hung so as to be capable of vibrating freely, there is a certain point, always somewhere below the centre of gravity, which possesses these remarkable properties: that if the pendulum were turned upside down, and set vibrating about this point, it would vibrate in the same time as before; and moreover, the distance of this point from the point of suspension is exactly the length of that imaginary simple pendulum which would vibrate in at the same time. This point is therefore called the *centre of oscillation*. The rules for finding it by calculation are too complicated for ordinary use, except in bodies of certain simple and regular forms; but they are fortunately not requisite in practice, because in all clock pendulums the centre of oscillation is only a short distance below the centre of gravity of the whole pendulum, and generally so near to the centre of gravity of the bob—in fact a little above it—that there is no difficulty in making a pendulum for any given time of vibration near enough to the proper length at once, and then adjusting it by screwing the bob up or down until it is found to vibrate in the proper time.

REVOLVING OR CONICAL PENDULUM.

Thus far we have been speaking of vibrating pendulums; but the notice of pendulums would be incomplete without some allusion to revolving or *conical* pendulums, as they are called, because they describe a cone in revolving. Such pendulums are used where a continuous instead of an intermittent motion of the clock train is required, as in the clocks for keeping an equatorial telescope directed to a star, by driving it the opposite way to the motion of the earth, to whose axis the axis on which the telescope turns is made parallel. Clocks with such pendulums might also be used in bedrooms by persons who cannot bear the ticking of a common clock. The pendulum, instead of being hung by a flat spring, is hung by a thin piece of piano-forte wire; and it should be understood that it has no tendency to twist on its own axis, and so to twist off the wire, as may be apprehended: in fact it would require some extra force to make it twist, if it were wanted to do so. The time of revolution of such a pendulum may be easily ascertained as follows:—Let l be its length; a the angle which it makes with the vertical axis of the cone which it describes; ω the angular velocity; then the centrifugal force $= \omega^2 l \sin a$; and as this is the force which keeps the pendulum away from the vertical, it must balance the force which draws it to the vertical, which is $g \tan a$: and therefore $\sqrt{\frac{g}{l \cos \theta}} = \omega$, the angular velocity, or the angle described in a second of time; and the time of complete revolution through the angle 360° or 2π, is $\frac{2\pi}{\omega} = 2\pi \sqrt{\frac{l \cos a}{g}}$; that is to say, the time of revolution of a pendulum of any given length is less than the time of a double oscillation of the same pendulum, in the proportion of the cosine of the angle, which it makes with the axis of revolution, to unity.

A rotary pendulum is kept in motion by the train of the clock ending in a horizontal wheel with a vertical axis, from which projects an arm pressing against a spike at the bottom of the pendulum; and it has this disadvantage, that any inequality in the force of the train, arising from variations of friction or any other cause, is immediately transmitted to the pendulum; whereas it will be seen that in several kinds of escapement which can be applied to a vibrating pendulum, the variations of force can be rendered nearly or quite insensible. And it is a mistake to imagine that there is any self-correcting power in a conical pendulum analogous to that of the governor of a steam-engine; for that apparatus, though it is a couple of conical pendulums, has also a communication by a system of levers with the valve which supplies the steam. The governor apparatus has itself been applied to telescope-driving clocks, with a lever ending in a spring which acts by friction on some revolving plate in the clock, increasing the friction, and so diminishing the force as the balls of the governor fly out farther under any increase in the force. And with the addition of some connection with the hand of the observer, by which the action can be farther moderated, the motion can be made sufficiently uniform for that purpose.

It has been proposed to obtain a uniform motion of the clock train from a vibrating pendulum, by means of a crank attached to a wheel revolving in two beats of the pendulum, and connected with it by a rod so long, that it may be considered always nearly horizontal; since it will be found on investigation that the horizontal velocity of any point in a pendulum swinging freely varies in the same ratio as that of the end of a crank revolving uniformly. But this will not do in practice, because any increase in the force of the train would immediately make the pendulum desire to increase its arc and its velocity, and the motion of the crank would be no longer uniform, but be checked at the end of every vibration; and if the force were diminished, the pendulum would not go far enough to carry the crank past the dead points, and the clock would stop.

The most complete contrivance for a continuous motion clock is that invented by M. Wagner of Paris, and shown

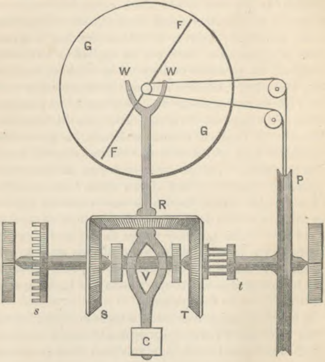

Fig. 2.

in the Exhibition of 1851, but apparently very little known in this country. Though it is rather anticipating a knowledge of some things not yet described, it is convenient to insert the description here in connection with the other telescope-driving machines. In this fig. 2, T is the last wheel in an ordinary clock, and *t* the pinion attached to it, which is driven by the train; and the train is connected with the telescope to be moved in the usual way, which may easily be imagined. In the common course of things, the scape wheel *s* would be on the same arbor as T *t*; but instead of that, it is on another arbor in the same line with that, but independent, and the connection is made by three bevelled wheels T R S. R, the intermediate bevelled wheel (commonly called in machinery an *idle* wheel, because it does not affect the velocity of the wheels it connects), rides loose on a horizontal lever VW, which turns on a pivot at V; so that the end W can move up and down without stopping the action of any of the wheels. At the other end of the lever there is a counterpoise C, which can be adjusted to balance anything hung at the end W, and from that end there hangs by two wires a thing just like a gong G G, only light, and made of tin. So long as the telescope-driving part of the clock goes with a continuous velocity, which just agrees with the average velocity of the intermittent motion of the scape-wheel S, regulated by the vibrating pendulum, the lever and the gong stand still, or scarcely move at all. But if the T wheel begins to go above the average velocity of S S, the lever and the gong will begin to rise; or, if too slow, to fall. Then what happens is this: inside the gong there is a fan-fly FF, turning on a spindle of its own, and driven fast from a large pulley P, fixed on the arbor of T*t*, and when the lever stands at its proper height, or about horizontal, the gong about half covers the fan. If the gong rises it exposes more of the fan to the external air, and so makes it more difficult to turn, and therefore turn slower. If the gong falls, it covers up more of the fan; and then the air inside is more easily whirled round with the fan, and therefore it runs faster, and lets the telescope work recover its velocity. By this means you have the advantage of a clock with a vibrating pendulum, which goes better than a revolving one, at the same time with a continuous motion of the telescope, or of a barrel for recording phenomena of any kind, such as is used at Greenwich, and driven by a much more complicated apparatus to keep the revolving pendulum going steadily.

PENDULUM SUSPENSION.

The suspension of the pendulum on what are called *knife-edges*, like those of a scale-beam, has often been advocated. But though it may do well enough for short experiments, in which the effects of the elasticity of the spring are wanted to be eliminated, it fails altogether in use, even if the knife-edges and the plates which carry them are made of the hardest stones. A suspension on friction wheels, or the small portion of the entire wheel which is required, has also been used, but only in two instances, by the late Mr Vulliamy, under an erroneous impression respecting the nature of the compensation for temperature required, both for the spring and the rod of a pendulum when of great size. This suspension may, no doubt, be made to answer; but as it involves extreme delicacy of adjustment and great expense, and possesses no corresponding advantage over the common method, it will probably never be used again. The suspension, which is now used universally in all but some inferior foreign clocks, which have strings instead, is a thin and short spring, with one end let into the top of the pendulum, and the other screwed between two *chops* of metal with a pin through them, which rests firmly in a nick in the cock which carries the pendulum; and the steadiness of this cock, and its firm fixing to a wall, are essential to the accurate performance of the clock. The thinner the spring the better; provided, of course, it is strong enough to carry the pendulum without being bent beyond its elasticity, or bent short; not that there is much risk of that in practice. Pendulum springs are much oftener too thick than too thin; and it is worth notice that, independently of their greater effect on the natural time of vibration of the pendulum, thick and narrow springs are more liable to break than thin and broad ones of the same strength. It is of great importance that the spring should be of uniform thickness throughout its breadth; and the bottom of the chops which carry it should be exactly horizontal; otherwise the pendulum will swing with a twist, as they may be often seen to do in ill-made clocks. If the bottom of the chops is left sharp, where they clip the spring, it is very likely to break there; and therefore the sharp edges should be taken off.

The bob of the pendulum used, till lately, to be generally made in the shape of a lens, with a view to its passing through the air with the least resistance. But after the importance of making the bob heavy was discovered, it became almost necessary to adopt a form of more solid content in proportion to its surface. A sphere has been occasionally used, but it is not a good shape, because a slight error in the place of the hole for the rod may make a serious difference in the amount of weight on each side, and give the pendulum a tendency to twist in motion. The mercurial jar pendulum suggested the cylindrical form, which is now generally adopted for astronomical clocks; and it has also lately been used in the best turret clocks, with a round top to prevent the effect of any bits of mortar or dirt falling and resting upon it, which would alter the time; it has also been thought to look better than a flat-topped cylinder. There is no rule to be given for the weight of pendulums. It will be shown hereafter, that whatever escapement may be used, the errors due to any variation of force are expressed in fractions which invariably have the weight and the length of the pendulum in the denominator, though some kind of escapements require a heavy pendulum to correct their errors much less than others. And as a heavy pendulum requires very little more force to keep it in motion than a light one, being less affected by the resistance of the air, we may almost say that the heavier and longer a pendulum can be made the better; at any rate, the only limit is one of convenience; for instance, it would obviously be inconvenient to put a large pendulum of 100 lb. weight in the case of an astronomical or common house clock. It may perhaps be laid down as a rule, that no astronomical clock or *regulator* (as they are also called) will go as well as is expected of such clocks with a pendulum of less than 12 lb. weight, and no turret clock with less than 1 cwt. Long pendulums are generally made with heavier bobs than short ones; and such a clock as that for the Houses of Parliament, with a two-seconds pendulum of 6 cwt., ought to go 44 times as well as a small turret clock with a one-second pendulum of 60 lb. Pendulums longer than 14 feet (2 seconds) are inconvenient, liable to be disturbed by wind, and impossible, or at least enormously expensive, to compensate, and they are now quite disused. An old clock with a 56 feet pendulum (4 seconds) was lately removed from Halifax church to be replaced by one with an 8 feet compensated pendulum, and a clock such as we shall have to describe when we come to turret clocks.

PENDULUM REGULATION.

The regulation of pendulums, or their exact adjustment to the proper length, is almost always effected by a nut on the end of the rod, by which the bob can be screwed up or down. In the best clocks the rim of this nut is divided, with an index over it; so the exact quantity of rise or fall, or the exact acceleration or retardation, may be known the amount due to one turn of the nut being previously ascertained. By the calculation used below for compensation of pendulums, it may be seen that if the length of the pendulum rod is l, and the breadth of one thread of the screw is called dl, then one turn of the nut will alter the rate of the clock by $43200 \frac{dl}{l}$ seconds a-day; which would be just 30 seconds, if the pendulum rod is 45 inches long, and the screw has 32 threads in the inch. To accelerate the clock the nut has always to be turned to the right, as it is called, and *vice versâ*. But in astronomical and in large turret clocks, it is desirable to avoid stopping, or in any way disturbing the pendulum; and for the finer adjustments, other methods of regulation are adopted. The best is that of fixing a collar, as shown in fig. 3, capable of having very small weights laid upon it, half-way down the pendulum, this being the place where the addition of any small weight produces the greatest effect; and where, it may be added, any moving of that weight up or down on the rod produces the least effect. An addition there of a weight $= \frac{1}{10,000}$th of the weight of the pendulum, will accelerate it a little more than 1 second a-day, or 10 grains will do that on a pendulum of 15 lb. weight (7000 gr. being = 1 lb.), or an ounce on a pendulum of 6 cwt.; and these small weights can be easily taken off and put on without any risk of disturbing the pendulum. The weights should be made in a series, and marked $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, according to the number of seconds a-day by which they will accelerate; and the pendulum adjusted at first to lose a little, perhaps a second a day, when there are no weights on the collar, so that it may always have some weight on, which can be diminished or increased from time to time with certainty, as the rate may vary.

COMPENSATION OF PENDULUMS.

Soon after pendulums began to be generally used in clocks, it was discovered that they contained within themselves a source of error independent of the action of the clock upon them, and that they lost time in hot weather and gained in cold, in consequence of all the substances of which they could be made expanding as the temperature increases. If l is the length of a pendulum, and dl the small increase of it from increased heat, t the time of the pendulum l, and $t + dt$ that of the pendulum $l + dl$; then $\frac{t+dt}{t} = \frac{\sqrt{l+dl}}{\sqrt{l}} = 1 + \frac{dl}{2}$; since $\left(\frac{dl}{l}\right)^2$ may be neglected as very small; or $dt=\frac{tdl}{2l}$; and the daily loss of the clock will be $43200\frac{dl}{l}$ seconds. The following is a table of the values of $\frac{dl}{l}$ for 10° of heat in different substances:—

White deal	·000024
Flint glass	·000048
Steel rod	·000064
Iron rod	·00007
Brass	·00010
Lead	·00016
Zinc	.00017
Mercury (in bulk, not in length)	·00100

Thus a common pendulum with an iron-wire rod would lose $43200 \times ·00007 = 3$ seconds a-day for 10° of heat; and if adjusted for the winter temperature it would lose about a minute a-week in summer, unless something in the clock happened to produce a counteracting effect, as we shall see may be the case when we come to escapements. We want therefore some contrivance which will always keep that point of the pendulum on which its time depends, viz., the *centre of oscillation*, at the same distance from the point of suspension. A vast number of such contrivances have been made, but there are only three which can be said to be at all in common use: and the old *gridiron pendulum*, made of 9 alternate bars of brass and steel is not one of them, having been superseded by one of zinc and iron, exactly on the same principle, but requiring much fewer bars on account of the greater expansion of zinc than brass. Although this is the most modern of the compensated pendulums, in consequence of the working of zinc being a modern art, we will describe it first. And as the centre of oscillation so nearly coincides in all clock pendulums with the centre of the *bob*, we may practically say that the object of compensation is to keep the bob always at the same height. Fig. 3 is a section of the great Westminster clock pendulum above mentioned. The iron rod which runs from top to bottom, ends in a screw, with a nut N, for adjusting the length of the pendulum after it was made by calculation as near the right length as possible. On this nut rests a collar M, which can slide up the rod a little way, but is prevented from turning by a pin through the rod. On a groove or annular channel in the top of this collar stands a zinc tube 10 feet 6 inches long, and nearly half-an-inch thick, made of three tubes all drawn together, so as to become like one:—for it should be observed that *cast* zinc cannot be depended on; it must be drawn. On the top of this tube or hollow column fits another collar with an annular groove much like the bottom one M. The object of these grooves is to keep the zinc column in its place, not touching the rod within it, as contact might produce friction, which would interfere with their relative motion under expansion and contraction. Round the collar C is screwed a large iron tube, also not touching the zinc, and its lower end fits loosely on the collar M; and round its outside it has another collar D of its own fixed to it, on which the bob rests. The iron tube has a number of large holes in it down each side, to let the air get to the zinc tube: before that was done, it was found that the compensation lagged a day or two behind the changes of temperature, in consequence of the iron rod and tube being exposed, while the zinc tube was inclosed

Fig. 3.

without touching the iron. The bottom of the bob is 14 feet 11 inches from the top of the spring A, and the bob itself is 18 inches high, with a dome-shaped top, and 12 inches in diameter. As it is a 2-seconds pendulum, its centre of oscillation is 13 feet from the top A, which is very near the centre of gravity of the pendulum, and higher than usual above the centre of gravity of the bob, on account of the great weight of the compensation tubes. The whole weighs 682 lb., which is half as large again as Mr Vulliamy's Post-Office clock pendulum, which was before the heaviest probably in the world, but not compensated. The same proportions will hold for zinc compensation pendulums of smaller size; the zinc tube and the iron tube being always nearly two-thirds of the length of the main rod. The distance from the top of the spring to the bottom of a 7½-inch bob, 2 inches thick, is 43 inches, and the zinc tube 30 inches long. The compensation action is evidently this: the iron rod and tube both let the bob down as they expand, and the zinc column pushes it up; and as the ratio of the expansion of iron to zinc is ·41, it will be found that if the rod and tubes are in the above proportions, the centre of oscillation will remain at the same height; and experience has ratified the calculation; the Westminster clock having been now going for several years in Mr Dent's factory, besides many others of the same kind.

The second kind of compensation pendulum in use is still more simple, but not so effective or certain in its action; and that is merely a wooden rod with a long lead bob resting on a nut at the bottom. According to the above table, it would appear that this bob ought to be 14 inches high in a 1-second pendulum; but the expansion of wood is so uncertain, that this proportion is not found capable of being depended on, and a somewhat shorter bob is said to be generally more correct in point of compensation. And we believe that all persons who have tried wooden pendulums severely, have come to the same conclusion as Mr Reid did long ago,—that they are capricious in their action, and consequently unfit for the highest class of clocks.

The best of all the compensations is undoubtedly the mercurial, which was invented by George Graham, a London clockmaker, above a century ago, who also invented the well-known dead escapement for clocks, and the horizontal or cylinder escapement for watches, which will be hereafter explained. And the best form of the mercurial pendulum is that which was introduced by the late Mr Dent, in which the mercury is inclosed in a cast-iron jar or cylinder, into the top of which the steel rod is screwed, with its end plunged into the mercury itself. For by this means the mercury, the rod, and the jar, all acquire the new temperature at any change, more nearly together, than when the mercury is in a glass jar hung by a *stirrup* (as it is called) at the bottom of the rod; and, moreover, the pendulum is safe to carry about, and the jar can be made perfectly cylindrical by turning, and also air-tight, so as to protect the mercury from oxidation; and, if necessary, it can be heated in the jar so as to drive off any moisture, without the risk of breaking. The height of mercury required in a cast-iron jar, 2 inches in diameter, is about 6·8 inches; for it must be remembered, in calculating the rise of the mercury, that the jar itself expands laterally, and that expansion has to be deducted from that of the mercury in bulk.

Several other kinds of compensation have been described in the *Rudimentary Treatise on Clocks*, and other books. But as the mercurial is indisputably the best, though expensive, and the zinc and iron pendulum is both better and cheaper than any of those others, we shall not fill our pages by describing them. We will only add this caution to persons who may be captivated with the apparent simplicity of that class of compensations in which the pendulum spring is drawn up through a slit, so as to shorten it as the length of the pendulum increases, that that method is not to be relied on in any of its forms. All the compensations also on the lever principle, invented by Mr Ellicott many years ago, are equally fallacious and uncertain; though this, as well as the spring-shortening methods, do not seem to have been yet abandoned by the French clockmakers—at least they had not at the time of the Great Exhibition in 1851.

We alluded a short time ago to the effect of the spring upon the time of vibration. However thin it may be, it has some tendency to make the pendulum move more quickly than if it were suspended on knife edges; and as all springs are stiffer the colder they are, the spring accelerates the pendulum in cold weather a little more than in hot, though to a far less extent than the variation in the length of the pendulum itself. It is impossible to give any rule for the extra compensation thus required, except such as might be deduced from a large and careful series of experiments on pendulums and springs of various sizes. The late Mr Dent stated, in a paper read before the British Association in 1840, that he had found such a spring as is generally used in astronomical-clock pendulums to require about one-seventh to be added to the ordinary compensation for the rod. This effect is, of course, much greater on a short pendulum than a long one; indeed, on a 2-seconds pendulum it seems not perceptible at all when the spring is of no more than the proper thickness: that of the Westminster clock is only $\frac{1}{60}$th inch thick.

ESCAPEMENTS.

The escapement is that part of the clock in which the rotary motion of the wheels is converted into the vibratory motion of the balance or pendulum, which by some contrivance or other is made to let one tooth of the quickest wheel in the train escape at each vibration; and hence that wheel is called the "scape-wheel." Fig. 4 shows the form of the earliest clock escapement, if it is held sideways, so that the arms on which the two balls are set may vibrate on a horizontal plane. In that case the arms and weights form a balance, and the farther out the weights are set, the slower would be the vibrations. If we now turn it as it stands here, and consider the upper weight left out, it becomes the earliest form of the pendulum clock, with the *crown-wheel* or *vertical* escapement. CA and CB are two flat pieces of steel, called *pallets*, projecting from the axis about at right angles to each other, one of them over the front of the wheel as it stands, and the other over the back. The tooth D is just escaping from the front pallet CA, and at the same time the tooth at the back of the wheel falls on the other pallet CB, a little above its edge. But the pendulum, which is now moving to the right, does not stop immediately, but swings a little further (otherwise the least failure in the force of the train would stop the clock, as the escape would not take place), and in so doing it is evident that the pallet B will drive the wheel back a little, and produce what is called the ***recoil;*** which is visible enough in any common clock with a seconds-hand, either with this escapement or the one which will be next described.

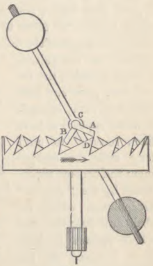

Fig. 4.

It will be seen, on looking at the figure, that the pallet B must turn through a considerable angle before the tooth can escape; in other words, the crown-wheel escapement requires a long vibration of the pendulum. This is objectionable on several accounts; first, because it requires a great force in the clock train, and a great pressure, and therefore friction, on the pallets; and besides that, any variation in a large arc, as was explained before, produces a much greater variation of time due to the circular error than an equal variation of a small arc. The crown-wheel escapement may indeed be made so as to allow a more moderate arc of the pendulum, though not so small as the 2° usually adapted now in the best clocks, by putting the pallet arbor a good deal higher above the scape-wheel, and giving a small number of teeth to the wheel; and that also diminishes the length of the run of the teeth, and consequently the friction, on the pallets, though it makes the recoil very great and sudden; but, oddly enough, it never appears to have been resorted to until long after the escapement had become superseded by the "anchor" escapement, which we shall now describe, and which appears to have been invented by the celebrated Dr Hooke as early as the year 1656, very soon after the invention of pendulums.

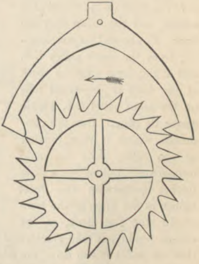
Fig. 5.

In fig. 5, a tooth of the scape-wheel is just escaping from the left pallet, and another tooth at the same time falls upon the right hand pallet at some distance from its point. As the pendulum moves on in the same direction, the tooth slides farther up the pallet, thus producing a recoil, as in the crown-wheel escapement. The acting faces of the pallets should be convex, and not flat, as they are generally made, much less concave, as they have sometimes been made, with a view of checking the motion of the pendulum, which is more likely to injure the rate of the clock than to improve it. But when they are flat, and of course still more when they are concave, the points of the teeth always wear a hole in the pallets at the extremity of their usual swing, and the motion is obviously easier, and therefore better, when the pallets are made convex; in fact they then approach more nearly to the "dead" escapement, which will be described presently. We have already alluded to the effect of some escapements in not only counteracting the circular error, or the natural increase of the time of a pendulum as the arc increases, but overbalancing it by an error of the contrary kind. The recoil escapement does so; for it is almost invariably found that whatever may be the shape of the pallets, the clock loses as the arc of the pendulum falls off, and *vice versâ*. It is, however, unfortunately impossible so to arrange the pallets that the circular error may be thus exactly neutralized, because the escapement error depends, in a manner reducible to no law, upon variations in friction of the pallets themselves, and of the clock train, which produce different effects; and the result is, that it has long been recognised as impossible to obtain very accurate timekeeping from any clock of this construction.

But before we pass on to the dead escapement, it may be proper to notice an escapement of the recoiling class, which was invented for the purpose of doing without oil, by the famous Harrison, who was at first a carpenter in Lincolnshire, but afterwards obtained the first government reward for the improvement of chronometers. We shall not however stop to describe it, since it never came into general use, and it is said that nobody but Harrison himself could make it go at all. It was also objectionable on account of its being directly affected by all variations in the force of the clock. It had the peculiarity of being very nearly silent, though the recoil was very great. Those who are curious about such things will find it described in the 7th edition of the Encylopædia Britannica. The recorded performance of one of these clocks, which is given in some accounts of it, is evidently fabulous.

DEAD ESCAPEMENTS.

The escapement which has now for a century and a half been considered the best practical clock escapement (though there have been constant attempts to invent one free from the defects which it must be admitted to possess), is the *dead escapement*, or, as the French call it with equal expressiveness, *l'echappement à repos;* because instead of the recoil of the tooth upon the pallet, which took place in the previous escapements, it falls dead upon the pallet, and reposes there until the pendulum returns and lets it off again. It is represented in fig. 6. It will be observed that the teeth of the scape-wheel have their points set the opposite way to those of the recoil escapement in fig. 4, the wheels themselves both turning the same way; or (as our engraver has represented it), *vice versâ*. The tooth B is here also represented in the act of dropping on to the right hand pallet as the tooth A escapes from the left pallet. But instead of the pallet having a continuous face as in the recoil escapement, it is divided into two, of which

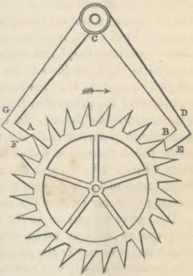

Fig. 6.

BE on the right pallet, and FA on the left, are called the impulse faces, and BD, FG, the dead faces. The dead faces are portions of circles (generally of the same circle), having the axis of the pallets C for their centre; and the consequence evidently is, that as the pendulum goes on, carrying the pallet still nearer to the wheel than the position in which a tooth falls on to the corner A or B of the impulse and the dead faces, the tooth still rests on the dead faces without any recoil, until the pendulum returns and lets the tooth slide down the impulse face, giving the impulse to the pendulum as it goes.

The great merit of this escapement is, that a moderate variation in the force of the clock train produces a very slight effect in the time of the pendulum. This may be shown in a general way, without resorting to mathematics, thus:—Since the tooth B drops on to the corner of the pallet (or ought to do so) immediately after the tooth A has escaped, and since the impulse will begin at B when the pendulum returns to the same point at which the impulse ceased on A, it follows that the impulse received by the pendulum before and after its vertical position is very nearly the same. Now that part of the impulse which takes place before zero, or while the pendulum is descending, tends to augment the natural force of gravity on the pendulum or to make it move faster; but in the ascending arc the impulse on the pallets acts against the gravity of the pendulum, and prevents it from being stopped so soon; and so the two parts of the impulse tend to neutralize each other's disturbing effects on the time of the pendulum, though they both concur in increasing the arc, or (what is the same thing) maintaining it against the loss from friction and resistance of the air. However, on the whole, the effect of the impulse is to retard the pendulum a little, because the tooth must fall, not exactly on the corner of the pallet, but (for safety) a little above it; and the next impulse does not begin until that same corner of the pallet has come as far as the point of the tooth; in other words, the retarding part of the impulse, or that which takes place after zero, acts rather longer than the accelerating part before zero. Again, the friction on the dead part of the pallets tends to produce the same effect on the time; the arc of course it tends to diminish. For, in the descent of the pendulum the friction acts against gravity, but in the ascent with gravity, and so shortens the time; and there is rather less action on the dead part of the pallets in the ascent than in the descent. For these reasons the time of vibration of a pendulum driven by a dead escapement is a little greater than of the same pendulum vibrating the same arc freely; and when you come to the next difference, the variation of time of the same pendulum with the dead escapement, under a moderate variation in the force, is very small indeed; which is not the case in the recoil escapement, for there the impulse begins at each end of the arc, and there is much more of it during the descent of the pendulum than during the ascent from zero to the arc at which the escape takes place and the recoil begins on the opposite tooth; and then the recoil itself is an action on the pendulum in its ascent in the same direction as gravity, and shortens the time. And hence it is that an increase of the arc of the pendulum with a recoil escapement is always accompanied with a decrease of the time.

But something more than this general mode of reasoning is requisite in order to compare the real value of the dead escapement with others of equal or higher pretensions, or of the several contrivances that have been suggested for remedying its defects. In the year 1827, Mr Airy wrote a paper in the *Cambridge Philosophical Transactions*, vol. iii., p. 105, on the disturbances of pendulums and the theory of escapements, which, though erroneous in some of the practical conclusions, is extremely valuable as the mathematical foundation for subsequent investigations; it is too long to insert here, and the mathematical part of it may be found in Pratt's *Mechanics*. We shall therefore take it up at the point which is convenient for making the proper deductions from it. He proved that if ϕ is the disturbing force on the pendulum of length l at the angle θ from zero, a the extreme arc, and g the accelerating force of gravity, the increase of time of one vibration due to the disturbance $=\frac{l}{\pi g \alpha^2}\int\frac{\phi\theta\, d\theta}{\sqrt{\alpha^2-\theta^2}}$, taken between the limits within which the disturbing force acts. He also gives an expression for the increase of the arc; but though of course mathematically correct, it is practically useless, because the increase of the arc for one vibration is no guide at all to what it will reach before the influence of friction and the resistance of the air prevents any further increase.

Proceeding with Mr Airy's formula for the variation of the time, and adopting the farther results obtained by Mr Denison in his paper of 1848, in the eighth volume of the *Cambridge Transactions*, let us call the angle which the impulse faces of the pallets make with the dead faces δ; then, since the tooth, considered as a prolonged radius of the wheel, ought to be a tangent to the dead face, δ will also be the inclination of the tooth to the impulse face at the beginning of the impulse, and it may be assumed to remain the same throughout: though in fact it increases towards the end of the impulse. Let p be the distance of each pallet from their arbor, and Pg the moving force of the clock-weight referred to the points of the scape-wheel, after deducting the force required to move the train, M the mass of the pendulum (supposed to be a simple one) and l its length, and θ the angle which the pendulum makes with the vertical; then the equation of motion of the pendulum is—

$$\frac{d^2\theta}{dt^2}=-\frac{g}{l}\left(\theta+\frac{Pp\tan\delta}{Ml}\right);$$

and therefore ϕ, the disturbing force, is $\frac{g\,Pp\tan\delta}{Ml^2}$;

and the increase of time for one vibration, which we may call—

$$\Delta = \frac{Pp \tan \delta}{Ml\pi a^2}\int\frac{\theta \, dt}{\sqrt{a^2-\theta^2}}.$$

If β is the angle before zero at which the impulse begins, and γ the angle after zero at which it ends, and which is necessarily rather larger than β, then this integral has to be taken between the limits $\theta = -\beta$, and $\theta = \gamma$, and the result is—

$$\Delta = \frac{Pp \tan \delta}{Ml\pi a^2}(\sqrt{a^2-\beta^2} - \sqrt{a^2-\gamma^2}).$$

And as β and γ are always small compared with a, higher powers than $\frac{\gamma^2}{a^2}$ may be neglected, and the equation may assume the simpler form $\Delta = \frac{Pp \tan \delta}{2\, Ml\pi a^3}(\gamma + \beta)(\gamma - \beta)$.

Since β may be made very nearly $= \gamma$ in a well-made clock—*i. e.*, the tooth may be made to drop almost exactly on the corner of the dead face, Mr Airy concludes that "this escapement approaches nearly to absolute perfection." Mr Denison shows, however, that this conclusion is somewhat too rapid; that the accuracy which really is found in the going of a good clock of this kind is due to a cause not apparent in this value of Δ; and that an escapement of another kind, in which Δ is much larger, admits of still greater perfection, inasmuch as it is not the magnitude but the variation of Δ which measures the goodness of the clock. And besides all this, the assumption that the friction of the pallets does not affect the performance of a dead escapement clock is very far from correct; on the contrary, it has generally more to do with the actual errors of time than all the other causes. In order to arrive at the actual amount of these errors, we will proceed with the examination of the quantity Δ.

Let h be the daily fall of the clock-weight Wg, T the number of beats of the pendulum in the day (= 86400 if it is a seconds pendulum); the drop of the tooth at each beat is a little less than the thickness of the pallets, which $= p\,(\gamma+\beta)$ tan δ; and therefore we may say (intending to make some deduction afterwards from the actual amount of W for the friction of the train and the loss of force at each drop)—

$$\Delta \mathrm{T} = \frac{Wh(\gamma-\beta)}{Ml2\pi a^3}$$

in which you observe that $\gamma+\beta$ has disappeared: $\gamma-\beta$ can hardly be less than $30'$; and therefore we may put $\frac{1}{720}$ for $\frac{\gamma-\beta}{2\pi}$, and that reduces the equation to the simple form—

$$\Delta \mathrm{T} = \frac{Wh}{720\ Mla^3}.$$

Now, though the clock-weight and its daily fall are constant in any given clock, yet the quantity of this moving force which arrives at the escapement is not constant, because it is diminished by friction, which varies with the state of the oil and other circumstances; and that produces the same effect as if the clock-weight itself varied. Let us call that variation of force on the escapement dW. The clock is also subject to variations of a, the arc of the pendulum, partly depending on these changes in the force of the clock train, but still more upon the variations in the friction on the pallets themselves, so that no definite relation can be established between any increase of arc da, and the variations of force or friction in the train. And in order to learn what effect is produced upon the rate of the clock by any given *small* changes in the arc or the force, we must differentiate the above equation, and we shall have (treating, as we shall throughout, the differences as finite)—

$$d\Delta \mathrm{T} = \frac{Wh}{720\ Mla^3}\left(\frac{dW}{W} - \frac{3da}{a}\right).$$

And to this must be added a third term to express the circular error due to the increase of the arc from a to $a+da$. This, as stated before, is theoretically $+\ 10800\ a da$; but practically it is a great deal less, from the effect of the pendulum-spring, which has a tendency to isochronize the pendulum, though all attempts to make it do so completely have failed, and no other figures can be given for estimating the actual amount of the circular error. The quantity we have called $d\Delta T$ is that which is technically called the *daily rate*, only with the sign reversed, as the rate is always called + when the clock is gaining, and assuming the pendulum to be properly adjusted so that the daily rate, but for the escapement error, would be 0.

Now, as to the numerical value of this quantity in seconds, or fractions of a second: in an ordinary astronomical clock, after allowing for the friction of the train, Wh may be taken as 2 lb. × 9 in.; l is 39 inches, and M about 15 lb., and a the angle 2° is ·035 in numerical value. Therefore $\frac{Wh}{720\,Mla^3} = 1$ second very nearly. As to the other parts of the expression for $d\Delta T$, it generally happens that the clock gains if the arc falls off, which shows that the two + terms, $\frac{dW}{W}$ and the circular error term, then preponderate over the one which involves $\frac{da}{a}$. Sometimes, however, the contrary is the case, as where the friction on the pallets alone is altered by oiling them, or by the self-polishing which they often perform for themselves in the course of a few months after the clock is made, especially in turret clocks. Mr Denison says, in his Cambridge paper of 1853 (vol. ix.), that from experiments made for testing the value of an invention of Mr Loseby's, in the Great Exhibition, for rendering pendulums isochronous, as well as from observations made before, it is clear that not only can no isochronizing of the pendulum for different arcs counteract the errors of the dead escapement, but that when the variation of time is due to the change of pallet friction, it would be still worse with an isochronous pendulum, because the circular error (as the above equation shows) tends to counteract the other error which is due to the change of arc, da.

Mr Airy showed, in his before-mentioned paper, that the friction on the dead faces of the pallets, if it acted through exactly instead of nearly the same arc before and after zero, would produce no direct effect upon the time. But it is a great mistake to infer that this friction does not materially affect the clock nevertheless. The fallacy of such an inference is shown at once by the above expressions for the escapement errors; for the effect of all the friction on the pallets is to reduce the arc, or to require a larger force to produce the same arc. And as the cube of the arc appears in the denominator, and a large increase of force is required to produce a small increase of arc, it is obvious that the friction on the pallets indirectly and largely increases all the errors of the escapement, although it may produce very little direct effect upon the time, as compared with that of a free pendulum vibrating the same arc. In order to diminish the friction and the necessity for using oil as far as possible, the best clocks are made with jewels (sapphires are the best for the purpose) let into the pallets. Mr Dent used them in the large clock at the Royal Exchange, probably the first time they had ever been used in a turret clock, though softer and cheaper stones had been occasionally used.

The pallets are generally made to embrace about one-third of the circumference of the wheel, and it is not at all desirable that they should embrace more; for the longer they are, the longer is the run of the teeth upon them, and the greater the friction. In the Great Exhibition Messrs Wagner of Paris had an apparatus for practically illustrating this, which however is obvious enough without any illustration. There is a good deal of difference in the practice of clockmakers as to the length of the impulse, or the amount of the angle $\gamma+\beta$. Sometimes you see clocks in which the seconds hand moves very slowly and rests a very short time, showing that $\gamma+\beta$ is large in proportion to $2a$; and in others the contrary. The transit clock at Greenwich was altered by the late Mr Dent to a short impulse, the escape taking place at only 30′ after zero; and he was decidedly of opinion that a short impulse was the best, probably because there is less of the force of the impulse wasted in friction then. It is not to be forgotten, as Mr Bloxam remarks in his paper on escapements in the *Transactions of the Astronomical Society* for 1853, that the scape-wheel tooth does not overtake the face of the pallet immediately, on account of the moment of inertia of the wheel. The wheels of astronomical clocks, indeed of all English house-clocks, are generally made too heavy, especially the scape-wheel, which, by increasing the moment of inertia, requires a larger force, and consequently has more friction. We shall show presently, from another escapement, how much of the force is really wasted in friction in the dead escapement.

But before proceeding to other escapements, it is proper to notice a very useful form of the dead escapement, which is adopted in many of the best turret clocks, called the *pin-wheel escapement*, the invention of which is commonly ascribed to Lepaute of Paris about the middle of the last century, though it appears to have been used as early by Whitehurst of Derby. Fig. 7 will sufficiently explain its action and construction. Its advantages are:—that it does not require so much accuracy as the other; if a pin gets broken, it is easily replaced, whereas in the other the wheel is

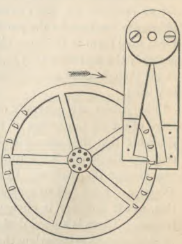

Fig. 7.

ruined if the point of a tooth is injured; a wheel of given size will work with many more pins than teeth, and therefore a train of less velocity will do, and that sometimes amounts to a saving of one wheel in the train, and a good deal of friction; and the blow on both pallets being downwards, instead of one up and the other down, the action is more steady; all of which things are of more consequence in the heavy and rough work of a turret clock than in an astronomical one. The pins are generally semicylinders, as the upper half of the cylinder would obviously be of no use, and would waste nearly half the force in drop without action. But when the wheel is small, and the pallets short, as they ought to be for the reason before given, it is impossible to get a short angle of escape with semicylindrical pins unless they are very small, and therefore Mr Denison suggested the form on the left side of fig. 7, which Mr Dent used in his Great Exhibition clock, and subsequently in others. The pins are bits of brass wire driven into the wheel, about ten for every inch of diameter, and then the upper, or non-acting half, and a small slice of the bottom, cut off in a cutting engine. The distance of the lowest pallet from their axis should not be more than the diameter of the wheel. The cross section of pallets as now generally made is convex, and not flat, which involves greater accuracy, and therefore greater risk of inaccuracy. It has also been found expedient to make the dead faces not quite dead, but with a very slight recoil, which rather tends to check the variations of the arc, and also the general disposition to lose time if the arc is increased; when so made the escapement is generally called "half-dead."

Passing by the various other modifications of the dead escapement which have been suggested and tried with little or no success, we proceed to describe one of an entirely different form, which was patented in 1851 by Mr C. Macdowall of Hyde Street, Bloomsbury, though it appeared afterwards that one very similar had been tried before, but failed from the proportions being badly arranged. It is represented in fig. 8. The scape-wheel is only a small disc with a single pin in it, made of ruby, parallel, and very near to the arbor. The disc turns half round at every beat of the pendulum, and the pin gives the impulse on the vertical faces of the pallets, and the dead friction takes place on the horizontal faces. Its advantages are, that the greatest part of the impulse is given directly across the line of centres, and consequently with very little friction; and therefore also, the friction on the dead faces is less than usual, and scarcely any oil is required; moreover, it is very easy to make. But there must be two more wheels in the train, consuming a good deal of the force of the clock-weight by their friction, which rather more than makes up for the friction saved in the escapement. It has however been applied successfully to watches, and they appear to be affected by cold less than the common lever watch with its oblique impulse, exactly like that of the common dead escapement. A prize medal was awarded for it in the Exhibition. In order to make the angle of escape not more than 1°, the distance of the pin from the centre of the disc must not be more than $\frac{1}{60}$th of the distance of centres of the disc and pallets.

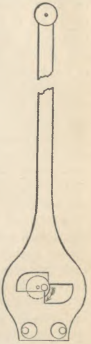

Fig. 8.

With the view of getting rid of one of these extra wheels in the train, and that part of the impulse which is least effective and most oblique, Mr Denison shortly afterwards invented what he called the *three-legged dead escapement;* which, though he afterwards superseded it by his *three-legged gravity escapement,* is still worth notice on account of the exceedingly small force which it requires, thereby giving a practical proof of the large proportion of the force which is wasted in friction in all the other impulse escapements.

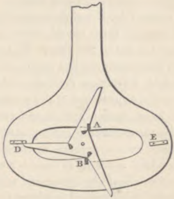

Fig. 9.

In fig. 9, the three long teeth of the scape-wheel are only used for locking on the dead pallets DE, which are set on the front of the pallet plate; AB are the impulse pallets, being hard bits of steel or jewels set in the pallet plate, and they are acted upon by the three sharp-edged pins which are set in the scape-wheel and point backwards. As soon as the pendulum moves a little further to the left than is here shown, the long tooth will slip past the dead pallet or stop D, and the pin at B will run after and catch the corner of that impulse pallet and drive it until the wheel has turned through 60°, and then it will escape ; and by that time the uppermost tooth will arrive at the stop E, and will slide along it as in the common dead escapement, but with a pressure as much less than that which gives the impulse as the points of the teeth are farther from the centre of the wheel than the impulse pins are. But the impulse is here given with so little friction, that even where the points of the teeth were made identical with the pins, the clock-weight required to keep the same pendulum with the same train (a common turret-clock movement), swinging the usual arc of 2°, was only *one-fifth* of what had been required with the common pin-wheel escapement, and the scape-wheel which kept the 6 cwt. pendulum of the Westminster clock going for half a-year, until superseded by the gravity escapement, weighed only ⅙th of an ounce. It appears also that it would be possible so to adjust the recoil of the half-dead pallets that the time would not be affected by any small variation of the force and the arc; since it was found that, when a certain amount of recoil was given, the clock gained instead of losing, under an increase of arc due to an increase of clock-weight. And if the force were kept constant by a train-remontoire, such as will be described hereafter, there would in fact be nothing capable of altering the arc or the time. But on account of the small depth of intersection of the circles of the pins and the pallets, on which its action depends, this escapement requires very careful adjustment of the pallets, except where they are on a large scale; and considering the superior qualities of the corresponding gravity escapement, it is not likely to be used, except perhaps in clocks required to go a long time, in which economy of force is a matter of consequence. The pallets should be connected with the pendulum by a spring fork (which indeed is advisable in the other dead escapements with a heavy pendulum, especially the pin-wheel escapement), to prevent the risk of their driving backwards against the scape-wheel when it is not in motion, as it will not clear itself. The distance of the centres should be not less than 25 times the radius of the circle of the edges of the impulse pins.

REMONTOIRE, OR GRAVITY ESCAPEMENTS.

A remontoire escapement is one in which the pendulum does not receive its impulse from the scape-wheel, but from some small weight or spring which is lifted or wound up by the scape-wheel at every beat, and the pendulum has nothing to do with the scape-wheel except unlocking it. When this impulse is received from a weight the escapement is also called a *gravity escapement;* and, inasmuch as all the remontoire clock escapements that are worth notice have been gravity escapements, we may use that term for them at once. The importance of getting the impulse given to the pendulum in this way was recognised long before all the properties of the dead escapement, as above investigated, were known. For it was soon discovered that, however superior to the old recoil escapement, it was far from perfect, and that its success depended on reducing the friction of the train and the pallets as far as possible, which involves the necessity of high-numbered pinions and wheels, small pivots, jewelled pallets, and a generally expensive style of workmanship. Accordingly the invention of an escapement which will give a constant impulse to the pendulum, and nearly free from friction, has been for the last century the great problem of clock-making. We can do no more than shortly notice a very few of the attempts which have been made to solve it. The most simple form of gravity escapement, and the one which will serve the best for investigating their mathematical properties (though it fails in some essential mechanical conditions), is that invented by Mudge. The tooth A of the scape-wheel in fig. 10 is resting against the stop or detent *a* at the end of the pallet CA, from the axis or arbor of which descends the half fork CP to touch the pendulum. From the other pallet CB descends the other half fork CO. The two arbors are set as near the point of suspension, or top of the pendulum spring, as possible. The pendulum, as here represented,

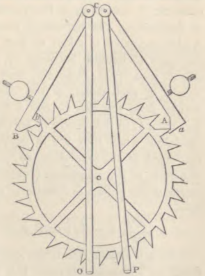

Fig. 10.

must be moving to the right and just leaving contact with the left pallet and going to take up the right one; as soon as it has raised that pallet a little it will evidently unlock the wheel and let it turn, and then the tooth B will raise the left pallet until it is caught by the stop *b* on that pallet, and then it will stay until the pendulum returns and releases it by raising that pallet still higher. Each pallet therefore descends with the pendulum to a lower point than that where it is taken up, and the difference between them is supplied by the lifting of each pallet by the clock, which does not act on the pendulum at all; so that the pendulum is independent of all variations of force and friction in the train.

If the angle of the pendulum after zero, at which it takes up the pallet, is called γ, and that at which it leaves the other $\pm \beta$, according as the pendulum is then ascending or descending, the impulse is received through $\gamma \pm \beta$. And if one pallet is taken up just when the other is left, the angle of impulse becomes 2γ, equally divided on each side of zero. Let P be the mass, and therefore Pg the weight, of each pallet, p the distance of its centre of gravity from the axis C, and δ the angle with a straight line from C to that centre of gravity would make with the pendulum when they are in contact; M the mass, and l the length of the pendulum, as before; then the equation of motion of the pendulum (omitting the small moment of inertia of the pallets as immaterial to this investigation) will be—

$$\frac{d^2\theta}{dt^2} = -\frac{g}{l}\left\{\sin\theta + \frac{Pp\ \sin(\delta+\theta)}{Ml}\right\}$$

This will expand into terms containing $\sin\theta$, for which θ may be substituted because it is very small, and one involving $\cos\theta$, which for the same reason may be treated as $= 1$; those containing θ only produce a permanent alteration of the time, just as if l was altered; the other is the term to which the escapement errors are due. Mr Denison shows, by following up Mr Airy's calculations, that from this equation may be deduced the result, that the daily increase of time over that of the same pendulum swinging freely, due to this cause, may be thus expressed:—

$$\Delta T = -\frac{Wh(\sqrt{\alpha^2-\gamma^2}+\sqrt{\alpha^2-\beta^2})}{Ml\pi\alpha^2(\gamma+\beta)}$$

Wh being the clock-weight × its daily fall, after allowing for all the friction involved in moving the train and lifting the pallets. If the descending pallet is left by the pendulum before zero, we must remember that $\gamma+\beta$ becomes $\gamma-\beta$, and consequently ΔT much larger than where the impulse is given through the middle of the arc. If one pallet is taken up by the pendulum just as it leaves the other (which is the best form of the escapement), then $\beta=\gamma$, and the expression assumes the more simple form—

$$\Delta T = -\frac{Wh}{Ml\pi\alpha^2}\sqrt{\frac{\alpha^2}{\gamma^2}-1}.$$

The $-$ sign indicates that the rate of a pendulum with this escapement is faster than without it, and the difference is a good deal more than the difference the other way in the case of a dead escapement. Hence, too, it follows, that if you reduce the arc in a gravity escapement by lightening the pallets, the clock will not gain but lose, because lightening the pallets is lowering the centre of gravity of the compound pendulum, which is formed by the pendulum and pallets together. But it does not follow that a gravity escapement must therefore be inferior to a dead one; for the going of the clock depends not on the magnitude, but on the variation of this quantity ΔT; and where a gravity escapement is free from the usual mechanical defects, which will be noticed presently, the variation of rate can only arise from some slight change in the arc, owing to a change in the density of the air, or in the very small friction of the pallets on their pivots or on the stops. We must therefore differentiate ΔT with regard to α, and then we shall have—

$$d\Delta \mathrm{T} = \frac{Wh}{Ml\pi a^2} \frac{\frac{a^2}{\gamma^2} - 2}{\sqrt{\frac{a^2}{\gamma^2} - 1}} \frac{da}{a}$$

And it is evident that if γ is made $= \frac{a}{\sqrt{2}} = \cdot 71a$, this quantity vanishes altogether; that is to say, the variation of the difference of time between a gravity escapement pendulum and a free pendulum of the same length, may be made *nothing* by making the difference itself a *maximum;* for it happens to be a maximum, and not a minimum, though the result would of course be the same in that case, by virtue of the well-known property of maxima and minima. It is not necessary to adhere strictly to this proportion of a and γ. Mr Denison found that, after allowing for the friction of the train, the quantity $\frac{Wh}{Ml}$ cannot be more than $\frac{1}{180}$ in the great Westminster clock; and Mr Bloxam found it only a little more in an astronomical clock, as it ought to be, because a light pendulum loses more of its vibration by the resistance of the air than a heavy one; and it will be seen, by applying this value to the above expression for the rate, that the variation will be quite inconsiderable for any such change of arc as is likely to occur in a gravity escapement, even if γ be made as small as $\frac{a}{2}$.

In those escapements where the pendulum leaves one pallet before it takes up the other, the expression for the variation of the rate is—

$$d\Delta \mathrm{T} = \frac{Wh\, da}{Ml\pi a^3 (\gamma + \beta)} \left\{ \frac{a^2 - 2\gamma^2}{\sqrt{a^2 - \gamma^2}} + \frac{a^2 - 2\beta^2}{\sqrt{a^2 - \beta^2}} \right\}$$

remembering that if the descending pallet is left before zero, $\gamma + \beta$ becomes $\gamma - \beta$; from which it is evident that that kind of escapement is very inferior to the other, although the pendulum being left free in the middle of its swing has a tempting appearance. Indeed this result may be easily arrived at without mathematics, because the angle through which the impulse is given (the difference between the drop and the lift of each pallet), is necessarily smaller when one is dropped before zero; and consequently any given variation of the arc of vibration bears a large proportion to the arc of impulse, and also to the whole arc through which the pallets act on the pendulum at all. This expression however may be reduced to o like the former one, by making α, β, and γ satisfy a certain condition, viz.:—

$$\sqrt{\alpha^2-\gamma^2}\ \sqrt{\alpha^2-\beta^2}=\frac{\alpha^2}{2}$$

Thus if $\gamma = 90'$ instead of $85'$, $\pm\,\beta$ should $= 78'$, α being taken at 2° as usual; but for the reason just now given, any deviation from these proportions will produce much larger errors where the descending pallet is left before zero than where it is left just when the other is taken up.

Mr Bloxam notices the changes of density of the air as sensibly affecting the arc and the rate in a gravity escapement; probably they affect a dead escapement less, because there the friction on the pallets greatly preponderates over every other cause of disturbance. He says (p. 133, note), that though "it has been repeatedly *proved* in works on dynamics that the resistance of the air does not alter the time of vibration, this is only true on the supposition that the resistance is the same in the ascent and the descent;" whereas the current produced by the increasing velocity in the descent prevents the ascent from being retarded as it would be if the air were at rest; and he has no doubt that any increased density of the air makes the pendulum go slower; as indeed it must from this cause also, that it practically diminishes the specific gravity of the pendulum; and therefore a rise of the barometer tends to make the clock gain, some persons have thought, as much as $\frac{1}{6}$th or $\frac{1}{4}$th of a second a-day for one inch. But there does not seem yet to exist any sufficient collection of experiments to allow a definite conclusion to be arrived at as to the magnitude of this disturbance. No doubt the resistance of the air tends to diminish considerably the effect of the circular error, which Mr Bloxam and others have found to be always much less than its theoretical value, even judging from the dead escapement with its large amount of friction.

Besides the above mathematical condition, there are several mechanical ones which are still more essential to the success of a gravity escapement. The first is, that it must be safe from what is called *tripping*. Referring again to fig. 10, it will be seen at once that if the scape-wheel should happen to move too fast when it is released, the left pallet will not be raised gradually by the tooth B, but be thrown up with a jerk, perhaps so high that the tooth slips past the hook; and then not only will that tooth slip, but several more, and at last when the wheel is stopped it will be running fast, and the points of some of the teeth will probably be bent or broken by catching against the pallet. And even if the pallet is not raised high enough for the tooth to get past or completely trip, it may still be raised so high that the point of the tooth does not rest on the hook exactly where the slope of the pallet ends, but lower, and the friction between them is quite enough to keep the pallet there; and consequently the pendulum does not begin to lift it at the angle γ, but at some larger angle; and as the pallet always descends with the pendulum to the same point, the duration of the impulse is increased, and the pendulum made to swing farther. Mr Denison calls this *approximate tripping*, and though not so injurious to the clock as actual tripping, it is obviously fatal to its accurate performance, though it appears never to have been noticed before. Various contrivances have been resorted to for the purpose of getting rid of the liability to trip. Cumming, the first inventor of gravity escapements, used two pairs of pallets, one pair being only for the locking, and not lifted at all by the scape-wheel, but only by the pendulum; and this was effectual; but still the teeth suffered in time from the rapid blows on the pallets, and the friction at unlocking was considerable. Hardy's escapement was just the same in principle, but worse, because he set the four pallets on springs instead of pivots, which being stronger in cold weather, and acting on the pendulum at the extremity of its arc, made the clock gain in winter; and accordingly his escapement was taken out of the transit clock at Greenwich, and replaced by a dead escapement, with a short angle of escape, as before mentioned. The late Captain Kater invented an escapement in which he attempted to get rid of tripping by making the impulse pallets drop on to an anchor, like that of a dead escapement with the impulse faces cut off, and so unlock the wheel by their own weight. Mr Gowland's escapement was on the same principle as regards the unlocking, but he provided against tripping by the not very elegant contrivance of putting paddles on the pallets descending into a pot of oil. M. Gannery, of Paris, had an escapement in the Great Exhibition, also on this principle as to the unlocking, but, to prevent the trip, he gave the wheel only a few teeth and a long run, with a very gradual rise of the pallets. Mr Bloxam had previously done the same thing with a wheel also of nine teeth, and with much less friction, as will be noticed presently. But on account of the delicacy required in all of these escapements (which we select out of a multitude of others as the best of their respective classes), and other objections, none of them have ever come into use. In fact, none of the inventors of them seem to have felt sufficient confidence in their success to venture upon a coarse and cheap train of wheels; whereas, if a gravity escapement is not so independent of the force of the train that all variations in its friction may be disregarded, it fails in the most essential point, and descends to the condition of a common impulse escapement.

For this reason, also, it is necessary that it should be independent of oil, or at any rate, that the friction which affects the pendulum in unlocking, should be so small that no difference can be perceived in the arc whether oil is used or not. The oil in the parts which do not affect the pendulum is of no consequence, for the same reason that the friction of the train is of no consequence—if the escapement is what it professes to be. And lastly, it is essential to the success of a gravity escapement that it should be easy to make, and tolerably cheap; for, considering the accuracy of performance which can be attained by a highly-finished dead escapement clock, there is no chance of superseding it unless you can get at least as much accuracy with less expense. The only one of the above-mentioned escapements which approaches near enough to satisfying all these conditions to be worth any further description is Mr Bloxam's; and we accordingly give a sketch of it in fig. 11, which is copied (with a little alteration for distinctness) from his own description of it, communicated in 1853 to the Astronomical Society, some years after he had had it in action in a clock of his own. This drawing will enable any one conversant with these matters to understand its action. He made the pallet arbors cranked, to embrace the pendulum-spring, so that their centres of motion might coincide with that of the pendulum as nearly as possible; perhaps an unnecessary refinement; at least the three-legged gravity escapement, which we shall presently describe, answers very well with the pallet arbors set on each side of the top of the spring.

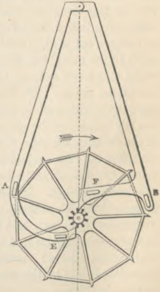

Fig. 11.

The size of the wheel determines the length of the pallets, as they must be at such an angle to each other that the radii of the wheel when in contact with each stop may be at right angles to the pallet arm; and therefore, for a wheel of this size, the depth of locking can only be very small. The pinion in Mr Bloxam's clock only raises the pallet through 40′ at each beat; *i.e.*, the angle which we called γ is only 20′; and probably, if it were increased to anything like $\frac{\alpha}{\sqrt{2}}$, the escapement would trip immediately. The two broad pins marked E, F, are the fork-pins. The clock which Mr Bloxam had, went very well; but it had an extremely fine train, with pinions of 18; and we know that the late Mr Dent was always afraid to adopt the escapement, on account of the great delicacy involved in it; and though the mere expense would have been of little consequence in the great Westminster clock, yet the risk of the teeth breaking if the wheel got a run, from any accidental lifting of the pallets, and the apparent impossibility of making γ even nearly satisfy the proper mathematical condition without risk of tripping, were considered by the Astronomer Royal and Mr Denison, sufficient reasons for not requiring it to be introduced. It should, however, be stated that Mr Bloxam is of opinion that $\alpha = 5\gamma$ is a better proportion than $\alpha = 3\gamma$, to counteract the variation of density of the air.

It was not till nearly a year after the Westminster clock was begun, that Mr Denison converted his three-legged dead escapement into the gravity escapement, which is used there, and which we shall now describe. It will be observed that in fig. 12 the three teeth or legs are no longer straight, as in fig. 9, but bent, so that the lifting pins and the points of the teeth would lie alternately on the radii of a hexagon. The pins too are no longer sharp, but plain bits of wire rivetted into the scape-wheel, which is of steel—in an astronomical clock about $\frac{1}{16}$th inch thick, and $\frac{1}{8}$th in a turret clock. The pins raise the pallets by the projecting pieces A, B, and the long teeth rest on the stops D, E, which are bits of steel screwed on, and hardened after they are adjusted. The points of the teeth are about six times as far from the centre as the pins are, and consequently their pressure on the stops is not enough to hold the pallets up if they do by accident get thrown too high; and thus the effects of approximate tripping are prevented; for the pallet immediately falls down again, and rests against the pin which lifted it until the pendulum returns and carries it off: moreover the friction at unlocking is thus rendered insensible. The beat is adjusted by two thumb-screws with broad and slightly convex steel heads set in the pendulum rod, which are embraced by brass fork-pins from the bottom of the pallets. In turret clocks, where there is plenty of room, there are no beat-screws, but the fork-pins are made eccentric, and so adjustable by the nuts which fix them to the pallets. In the finest clocks the lifting-faces of the pallets are jewelled, so that no oil is required. In turret clocks, however, there has been a striking proof that the escape-

Fig. 12.

ment is sufficiently independent of oil; for the first of these clocks was sent out to the cathedral at Fredericton, —indeed Mr Denison was led to invent it from being requested to see if any clock could be made which would go tolerably well through the cold of 40° below zero, which they have there in winter,—and the person who takes care of it reports that he could observe no variation of the arc during the winter, even while the oil was frozen as hard as tallow.

But we have not yet noticed a very material feature in this escapement, viz., the fly, which is set on the scape-wheel arbor, with a friction-spring, just like a common striking-fly. It is this which moderates the velocity and renders it safe against tripping, and against any damage to the teeth from an accidental run, the motion of 60° at each beat being quite enough to render the fly effective. In turret clocks the fly is made about 5 inches long in each vane, and 1¼th broad; in regulators, or clocks of astronomical size, nearly 1 inch long and ¾ths broad. The stop E, which is struck upwards, should be set a little higher than the scape-wheel centre; for if not, the blow has a tendency to throw the pallet out and make it trip, if the force is much increased; the other stop D may be about on a level with the centre. The distance of the pins from the centre may be about $\frac{1}{36}$th of the distance of that centre from the pallet arbors; and the weight of the pallets should be such as to make the pendulum swing not less than 2°, nor more than $2\frac{1}{2}^\circ$: this makes $\alpha = 3\gamma$, or thereabouts. In regulators, the distance of centres should be from 4 to 5 inches (the scape-wheel being put near the bottom instead of the top of the frame), and in turret clocks 9 inches. In the great Westminster clock it is 12 inches, on account of the great size of the pendulum, as will be further explained hereafter. Besides the other advantages, this escapement supersedes the necessity for a long and heavy pendulum which is generally wanted to resist the variations of force in the train, but which are here cut off before they reach the pendulum. Church clocks, with cast-iron wheels and this escapement, and pendulums only 5 feet long, will keep time within a second a week, and often less. There seems, however, one objection to it for observatory clocks, viz., that the beat makes very little noise; perhaps it might be made loud enough by increasing the weight of the scape-wheel, so as to make the blow on the pallets heavier. Before it was adopted for the Westminster clock, it was tried at the Royal Observatory in a common regulator; and Mr Airy, who was, as we have seen, not likely to be prejudiced in favour of gravity escapements, expressed his complete satisfaction with its performance, after trying upon it what he described as some "malicious experiments." Many clocks of this kind have been since made by Mr Dent and a few other clockmakers—the turret clocks with cast-iron wheels, and the regulators with pinions of only 8 leaves. The weight may be doubled without affecting the arc or the rate; and for this reason, it is very well adapted for telescope or barrel-driving clocks, such as we described above, at page 12. It only remains to be added, that it is very easy to make, and requires less delicacy than the common dead escapement; and as it is not patented, it may be made by anybody. We may now proceed to matters involving merely mechanical, and not mathematical considerations.

GOING BARRELS.

A clock which is capable of going accurately must have some contrivance to keep it going while you are winding it up. In the old-fashioned house clocks, which were wound up by merely pulling one of the strings, and in which one such winding served for both the going and striking parts, this was done by what is called the endless chain of Huygens, which consists of a string or chain with the ends joined together, and passing over two pulleys on the arbors of the great wheels, with deep grooves and spikes in them, to prevent the chain from slipping. In one of the two loops or festoons which hang from the upper pulleys, is a loose pulley without spikes, carrying the clock-weight, and in the other a small weight only heavy enough to keep the chain close to the upper pulleys. Now, suppose one of those pulleys to be on the arbor of the great wheel of the striking part, with a ratchet and click, and the other pulley fixed to the arbor of the great wheel of the going part; then (whenever the clock is not striking) you may pull up the weight by pulling down that part of the string which hangs from the other side of the striking part; and yet the weight will be acting on the going part all the time. And it would be just the same if you wound up the striking part and its pulley with a key, instead of pulling the string; and also the same, if there were no striking part at all, but the second pulley were put on a blank arbor, except that in that case the weight would take twice as long to run down, supposing that the striking part generally requires the same weight × fall as the going part.

This kind of going barrel, however, is evidently not suited to the delicacy of an astronomical clock; and Harrison's going-ratchet is now universally adopted in such clocks, and also in chronometers and watches, for keeping the action of the train on the escapement during the winding. This fig. 13 (in which the same letters are used as in the corresponding parts of fig. 1) shows its construction. The click of the barrel-ratchet R is

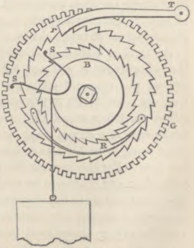

Fig. 13.

set upon another larger ratchet-wheel, with its teeth pointing the opposite way, and its click rT is set in the clock-frame. That ratchet is connected with the great wheel by a spring ss' pressing against the two pins s in the ratchet and s' in the wheel. When you wind up the weight (which is equivalent to taking it off), the click Tr prevents that ratchet from turning back or to the right; and as the spring ss' was kept by the weight in a state of tension equivalent to the weight itself, it will drive the wheel to the left for a short distance, when its end s is held fast, with the same force as if that end was pulled forward by the weight; and as the great wheel has to move very little during the short time the clock is winding, the spring will keep the clock going long enough.

In the commoner kind of turret clocks a more simple apparatus is used, which goes by the name of the *bolt and shutter*, because it consists of a weighted lever with a broad end, which shuts up the winding-hole until you lift it, and then a spring-bolt attached to the lever, or its arbor, runs into the teeth of one of the wheels, and the weight of the lever keeps the train going until the bolt has run itself out of gear. This spring-bolt is sometimes made—and by manufacturers of turret clocks, who ought to know better—in the form of a click, so contrived that in one position of the wheel-teeth it will not fall between them, but jams against the top, and stops the clock. Moreover, in the common construction of this apparatus there is nothing to ensure its being raised high enough to keep in gear the whole time of winding, if the man loiters over it, or on the other hand, to enable him to take it out of action when he has done. For this purpose Mr Denison has had the arbor of the bolt and shutter to be made to *pump* in and out of gear; and, instead of the shutter covering the winding-hole, it ends in a circular arc advanced just far enough to prevent the key or winder from being put on, by obstructing a ring set on the end of the pipe. In order to get the winder on, you *must* raise the lever high enough for the arc to clear the ring. During the two or three minutes which the clock may take to wind, the arc will be descending again behind the ring, so that now you cannot get the winder off again without also pulling the maintaining power out of gear; so that even if it is constructed to keep in action ten minutes, if required, still it will never remain in action longer than the actual time of winding.

In large clocks with a train remontoire, or even with a gravity escapement, it is hardly safe to use a spring going-barrel, because it is very likely to be exhausted too much to wind up the remontoire, or raise the gravity pallets, before the winding is finished, if it takes more than two or three minutes; whereas, with the common escapements, the wheel has only to escape, as the pendulum will keep itself going for some time without any impulse. On this account Mr Airy had a maintaining power, or going-barrel of his own invention, applied to the Exchange clock, which was self-acting by gravity, and kept as much force on the clock during the whole time of winding as before. But it is enormously expensive, difficult to make, and not unlikely to run itself out of gear, or else to stop, and takes up a great deal of room; and as it is never likely to be used again, it is not worth while to repeat the description of it which is given in the *Rudimentary Treatise on Clocks.* A very simple and certain self-acting gravity maintaining power was contrived by Mr Denison for the Westminster clock, as will be explained hereafter, as none of the common methods would do for a clock of that size.

EQUATION CLOCKS.

It is hardly worth while to occupy much space in describing a machine so nearly obsolete as what used to be called *equation* (*i.e.*, equation of time) *clocks.* Their object was to show true solar, or sundial time, instead of mean solar time, which, as we all know from the almanacs, is as much as 16 minutes behind the sun in November, and 14 minutes before it in February, and they only agree four times in the year. These clocks were never much used in England: but in Paris, even the public clocks, until the year 1826, were furnished with equation work so as to show solar time. But as the principle of this machinery is remarkable, and may be useful for some other purposes, we will shortly indicate the nature of it.

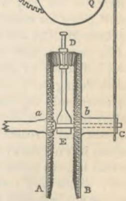

Fig. 14.

In fig. 14 let A*a* be the hour-wheel of the common dial work, with its arbor prolonged to C, and turning the opposite way to what the hands are intended to turn. The minute-hand is set on a pipe *b* of the wheel B*b*, which rides on the arbor *a*C. Both of these are bevelled wheels of the same number of teeth, and they are connected by an intermediate bevelled wheel or pinion D, of any number. This pinion rides on the end of the bar ED, which itself rides on the arbor *a*C, at right angles to it. Now, so long as the end D of the bar ED is held fast, the wheel B, which carries the hand, will turn in one hour exactly as A does, only the opposite way. But if while A is moving uniformly with the clock train, we move ED with its pinion, it will evidently superadd another motion to B besides that which it receives from A. If we move ED through α in the same direction as B is naturally moving, it will give B an additional motion of 2α; and if we move the bar the other way it will diminish B's motion by the same angle 2α. If then, the end of the bar is made to travel on the edge of a plate of the shape shown at Q*q*, turning in a year on a centre

O, the hand-wheel will be constantly accelerated or retarded from the mean time of the other wheel, according as the point of the plate in contact with D is at a longer or shorter distance from its centre O than the average. The equation-plate of course is not really in the position drawn here in order to exhibit its shape, but in a position for D to lie upon it, and it is driven by a slow train of wheels or an endless screw from the arbor *a*. Instead of bevelled wheels, it will be the same thing if we put a common pinion between a common spur-wheel on the arbor *a*, and an internal wheel (*i.e.*, a wheel with teeth on the inside of its rim) in the place of B; only in that case the two wheels will move with different velocities in proportion to the numbers of their teeth. The pinion between them rides on a stud in the side of the bar, which rides on the main arbor at one end, and the other end rests on the equation-plate, as before. Or again, it may be done without either bevelled or internal wheels, by an arrangement like that which we shall have to describe (see fig. 17) under the head of "train remontoires." Professor Willis, in his ***Principles of Mechanism***, gives the name of *encyclical trains* to all those arrangements for adding a secondary motion to a wheel without interfering with the primary motion which it receives from the principal train.

We cannot stop to describe the various contrivances for making clocks show the days of the month, periods of the moon, and other phenomena. The old day of the month clocks required setting at the end of every month which has not 31 days, and have long been obsolete. We have lately seen some cheap clocks made at Wolverhampton (the first attempt at rivalling the American clocks) with day of the month work which does not require setting; but it would take more space to describe than our limits allow, and we must proceed to matters of more common use.

STRIKING CLOCKS.

There are two kinds of striking work used in clocks. The older of them, which is still used in all the foreign clocks, and in most turret clocks in England also, will not allow the striking of any hour to be either omitted or repeated, without making the next hour strike wrong; whereas, in that which is used in all the English house clocks, the number of blows to be struck depends merely on the position of a wheel attached to the going part; and therefore the striking of any hour may be omitted or repeated without deranging the following ones. In turret clocks there is no occasion for the repeating movement; and for the purpose of describing the other, which is called the *locking-plate* movement, we may as well refer to fig. 19, which is the front view of a large clock, striking both hours and quarters on this plan. In the hour part (on the left), you observe a bent lever BAH, called the "lifting-piece," of which the end H has just been let off by the snail on the hour-wheel 40 of the going part; and at the other end there are two stops on the back side of the lever, one behind, and rather below the other; and against the upper one a pin in the end of a short lever 9 B, which is fixed to the arbor of the fly, is now resting, and thereby the train is stopped from running, and the clock from striking any more. The stops are shown on the quarter lifting-piece of the Westminster clock in the frontispiece. We omit the description of the action of the wheels, because it is evident enough. At D may be seen a piece projecting from the lever AB, and dropping into a notch in the wheel 78. That wheel is the locking-wheel or locking-plate; and it has in reality notches such as D all round it, at distances 2, 3, up to 12, from any given point in the circumference, which may be considered as marked off into 78 spaces, that being the number of blows struck in 12 hours. These notches are shown in the locking-plate of the quarter part in fig. 19, but not in the hour part, for want of size to show them distinctly. Now, when the arm AB of the lifting-piece is raised by the snail a few minutes before the hour, the fly-pin slips past the first of the stops at B, but is stopped by the second and lower one, until the lever is dropped again exactly at the hour. Thus the pin can pass, and would turn once round freely, allowing the train to go on a little; but before it has got once round, the lifting-piece has been lifted again high enough to carry both stops out of the way of the fly-pin, by means of the cylinder with two slices taken off it, which is set on the arbor of the wheel 90, and on which the end of the lifting piece rests by means of a small roller (to diminish the friction). If the clock has only to strike one, the lifting-piece will then drop again, and the fly-pin will be caught by the first stop, having made (according to the numbers of the teeth given in fig. 19) 5 turns. But if it has to strike more, the locking-wheel comes into action. That wheel turns with the train, being either driven by pinion 20 on the arbor of the great wheel, or by a gathering pallet on the arbor of the second wheel, like G in fig. 15; and when once the lifting-piece is lifted out of a notch in the locking-plate, it cannot fall again until another notch has come under the bit D; and as the distance of the notches is proportioned to the hours, the locking-plate thus determines the number of blows struck. It may occur to the reader, that the cylinder 10 and roller are not really wanted, and that the locking-plate would do as well without; and sometimes clocks are so made, but it is not safe; for the motion of the locking-plate is so slow, that unless everything is very carefully adjusted and no *shake* left, the corner of the notch may not have got fairly under the bit D before the fly has got once round, and then the lifting-piece will drop before the clock can strike at all; or it may hold on too long and strike 13, as St Paul's clock did once at midnight, when it was heard at Windsor.

Fig. 15 shows the other kind of striking work, being the front view of an English house clock when the dial is taken

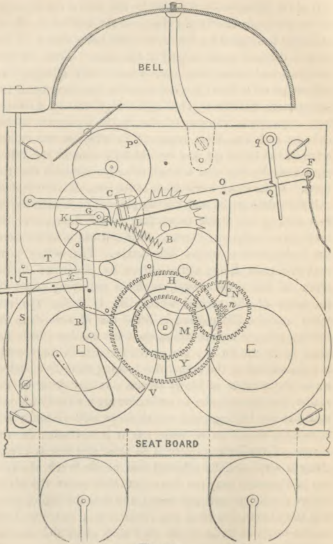

Fig. 15.

off. As in fig. 1, M is the hour-wheel, on the pipe of which the minute-hand is set, N the reversed hour-wheel, and *n* its pinion, driving the twelve-hour wheel H, on whose socket is fixed what is called the snail Y, which belongs to the striking work exclusively. The hammer is raised by the eight pins in the rim of the second wheel in the striking train, in the manner which is obvious. The hammer does not quite touch the bell, as it would jar in striking if it did, and prevent the full sound; and if you observe the form of the hammer-shank at the arbor where the spring S acts upon it, you will see that the spring both drives the hammer against the bell when the tail T is raised, and also checks it just before it reaches the bell, and so the blow on the bell is given by the hammer having acquired momentum enough to go a little farther than its place of rest. Sometimes two springs are used, one for impelling the hammer, and the other for checking it. A piece of vulcanized India-rubber tied round the pillar just where the hammer-shank nearly touches it, forms as good a check-spring as anything. The pinion of the striking-wheel generally has eight leaves, the same number as the pins; and as a clock strikes 78 blows in 12 hours, the great wheel will turn in that time if it has 78 teeth instead of 96, which the great wheel of the going part has for a centre pinion of eight. The striking-wheel drives the wheel above it once round for each blow, and that wheel drives a fourth (in which you observe a single pin P), six, or any other integral number of turns, for one turn of its own, and that drives a fan-fly to moderate the velocity of the train by the resistance of the air, an expedient at least as old as De Vick's clock, in 1370. The wheel N is so adjusted that, within a few minutes of the hour, the pin in it raises the *lifting-piece* LON so far, that that piece lifts the click C out of the teeth of the *rack* BKRV, which immediately falls back (helped by a spring near the bottom) as far as its tail V can go by reason of the snail Y, against which it falls; and it is so arranged that the number of teeth which pass the click is proportionate to the depth of the snail; and as there is one step in the snail for each hour, and it goes round with the hour-hand, the rack always drops just as many teeth as the number of the hour to be struck. This drop makes the noise of "giving warning." But the clock is not yet ready to strike till the lifting-piece has fallen again; for as soon as the rack was let off, the tail of the thing called the *gathering pallet* G, on the prolonged arbor of the third wheel, was enabled to pass the pin K of the rack on which it was pressing before, and the striking train began to move; but before the fourth wheel had got half round, its pin P was caught by the end of the lifting-piece, which is bent back and goes through a hole in the plate, and when raised, stands in the way of the pin P, so that the train cannot go on till the lifting-piece drops, which it does exactly at the hour, by the pin N then slipping past it. Then the train is free; the striking-wheel begins to lift the hammer, and the gathering pallet gathers up the rack, a tooth for each blow, until it has returned to the place at which the pallet is stopped by the pin K coming under it. In this figure, the lifting-piece is prolonged to F, where there is a string hung to it, as this is the proper place for such a string when it is wanted for the purpose of learning the hour in the dark, and not (as it is generally put) on the click C; for if it is put there, and you hold the string a little too long, the clock will strike too many; and if the string accidentally sticks in the case, it will go on striking till it is run down; neither of which things can happen when the string is put on the lifting-piece.

The snail is sometimes set on a separate stud with the apparatus called a *star-wheel* and *jumper* (described in *Rudimentary Treatise*, p. 123); but, as this only increases the cost without any advantage that we can see, we omit any further reference to it. On the left side of the frame we have placed a lever *x*, with the letters *st* below it, and *si* above. If it is pushed up to *si*, the other end will come against a pin in the rack, and prevent it from falling, and will thus make the clock silent; and this is much more simple than the common "strike and silent" apparatus, which we shall therefore not describe.

If the clock is required to strike quarters, a third part, or train of wheels, is added on the right hand of the going part; and its general construction is the same as the hour-striking part; only there are two more bells, and two hammers so placed that one is raised a little after the other. There is a method of making the same part do both the quarter and hour striking; but it is very seldom used, and would take too long to describe here. If there are more quarter bells than two, the hammers are generally raised by a chime-barrel, which is merely a cylinder set on the arbor of the striking-wheel (in that case generally the third in the train), with short pins stuck into it in the proper places to raise the hammers in the order required for the tune of the chimes. The quarters are generally made to let off the hour, and this connection may be made in two ways. If the chimes are different in tune for each quarter, and not merely the same tune repeated two, three, and four times, the repetition movement must not be used for them, as it would throw the tunes into confusion, but the old locking-plate movement, as in turret clocks; and therefore, if we conceive the hour lifting-piece connected with the quarter locking-plate, as it is with the wheel N in fig. 15, it is evident that the pin will discharge the hour striking part as the fourth quarter finishes.

But where the repetition movement is required for the quarters, the matter is not quite so simple; but the principle of it may shortly be described thus:—the quarters themselves have a rack and snail, &c., just like the hours, except that the snail is fixed on one of the hour-wheels M or N, instead of on the twelve-hour wheel, and has only four steps in it. Now, suppose the quarter-rack to be so placed, that when it falls for the fourth quarter (its greatest drop), it falls against the hour lifting-piece somewhere between O and N, so as to raise it and the click C. Then the pin Q will be caught by the click Q*q*, and so the lifting-piece will remain up until all the teeth of the quarter-rack are gathered up; and as that is done, it may be made to disengage the click Q*q*, and so complete the letting off of the hour striking part. (This click Q*q*, of course, has no existence except where there are quarters.)

These quarter clocks are sometimes made so as only to strike the quarters at the time when a string is pulled—as by a person in bed, just like repeating watches, which are rarely made now, on account of the difficulty of keeping in order such a complicated machine in such a small space. In this case, the act of pulling the string to make the clock strike winds up the quarter-barrel, which is that of a spring-clock (not yet described), as far as it is allowed to be wound up by the position of a snail on the hour-wheel, against which a lever is pulled, just as the tail of the common striking rack falls against the snail on the twelve-hour wheel; and it is easy to see that the number of blows struck by the two quarter hammers may thus be made to depend upon the extent to which the spring that drives the train is wound up; and it may even be made to indicate half-quarters; for instance, if the snail has eight steps in it, the seventh of them may be just deep enough to let the two hammers strike three times, and the first of them once more, which would indicate $7\frac{1}{2}$ minutes to the hour. It is generally so arranged that the hour is struck first, and the quarters afterwards.

ALARUMS.

In connexion with these bed-room clocks we ought to mention *alarums*. Perhaps the best illustration of the mode of striking an alarum is to refer to either of the recoil escapements (figs. 4 and 5). If you suppose a short hammer instead of a long pendulum attached to the axis of the pallets, and the wheel to be driven with sufficient force, it will evidently swing the hammer rapidly backwards and forwards; and the position and length of the hammer-head may be so adjusted as to strike a bell inside, first on one side and then on the other. Then as to the mode of letting off the alarum at the time required; if it was always to be let off at the same time, you would only have to set a pin in the twelve-hour wheel at the proper place, to raise the lifting-piece which lets off the alarum at that time. But as you want it to be capable of alteration, this discharging pin must be set in another wheel (without teeth), which rides with a friction-spring on the socket of the twelve-hour wheel, with a small moveable dial attached to it, having figures so arranged with reference to the pin, that whatever figure is made to come to a small pointer set as a tail to the hour-hand, the alarum shall be let off at that hour. The letting off does not require the same apparatus as a common striking part, because an alarum has not to strike a definite number of blows, but to go on till it is run down; and therefore the lifting-piece is nothing but a lever with a stop or hook upon it, which, when it is dropped, takes hold of one of the alarum wheels, and lets them go while it is raised high enough to disengage it. You must of course not wind up an alarum till within 12 hours of the time when it is wanted to go off, unless the hour-hand is one that turns in 24 hours, instead of 12.

The *watchman's* or *tell-tale* clock, the reader may have seen in one of the lobbies of the House of Commons, and in prisons, and some other places, where they want to make sure of a watchman being on the spot and awake all the night; it is a clock with a set of spikes, generally 48 or 96, sticking out all round the dial, and a handle somewhere in the case, by pulling which you can press in that one of the spikes which is opposite to it, or to some lever connected with it, but no others; and it will be observed, that this wheel of spikes is carried round with the hour-hand, which in these clocks is generally a 24-hour one.

It is evident that every spike which is seen still sticking out in the morning indicates, that at the particular time to which that spike belongs, the watchman was not there to push it in—or at any rate, that he did not do it; and hence its name. At some other part of their circuit, the inner ends of the pins are carried over a roller or an inclined plane which pushes them out again ready for business the next night.

SPRING CLOCKS.

Hitherto we have supposed all clocks to be kept going by a weight. But, as is well known, many of them are driven by a spring coiled up in a barrel. In this respect they differ nothing from watches, and therefore we shall defer all consideration of the construction of the parts belonging to the spring till we treat of watches. It may however be mentioned here, that the earliest form in which a spring seems to have been used was not that of a spiral ribbon of steel rolled up, but a straight stiff spring held fast to the clock frame at one end, and a string from the other end going round the barrel, which was wound up: of course such a spring would have a very small range. Spring clocks are generally resorted to for the purpose of saving length; for as clocks are generally made in England, it is impossible to make a weight-clock capable of going a week, without either a case nearly 4 feet high, or else the weights so heavy as to produce a great pressure and friction on the arbor of the great wheel. But this arises from nothing but the heaviness of the wheels, and the badness of the pinions used in most English clocks, as is simply proved by the fact, that the American clocks go a week with smaller weights and less fall for them than the English ones, and this with no assistance from fine workmanship for the purpose of diminishing friction, as they are remarkable for their want of what is called "finish" in the machinery, on which so much time and money is wasted in English clock-work.

Moreover, in the American clocks the pinions are all of the kind called *lantern pinions* (see fig. 35), which are pinions having their leaves made only of bits of wire set round the axis in two collars; and, oddly enough, they are the oldest form of pinion, as well as the best, acting with the least friction, and requiring the least accuracy in the wheels, but now universally disused in all English and French house clocks. The American clocks prove that they are not too expensive to be used with advantage when properly made, although, so long as there are no *manufactories* of clocks here as there are in America, it may be cheaper to make pinions in the slovenly way of cutting off all the ribs of a piece of pinion wire, so as to reduce it to a pinion a quarter of an inch wide, and an arbor 2 or 3 inches long. The wheels of the American clocks are all stamped, and the holes in the plates also; in fact, there is probably not two shillings worth of mere manual labour in the whole of an American clock movement. There is no doubt that in the making of machines by machinery the Americans are far ahead of us; witness also Colt's revolvers and Hobbs's locks. On the whole, the common English house clocks, so far from having improved with the general progress of machinery, are worse than they were fifty years ago, and at the same time are of such a price that they are being fast driven out of the market by the American plain clocks, and by the French ornamental ones; for their movements are also made by machinery at surprisingly low prices. Indeed, until very lately we were inferior to the French also in a kind of clock in which above all others we ought to be superior to the rest of the world, viz., in the largest kind of clocks, to which we shall devote a few pages presently.

ELECTRICAL CLOCKS.

It should be understood that under this term two, or we may say three, very different things are comprehended. The first is a mere clock movement, *i.e.*, the works of a clock without either weight or pendulum, which is kept going by electrical connexion with some other clock of any kind; and these ought to be called *electrical dials*, not clocks: the second is a clock with a weight, but with the escapement worked by electrical connexion with another clock instead of by a pendulum; and the third alone are truly *electrical clocks*, the motive power being electricity instead of gravity; for although they have a pendulum, which of course swings by the action of gravity, yet the requisite impulse for maintaining its vibrations against friction and resistance of the air is supplied by a galvanic battery, instead of by the winding up of a weight.

Electrical dials were, as far as we know, first made by Professor Wheatstone; at least, we remember his exhibiting one as a novelty at King's College, London, about fifteen years ago, and this is the principle of all of them.

If you take the weight off a common recoil escapement clock, and work the pallets backwards and forwards by hand, you will drive the hands round, only the wrong way: consequently, if the escapement is reversed, and the pallets are driven by magnets alternately made and unmade, by the well-known method of sending an electrical current through a wire coiled round a bar of soft iron, the contact being made at every beat of the pendulum of a standard clock, the clock without the weight will evidently keep exact time with the standard clock; and the only question is as to the best mode of making the contact, which is not so easy a matter as it appears to be, on account of the short time in which it has to be done. The first plan was to have a wheel set on the scape-wheel arbor divided into 60 conducting, and 60 non-conducting spaces, with a contact spring pressing upon it. But to this there are several objections; one is the friction, which seriously affects the going, unless it is a large clock with a heavy pendulum; and a still more serious evil is, that the contact surfaces will not keep clean enough to ensure the contact, wherever there is rubbing between them, as it promotes oxidation. It seems that nothing except contact without friction between gold or platinum surfaces will do permanently. The late Mr Dent made an electrical dial, and kept it going in this way long enough to ascertain that it would answer. Then there is the plan (which Mr Shepherd adopts) of letting the pendulum itself make contact with two springs acting near the top at each vibration; and if they are made very weak and the pendulum heavy, and if the escapement is such as to maintain a constant arc of vibration, this method seems to answer. Mr Denison's first gravity escapement clock (a small house clock movement) is now working a large dial in this way, outside the Chester Railway station, by electrical contact with the pendulum. Another method, which has been lately used at the Royal Observatory, is to make a wheel on the scape-wheel arbor with 60 teeth press a slight spring against a contact-plate or another spring at every second, the circuit passing through the two springs. But if any change takes place in the friction between the wheel and the spring, it will affect the going of the clock, unless it has a gravity escapement.

But for electrical *dials* it is generally better to make the hands move only by half-minute jumps, so that the time may be taken exactly, as with a train remontoire; and in that case nothing is required but the three dial wheels, and some kind of scape-wheel or ratchet for driving them. If they are driven by pallets, a scape-wheel of 60 teeth will do; if it is a ratchet-wheel with a driving click, it will want 120 teeth. But here comes in a difficulty of some weight, at least in large dials, and especially in those exposed to wind. In that case it is found that pallets cannot be relied on to drive with certainty, and the ratchet and click must be resorted to. But if the wind happens to be pushing the hand forward at the time of lifting the click, it may run on 3 or 4 teeth at once. To prevent this, two ratchets have been used, set opposite ways, and the clicks so disposed that the wheels can only move one tooth at a time, under the proper action of the driving click; such at any rate is the intention of them; but it does not seem to be always carried into effect; and besides that, it requires great delicacy in construction. Mr Denison contrived the following apparatus for this purpose, which has been made by Mr Dent, and tried by pressing the wheel both ways more strongly than the wind could, and it remains quite steady, which proves that its mechanical action is safe, and that if it fails, it must be from failure in electrical contact, to which any other plan is equally liable. In fig. 16, H is the wheel on the arbor of the minute-hand, with 120 square teeth in it. When the circuit is complete, the magnet M raises the lever L into the position here shown, and with it the driving click A. The pin B at the same time lifts the forward click DG out of the teeth, and the spring behind it at D sends it forward a little (there being some play left in the pivot-hole for the purpose), and makes it trip on to the top of the tooth at G. The top of the lever at F also then reaches the tail of the backward click CF; so that while things are in this state, the wheel cannot go forward without pulling the lever out of contact with the magnet, which no wind would be strong enough to do while it remains a magnet; and as soon as the circuit is broken, the lever

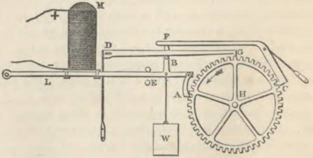

Fig. 16.

ought to go, and will go, being pulled down by the weight W, till it rests on the lower banking-pin E; and in so doing, the click A will drive the wheel forward one tooth, and the click DG will drop into the space next after the tooth G, and be pressed back against its spring till it is lifted again by the lever. Another advantage of this plan over those in which the magnet drives the wheel directly is, that the weight is always ready to pull down the lever as soon as the current ceases; so that if there should be any momentary impediment from residual magnetism or otherwise, it will not signify; and moreover, the wind can never prevent the lever from being lifted; and if there should be any resistance to the hands from wind at the moment when the current ceases, the weight is sure to have the opportunity of overcoming it before the next 29 seconds are over; so that a whole move of the hands can never be lost, which has always been liable to happen under the other arrangement in large dials.

There is no such difficulty in making the half-minute contact as there is in seconds contact, because plenty of time can always be taken for it. As the third wheel in the train generally turns in 7½ minutes, there may be 15 pins in it pressing a spring which makes contact, or raising a lever or a spring which drops on to a plate. Where the gravity escapement is used, there may be a snail with two steps on the arbor of the minute-wheel, which will drop the lever on to the contact-plate at every thirtieth second, and begin to lift it off again at the thirty-first,—the snail being made square at the bottom in order to raise it immediately, and waste as little electricity as possible. It was intended originally to drive the numerous small clocks in and about the Houses of Parliament by electrical connection with the great clock; but as they are finished, and the great clock is not yet in its place, we suppose this plan will be abandoned, unless the bad going of some of these small clocks suggests the expediency of replacing them by electrical dials. In that case there ought to be one other strong gravity clock with which they might be connected in case of any accident at the great clock, which would otherwise stop them all. There is apparently to be a small clock in the front facing the Abbey, which would do very well for this purpose, if it is a good one. But we are bound to say that the experience of six more years has confirmed the doubts raised by the failure of all the electrical clocks in the Exhibition of 1851, whether any contrivance for driving clocks, or large dials, by electricity alone, without the help of a weight, can be permanently relied on. Such clocks or dials will go for several weeks, or months perhaps, steadily enough, and then fail quite capriciously, as if every now and then the electricity had a fit of weakness which renders it unable to overcome a very slight resistance. Even the time-ball in the Strand, which has only to be let off once a day by galvanic connexion with the Greenwich observatory, frequently fails.

Probably no person in England has paid so much attention to this subject, and understands it so thoroughly as Mr R. Jones, the station master at Chester, a gentleman of great ingenuity in several branches of science; and his much larger experience seems to agree with our own in this respect. He has, accordingly, himself invented a plan which seems to possess great advantages over any other that we know of. He abandons the really insignificant object of dispensing with winding, which can be done by any body as well as a clockmaker's man, and can hardly be said to be of any money value at all; and instead of making the electrical connection with a standard clock (whether itself an electrical one or not) *drive* the others, he makes it simply let the pallets go at every beat of the standard clock; and, by way of helping it, the pallets are made what we called half-dead in describing the dead escapement, except that they have no impulse faces, but the dead faces have just so much slope that they would overcome their own friction, and escape of themselves under the pressure of the clock-train, except while they are held by the magnet, which is formed at every beat of the standard clock, or at every half-minute contact, if it is intended to work the dials by half-minute jumps. By this plan, which is used in driving the large dial outside the railway station, from the gravity escapement clock in Mr Jones's room, an enormous saving in battery-power has been effected, besides securing nearly absolute certainty of action, which Mr Shepherd had failed in getting after working at the clocks for a long time. It has been stated in the newspapers that the clocks, both large and small, in the General Post-office in London, are now being altered, to go without winding, by electrical connection with Greenwich, although most of them were before merely dials driven by the large clock by the common mechanical connection; and nothing more was needed than to alter the escapement of the large clock, which went very ill, though six times as much was paid for it as Mr Dent now charges for more powerful clocks of the best construction. We shall be surprised if they do not spend three times as much as such an alteration would have cost, and have all the clocks occasionally stopping besides.

The first electrical *clocks*, in the proper sense of the term, were invented by Mr Bain, who directed the impulse to the bob of the pendulum by magnets alternately made and unmade by the motion of the escapement and pendulum itself. But these clocks, as might have been foreseen, were worth nothing for time-keeping, and were moreover unable to keep themselves—or Bain and his shop—going for any length of time. The only electrical clocks that have been at all successful are those invented by Mr Shepherd, the chronometer-maker in Leadenhall Street, or rather by his son, whose large dials in the south transept and other conspicuous parts of the original "Crystal Palace" will be remembered. It was announced that the time of the Exhibition was to be kept by these clocks, and Mr Dent was refused permission to put up his in connection with the building, and was consequently obliged to sink a pit for his weights, with a rather frightful erection for his dials, in the middle of the nave. However, the various clocks soon settled the question for themselves, and before a week was over, orders were given that the time should be taken from Mr Dent's clock alone, as the only one in the building that could be relied on; and the electrical dials failed altogether. There were some foreign clocks also exhibited on exactly the same principle as Mr Shepherd's then were. But he afterwards improved his plan, and its present form is this: A single pallet, like one of the pallets in the pin-wheel escapement (fig. 7), is fixed to the pendulum, and there is a small lever set in the frame, the end of which is lifted on to this pallet at every swing of the pendulum in one direction by the magnet; and as the pendulum draws the pallet away from the lever end, it slides down the sloped face and gives the impulse. This is a single-beat escapement, of which there are other forms, without reference to electricity. They have the advantage that the impulse may be made to end exactly at the same arc of the pendulum after zero as it begins before zero, or even less; but there are countervailing disadvantages in the mode of unlocking (not applying however to this electrical method, which has no unlocking), and they have consequently never come into use. This escapement is not without friction, but it is small and cannot vary much, as the weight of the pallet is constant, and there is no clock-train acting on it. For, so far as we have yet described it, we have got nothing but a self-acting pendulum; the connection with a clock-train is made in just the same way as if this were an ordinary pendulum, from which the pallets of an electrical dial are to be driven by alternate contact springs on each side of the pendulum.

Another peculiarity of Mr Shepherd's clocks is, that the pallets which drive the train are alternately attracted and repelled, not simply attracted and let loose, and this is stated to economize the force. In order to effect it, there are two batteries which come into action alternately; and there are two permanent straight bar magnets set across the pallet arbor, with their poles opposite ways, so that on one side, say the left, the adjacent ends of the two bars would be north and south, and on the right side south and north. Consequently a temporary horse-shoe magnet, with its poles standing south and north, will attract the left side of the pallet magnets, and a similar magnet will repel the right side; and therefore, if the current is made to pass one way when the pendulum makes the contact on the right side, and the other way when it makes it on the left, the pallets will be driven both ways by the combined force of the attraction and repulsion of both magnets. For this purpose it is only necessary that the right pendulum spring should be connected with the + pole of one battery, and the left spring with the − pole of the other; the other wires of each battery being soldered together, and ultimately connected with the pendulum-cock after passing round both the soft-iron magnets.

If anything is to be let off by electricity at a given second in every day, the requisite precision is obtained by Mr Shepherd thus: There are pins for making contact with springs in the minute-wheel, the hour-wheel, and the 12-hour wheel; and it is only when the contact is made with all of them at once that the circuit is complete. In this way the time-ball at the Greenwich Observatory, and also the one in the Strand in connection with it, are let off at one o'clock every day, by the clock pulling a trigger by a temporary magnet. The balls are pulled up by hand a few minutes before one. The Greenwich one is a large covered basket of wicker-work, and it descends with a piston plunging into a tube with a bell-mouth to facilitate the entrance, and the piston compressing the air as it goes down, which acts as an elastic cushion to the ball, and makes it drop without concussion; there is a small hole at the bottom through which the air afterwards gradually escapes. Mr Shepherd also describes in his pamphlet some apparatus for striking by means of electricity, without the aid of any striking weight. But we have not heard of any such clocks being in use, and we think it not very likely they should be, on account of the much greater force which is required for striking than for keeping a pendulum going.

CHURCH AND TURRET CLOCKS.

Seeing that a clock—at least the going part of it—is a machine in which the only work to be done is the overcoming of its own friction and the resistance of the air, it is evident, that when the friction and resistance are much increased, it may become necessary to resort to expedients for neutralizing their effects which are not required in a smaller machine with less friction. In a turret clock the friction is enormously increased by the great weight of all the parts; and the resistance of the wind, and sometimes snow, to the motion of the hands, further aggravates the difficulty of maintaining a constant force on the pendulum; and besides that, there is the exposure of the clock to the dirt and dust which are always found in towers, and of the oil to a temperature which nearly or quite freezes it all through the usual cold of winter. This last circumstance alone will generally make the arc of the pendulum at least half a degree more in summer than in winter; and inasmuch as the time is materially affected by the force which arrives at the pendulum, as well as the friction on the pallets when it does arrive there, it is evidently impossible for any turret clock of the ordinary construction, especially with large dials, to keep any constant rate through the various changes of temperature, weather, and dirt, to which it is exposed. And yet it is remarkahle that, with the few exceptions we shall have to mention, the English clockmakers have universally set their faces against the adoption of any of the contrivances, whether of foreign or of English invention, for the purpose of obtaining a constant force on the pendulum, and have even presumed so far on the ignorance of the public, as to assert that the compensation of the pendulum is unnecessary, although turret clocks are of course exposed to greater variations of temperature than any others. The only excuse for such an assertion—and indeed a sufficient one—is, that it certainly is not worth while to provide against the errors from change of temperature while the clock is left exposed to greater errors from other causes, against which the makers do not know how to provide, and do not choose to learn. Two of the best known clockmakers in London admitted that they could not undertake to make the Westminster clock keep such time as was required by the Astronomer-Royal, on account of the great size of the dials.

But in the year 1843 a series of improvements began, which have completely changed the construction and the character of the best English turret clocks, and they can now be made to go better than the best astronomical clocks; while, at the same time, the merely superficial refinements, which it had become the fashion to introduce as a disguise for the absence of all scientific improvement, have been dispensed with, and the price considerably reduced. In that year, it appears from the papers which were afterwards published on the subject, the late Mr Dent was engaged to make the large clock for the newly built Royal Exchange, which was required to be superior to any public clock in England, and to satisfy certain conditions proposed for the first time by the Astronomer-Royal, and such as could not be satisfied by any clock of the common construction. He had then no factory of his own for making large clocks, and relied on getting it made under his directions by some of the few real makers of such things. But although these persons are generally willing enough to execute the orders of other clockmakers, and even allow them to put their own names on the clocks, Mr Dent found himself unable to get this clock made for him at all, and it was expected as a matter of course that he would be obliged to give up the contract; but with the energy and genius by which that remarkable man raised himself from a tallow chandler's apprentice to the position of the first horologist in the world, he set up a factory for himself at a great expense, and made the clock there; and of this, the first turret clock he had ever made, the Astronomer-Royal certified in 1845, that it not only satisfied his conditions, but that Mr Dent had made some judicious improvements upon his suggestions, and that he had no doubt it was the best public clock in the world. The clock tower of the Exchange has been prolific of disputes, for the peal of bells on which the clock was to play chimes every three hours have been cast and recast three times over, twice by Mr Mears, and once by Messrs Taylor of Laighborough; and they are not yet completed to the satisfaction of the referees.

The construction of the Exchange clock however was too expensive for general use; and accordingly Mr Dent next devoted himself to simplifying it. At first, he borrowed a good deal from the clocks of Messrs Wagner, the eminent makers of Paris; but by degrees he introduced various modifications of their plans, chiefly from the suggestions of Mr Denison; and before his death in 1853, the plans which we shall now describe were adopted as the settled forms for the different kinds of the best turret clocks. They have since been followed by his successor, Mr Dent of the Strand and the Royal Exchange, and also by Mr Joyce of Whitchurch (Salop), who had before enjoyed the reputation of one of the best provincial clockmakers, and by Mr Potts of Pudsey, near Leeds, who has made some of the best church clocks in Yorkshire; and possibly by some other country clockmakers, but by no London ones, though they are free from the incumbrance of patents.

Not that the majority of the country clockmakers are at all inferior to the London ones in ignorance and prejudice, and determination to prevent improvements from answering if they can. Very few, either of the London or the country clock-sellers, really make large clocks themselves; and as the Clerkenwell makers supply them on commission, and Mr Dent does not, it is easy enough to understand why there is always an opposition got up to any proposal for a church or other public clock of his construction, even independently of the genuine English hatred of improvements. A few years ago he put up two clocks, exactly the same as some which have been going in London and elsewhere with the accuracy of astronomical clocks for seven years, at Manchester and Halifax—places where one would expect good machinery to be appreciated, if anywhere. They had not been long in the hands of the local clockmakers before the remontoire work was broken, and then removed, and the clocks appealed to as proofs of the "failure of Mr Dent's improvements." Nearly the same thing happened at Leeds, until his clock at St George's Church was given into the care of Mr Potts. It is only fair to add, that in some other places local clockmakers have been found to take pride in showing what these clocks can do when they are allowed fair play. The public will soon have the opportunity of seeing one in action, which is to be placed on the ground, and the works exposed to view, in the new building for the Department of Science and Art at Kensington.

The old, or as the clockmakers would say, the "long established" form of a turret clock is that of a large iron cage, of which some of the vertical bars take off, and are fitted with brass bushes for the arbors of the wheels to run in; and the wheels of each train, *i.e.*, the striking train, the going, and the quarter train, stand over each other with their pivots all in the vertical bar belonging to that part. Occasionally they have advanced so far as to make the bushes moveable, *i.e.*, fixed with screws instead of rivetted in, so that

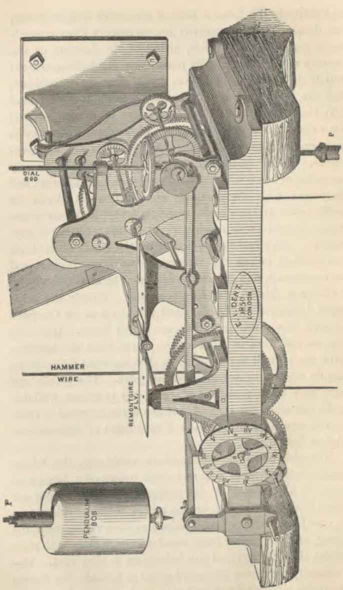
P
DIAL ROD
E. J. DENT. 1850 LONDON
HAMMER WIRE
REMONTOIRE FLY
PENDULUM BOB
P

Fig. 17.

one wheel may be taken out without the others ; but very few of the makers, except the late Mr Vulliamy, admitted even this most obvious improvement. This cage generally stood upon a wooden stool on the floor of the clock room. The French clockmakers long ago saw the objections to this kind of arrangement, and adopted the plan of a horizontal frame or bed, cast all in one piece, and with such smaller frames or cocks set upon it as might be required for such of the wheels as could not be conveniently got on the same level. Mr Dent's Great Exhibition clock (now at the King's Cross station in London), for which he received the Council medal, by the unanimous votes of the horological jury (except the chairman, who designed it), the group of seven mechanical juries, and the council of chairmen, was on this plan; and the adjoining sketch (fig. 17) of the clock at Meanwood church, near Leeds, will sufficiently explain it. All the wheels of the going part, except the great wheel, are set in a separate frame called the movement frame, which is complete in itself, and light enough to take off and carry away entire, so that any cleaning or repairs required in the most delicate part of the work can be done in the clock factory, and the great wheel, barrel, and rope need never be disturbed at all. Even this movement-frame is now dispensed with; but we will reserve the description of the still more simple kind of frame in which *all* the wheels lie on, or under, the great horizontal bed, until we have described that part of the clock which is referred to by the words "remontoire fly" in fig. 17.

TRAIN REMONTOIRES.

Under the head of escapements we mentioned the causes of error in all the common escapements which derive the impulse to the pendulum from the clock-train, viz., the variation of friction arising from dirt, want of fresh oil, thickening of the oil in cold weather, and the action of the wind on the hands. It was long ago perceived that all these sources of error, except the friction of the pallets, might he cut off (assuming the problem of a gravity escapement to be as hopeless as it had come to be considered from the numerous failures) by making the force of the scape-wheel to depend on a small weight or spring wound up at short intervals by the great clock weight and the train of wheels.

This also has the advantage of giving a sudden and visible motion to the minute hand at those intervals, say of half a minute, when the remontoire work is let off, so that time may be taken from the minute hand of a large public clock as exactly as from the seconds hand of an astronomical clock ; and besides that, greater accuracy may be obtained in the letting off of the striking part. The attempt to secure the advantage of a more constant force was made many years before the possibility of making turret clocks go with anything like the accuracy of astronomical clocks was contemplated ; and we believe the first maker of a large clock with a train remontoire, was the late Mr Thomas Reid, clockmaker, of Edinburgh, who wrote the article on clocks in the first edition of the *Encyclopædia Britannica*, which was afterwards expanded into a well known book, in which this remontoire is described. The scape-wheel was driven by a small weight hung by a Huygens' endless chain, of which one of the pulleys was fixed to the arbor, and the other rode upon the arbor with the pinion attached to it, and the pinion was driven, and the weight wound up by the wheel below (which we will call the 3d wheel), as follows :—Assuming the scape-wheel to turn in a minute, its arbor has a notch cut half through it on opposite sides in two places near to each other : on the arbor of the wheel, which turns in 10 minutes suppose, there is another wheel with 20 spikes sticking out of its rim, but alternately in two different planes, so that one set of spikes can only pass through one of the notches in the scape-wheel arbor, and the other set only through the other. Whenever, then, the scape-wheel completes a half turn, one spike is let go, and the third wheel is able to move, and with it the whole clock-train and the hands, until the next spike of the other set is stopped by the scape-wheel arbor; at the same time the pinion on that arbor is turned half round, winding up the remontoire weight, but without taking its pressure off the scape-wheel. Reid says that so long as this apparatus kept in good order, the clock went better than it did after it was removed in consequence of its getting out of order, from the constant banging of the spikes against the arbor.

The Exchange clock was originally made on the same principle, except that, instead of the endless chain, an internal wheel was used, with the spikes set on it externally, which (as we explained under *equation work*) is one of the modes by which an occasional secondary motion may be given to a wheel without disturbing its primary and regular motion. A drawing of the original Exchange clock remontoire, and also one of the bevelled-wheel plan (like that in fig. 2), which is generally used in the French remontoire clocks, is given in the *Rudimentary Treatise;* but for the reasons which will appear presently, it need not be repeated here, especially as the following is a more simple arrangement of a gravity train remontoire, also used by the French. Let E in fig. 18 be the scape-wheel turning in a minute, and *e* its pinion, which is driven by the wheel D having a pinion *d* driven by the wheel C, which we may suppose to turn in an hour. The arbors of the scape-wheel and hour-wheel are distinct, as in fig. 2, their pivots meeting in a bush fixed somewhere between the wheels. The pivots of the wheel D are set in the frame AP, which rides on the arbors of the hour-wheel and scape-wheel, or on another short arbor between them. The hour-wheel also drives another wheel G, which again drives the pinion *f* on the arbor which carries the two arms *f* A, *f* B; and on the same arbor is set a fly with a ratchet, like a common striking fly, and the numbers of the teeth are so arranged that the fly will turn once for each turn of the

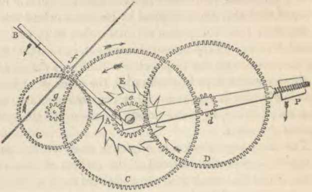

Fig. 18.

scape-wheel. The ends of the remontoire arms *f* A, *f* B, are capable of alternately passing the notches cut half through the arbor of the scape-wheel, as those notches successively come into the proper position at the end of every half minute; and as soon as that happens the hour-wheel raises the moveable wheel D and its frame through a small angle; but nevertheless, that wheel keeps pressing on the scape-wheel as if it were not moving, the point of contact of the wheel C and the pinion *d* being the fulcrum or centre of motion of the lever A *d* P. It will be observed that the remontoire arms *f* A, *f* B, have springs set on them to diminish the blow on the scape-wheel arbor, as it is desirable not to have the fly so large as to make the motion of the train, and consequently of the hands, too slow to be distinct. In all the French remontoire clocks in the Great Exhibition the motion was too slow, and consequently less easy to observe accurately than in the Royal Exchange, and King's Cross station clocks, or the clock over Mr Dent's shop in the Strand, in which the half-minute jump of the hands is very distinct. In the French clocks also the fly is generally driven by an endless screw, without the intermediate wheel G; but there is an enormous loss of force by friction in driving an endless screw, and consequently considerable risk of the clock stopping from either cold or wasting of the oil.

In all these gravity remontoires, however, it must have been observed that we only get rid of the friction of the heavy parts of the train and the dial-work, and that the scape-wheel is still subject to the friction of the remontoire wheels, which, though much less than the other, is still something considerable. And accordingly, attempts have frequently been made to drive the scape-wheel by a spiral spring, like the mainspring of a watch. One of these was described in the 7th edition of the *Encyclopædia Britannica ;* and Mr Airy, a few years ago, invented another, of which two or three specimens were made by Mr Dent. But it was found, and indeed it ought to have been foreseen. that these contrivances were all defective in the mode of attaching the spring, by making another wheel or pinion ride on the arbor of the scape-wheel, which produced a very mischievous friction, and so only increased the expense of the clock without any corresponding advantage ; and the consequence was, that spring remontoires, and remontoires in general, had come to be regarded as a mere delusion. It has, however, now been fully proved that they are not so ; for, by a very simple alteration of the previous plans, a spiral spring remontoire may be made to act with absolutely no friction, except that of the scape-wheel pivots, and the letting-off springs A, B, in the last drawing. The Meanwood clock (fig. 17) was the first of this kind ; but it will be necessary to give a separate view of the remontoire work.

In the next figure (19), A, B, D, E, *e*, *f*, are the same things as in fig. 18. But *e*, the scape-wheel pinion, is no longer fixed to the arbor, nor does it ride on the arbor, as had been the case in all the previous spring remontoires, thereby producing probably more friction than was saved in other respects; but it rides on a stud *k*, which is set in the clock-frame. On the face of the pinion is a plate, of which the only use is to carry a pin *h* (and consequently its shape is immaterial), and in front of the plate is set a bush *b*, with a hole through it, of which half is occupied by the end of the stud *k*, to which the bush is fixed by a small pin, and the other half is the pivot-hole for the scape-wheel arbor. On the arbor is set the remontoire spring *s* (a moderate-sized musical-box spring is generally used) of which the outer end is bent into a loop to take hold of the pin *h*. In fact, there are two pins at *h*, one a little behind the other, to keep the coils of the spring from touching each other. Now, it is evident that the spring may be wound up half or a quarter of a turn at the proper intervals, without taking the force off the scape-wheel, and also without affecting it by any friction whatever. When the scape-wheel turns in a minute, the letting off would be done, as before described, by a couple of notches in the scape-wheel arbor, through which the spikes A, B, as in fig. 18, would pass alternately. But in clocks with only three wheels in the train, it is best to make the scape-wheel turn in two minutes, and consequently you would

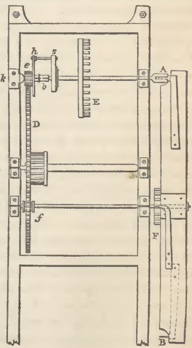

Fig. 19.

want four notches and four remontoire arms, and the fly would only make a quarter of a turn. And therefore Mr Denison, who invented this remontoire, made the following provision for diminishing the friction of the letting-off work. The fly pinion *f*, has only half the number of teeth of the scape-wheel pinion, being a lantern pinion of 7 or 8, while the other is a leaved pinion of 14 or 16, and therefore the same wheel D will properly drive both, as will be seen hereafter. The scape-wheel arbor ends in a cylinder about ⅝th inch in diameter, with two notches at right angles cut in its face, one of them narrow and deep, and the other broad and shallow, so that a long and thin pin B, can pass only through one, and a broad and short pin A, through the other. Consequently, at each quarter of a turn of the scape-wheel, the remontoire fly, on which the pins A, B, are set on springs, as in fig. 17, can turn half round. It is set on its arbor *f* by a square ratchet and click, which enables you to adjust the spring to the requisite tension to obtain the proper vibration of the pendulum. The fly is not separate from the letting-off arms, because there is found to be no occasion for it, except in very large clocks; but the blow on the cylinder is diminished by the fly having to pass over a friction-spring (which cannot be distinctly shown in this drawing) just before it reaches the cylinder. It makes, indeed, a considerable noise at each let off; but that is chiefly owing to the recoil against the top of this friction-spring; and some of these clocks have now been going since the year 1849, without any inconvenience from that cause. And their performance is so much more satisfactory than that of the gravity remontoires, that Mr Dent altered the gravity remontoire of the Royal Exchange to a spring one in 1854, which had the effect of reducing the clock-weight by one-third, besides improving the rate of going. It should be observed, however, that even a spring remontoire requires a larger weight than the same clock without one; but as none of that additional force reaches the pendulum, that is of no consequence. The variation of force of the remontoire spring from temperature, as it only affects the pendulum through the medium of the dead escapement, is far too small to produce any appreciable effect; and it is found that clocks of this kind, with a compensated pendulum 8 feet long, and of about 2 cwt., will not vary above a second a month, if the pallets are kept clean and well oiled. No turret clock without either a train remontoire or a gravity escapement will approach that degree of accuracy. The King's Cross clock has sometimes gone for two months without any discoverable error, even of a second, though without the jewelled pallets which the Exchange clock has.

The introduction of this remontoire led to another very important alteration in the construction of large clocks. Hitherto it had always been considered necessary, with a view to diminish the friction as far as possible, to make the wheels of brass or gun-metal, with the teeth cut in an engine. The French clockmakers had begun to use cast iron striking parts, and cast-iron wheels had been occasionally used in the going part of inferior clocks for the sake of cheapness. Mr Vulliamy used them for cheap clocks some years ago; but cast-iron wheels had never been used in any clock making pretensions to accuracy before Mr Dent's clock in 1851, which is stated in the jury report to have only varied 3 seconds in the last 10 weeks of the Exhibition. Since then all the large clocks made at his factory, either with this remontoire or with the three-legged gravity escapement before described, have been made with cast-iron wheels; and in 1852 it was determined by the Astronomer Royal and Mr Denison, who were jointly consulted by the Board of Works about the great Westminster clock, to alter the original requisition for gun-metal wheels there to cast-iron. Some persons have expressed their apprehension of iron wheels rusting; but nothing can be more unfounded, for the non-acting surfaces are always painted, and the acting surfaces oiled. A remarkable proof of the folly of the clockmakers' denunciations of cast-iron wheels has lately been afforded at the Royal Exchange. In consequence of the bad ventilation of the clock-room, together with the effects of the London atmosphere, some thin parts of the brass work had become so much corroded that they had to be renewed, and some of it replaced with iron ; and all the polished iron and brass work had become as rough as if it had never been polished at all ; the only parts of the clock which had not suffered from the damp and the bad air were the painted iron-work. The room has now been ventilated, with a draught through it, and all the iron-work, except acting surfaces, is painted. But even in the most favourable positions brass or gun-metal loses its surface long before cast-iron wants repainting.

There is, however, a curious point to be attended to in using cast-iron wheels. If the teeth have not the sharp roughness of the sand taken off, they will only work well with cast-iron pinions, and will wear out steel. When they are small, the expense of filing this roughness off is more than the difference between the cost of brass wheels cut and iron wheels cast ; but not so when they are large ; and therefore the best plan is to make the great wheel of the going part, and the pinion which it drives, of cast-iron, besides all the leading-off and motion wheels and pinions in the dial-work, and the two smaller wheels in the train of brass, which may as well be painted like the iron. The whole of the striking part wheels and pinions may be of iron. A great deal of nonsense is talked about gun-metal, as if it was necessarily superior to brass. The best gun-metal may be, and is, for wheels which are too thick to hammer ; but there is great variety in the quality of gun-metal : it is often unsound, and has hard and soft places ; and, on the whole, it has no advantage over good brass, when not too thick to be hammered. In clocks made under the pressure of competing tenders, if the brass is likely not to be hammered, the gun-metal is quite as likely to he the cheapest and worst possible, like everything else which is always specified to be "best," as the clockmakers know very well that it is a hundred to one if anybody sees their work that can tell the difference between best and worst.

TURRET CLOCKS WITH GRAVITY ESCAPEMENT.

Fig. 20 is a front view of one of Mr Dent's large quarter clocks, with all the wheels on the great horizontal bed, a gravity escapement, and a compensated pendulum. They are made in two sizes, one with the great striking wheels 18 inches wide, and the other 14. The striking is done by cams cast on the great wheels, about 1⅛ inch broad in the large-sized clocks, which are strong enough for an hour bell of 30 cwt., and corresponding quarters. Wire ropes are used, not only because they last longer, if kept greased, but because a sufficient number of coils will go on a barrel of less than half the length that would be required for hemp ropes of the same strength, without overlapping, which it is as well to avoid, if possible, though it is not so injurious to wire ropes as it is to hemp ones. By this means also the striking cams can be put on the great wheel, instead of the second wheel, which saves more in friction than could be imagined by any one who had not tried both. In clocks of the common construction two-thirds of the power is often wasted in friction and in the bad arrangement of the hammer work, and the clock is wearing itself out in doing nothing.

We have given the same number of cams to the quarter as to the hour-striking wheel, rather for the purpose of suggesting the expediency of omitting the 4th quarter, as has been done in several clocks lately made from this design. It is of no use to strike the quarters at the hour, and it nearly doubles the work to be done, and if it is omitted, it allows the quarter bells to be larger, and therefore louder,

TURRET CLOCKS WITH DENISON'S GRAVITY ESCAPEMENT.

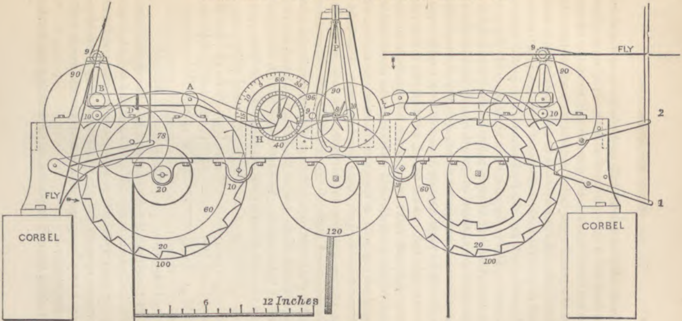

Fig. 20.

because the 1st quarter bell ought to be an octave above the hour bell, if they are struck at the hour; whereas, if they are not heard together, the quarters may be on the 4th and 7th of a peal of eight bells; and where cheapness has to be considered, and there are no bells ready for the clock, there need only be two bells, the larger of them being used for the 2d quarter bell, and also for the hours, with a rather heavier hammer. This is the case with the clock by Mr Joyce at the savings bank at Chester, made on the plan of fig. 20. Moreover, the omission of the 4th quarter enables you to have the celebrated quarter chimes of St Mary's, Cambridge (with a slight variation only in one of them), with a peal of only eight bells, on the 2d, 3d, 4th, and 7th, and at very little additional cost; whereas the full quarters, on four bells, require a considerable addition to the clock, besides a peal of ten bells, as they must be struck on the 1st, 2d, 3d, and 6th—the 10th being the hour bell. The following are the quarters on this plan, first used in the before-mentioned clock of the cathedral at Fredericton—of St Mary's, Cambridge, which are adopted also in the great Westminster clock—and of the Exchange, which are very inferior to the others. Quarters on the 1st, 2d, 3d, and 4th bells of a peal are still worse, though more common.

	Fredericton.		Cambridge.		Exchange.
1st	2347	*2d*	3126		3126
2d	4237		3213		6213
	4324	*3d*	1326	*4th*	1326
3d	3724		6213		3213
	7324		1236	*1st*	
	2347				
hour……8.		hour…10			hour…10

At Cambridge the chimes are set on a barrel which turns twice in the hour, as this table indicates, and which is driven by the great wheel with a great waste of power: the clock is wound up every day; in an eight-day clock it would require a very heavy weight, and a very much greater strain on the wheels.

Indeed, there is some reason for doubting whether the modern introduction of eight-day clocks is an improvement, where they have to strike on large bells. Such clocks hardly ever bring the full sound out of the bells; because, in order to do so, the weights would have to be so heavy, and the clock so large, as to increase the price considerably. A *good* bell, even of the ordinary thickness, which is less than in the Westminster bells, requires a hammer of not less than $\frac{1}{40}$th of its weight, rising 8 inches from the bell, to bring out the full sound; and therefore, allowing for the loss by friction, a bell of 30 cwt., which is not an uncommon tenor for a large peal, would require a clock weight of 15 cwt., with a clear fall of 40 feet; and either the Cambridge quarters on a peal of ten, or the Fredericton ones on a peal of eight, will require above a ton, according to the usual scale of bells in a ringing peal (which is very different from that of the Westminster clock bells). Very few clocks are adapted for such weights as these; and without abundance of strength and great size in all the parts, it would be unsafe to use them. But if the striking parts are made to wind up every day, of course $\frac{1}{7}$th of these weights will do; and you may have a more powerful clock in effect, and a safer one to manage, in half the compass, and for much less cost. Churches with such bells as these have always a sexton or some other person belonging to them, and in attendance every day, who can wind up the clock just as well as a clockmaker's man. The going part always requires a much lighter weight, and may as well go a week, and be in the charge of a clockmaker, where it is possible.

There should be some provision for holding the hammers off the bells while ringing, and at the same time a friction-spring or weight should be brought to bear on the fly arbor, to compensate for the removal of the weight of the hammers; otherwise there is a risk of the train running too fast and being broken when it is stopped.

No particular number of cams is required in the striking wheel: any number about 20 will do; but when four quarters on two bells are used, the quarter-striking wheel should have half as many cams again as the hour-wheel: for, if not, the rope will go a second time over half of the barrel, as there are 120 blows on each quarter bell in the 12 hours, to 78 of the hours, while with the three quarters there are only 72. If the two quarter levers are on the same arbor, there must be two sets of cams, one on each side of the wheel; but one set will do, and the same wheel as the hour-wheel, if they are placed as in fig. 20. The hour-striking lever, it will be seen, is differently shaped, so as to diminish the pressure on its arbor by making it only the difference, instead of the sum of the pressures at the two points of action. This *can* be done with the two quarter levers, as shown in the Rudimentary Treatise; but the arrangement involves a good deal of extra work; and as the quarter hammers are always lighter than the hour one, it is hardly worth while to resort to it. The shape of the cams is a matter requiring some attention, but it will be more properly considered when we come to the *teeth of wheels*. The Fredericton quarters may have separate cam-wheels cast in pairs, and one pair may be on the great wheel, with the cams on its opposite sides.

The fly ratchets should not be made of cast-iron, as they sometimes are by clockmakers who will not use cast-iron wheels on any account, because the teeth get broken off by the click. This breaking may indeed be avoided by making the teeth rectangular, like a number of inverted V's set round a circle, and the click only reaching so far that the face of the tooth which it touches is at right angles to the click; but, as before observed, cast-iron and steel do not work well together.

The hammer of a large clock ought to be left "on the lift," when the clock has done striking, especially if it is a clock with a train remontoire, in which the first blow ought to be struck at the moment the hand jumps from 59½ min. to 60, as there are always a good many seconds lost in the train getting into action and raising the hammer. Moreover, when it stops on the lift, the pressure on the stops, and on all the pinions above the great wheel, is only that due to the excess of the power of the clock over the weight of the hammer, and not the full force of the weight, and it is therefore easier for the going part to discharge, and less likely to break, the stops.

In fig. 20 the wheel marked 60 in each of the striking parts is a winding wheel on the front end of the barrel, and the winding pinion is numbered 10; a larger pinion will do where the hammer does not exceed 40 lb.; and in small clocks no auxiliary winding wheel is needed. But in that case the locking-plate must be driven by a gathering-pallet, or pinion with two teeth, on the arbor of the second wheel, with a spring click to keep it steady. In all cases the hammer shanks and tails should not be less than two feet long, if possible; for the shorter they are, the more is lost by the change of inclination for any given rise from the bell. In some clocks lately put up by Mr Dent with fixed, not swinging bells, the hammer-head is set on a double shank embracing the bell, with the pivots, not above it, in the French way, which makes the hammer strike at a wrong angle, but on each side of the bell, a little below the top. On this plan less of the rise is lost than in the common mode of fixing. The Westminster clock hammer will be fixed in this way.

The first thing to remark in the going part of fig. 20 is, that the hour-wheel which carries the snails for letting off the quarters and striking, is not part of the train leading up to the scape-wheel, but independent, so that the train from the great wheel to the scape-wheel is one of three wheels only. If it were a dead escapement, instead of a gravity escapement clock, the wheel numbered 96 would be the scape-wheel; and as it turns in 90 seconds, it would require 36 teeth or pins for a 1¼ sec. pendulum, which these gravity-escapement clocks have; it is about 6 feet long to the bottom of the bob, which, if sunk just below the floor, brings the clock frame to a very convenient height. The hour-wheel rides loose on its arbor, or rather the arbor can turn within it, carrying the snails and the regulating hand and the bevelled wheel which drives all the dials, and it is fixed to the hour-wheel by means of clamping screws on the edge of a round plate on the arbor just behind it, which turn by hand. In a gravity-escapement clock this adjusting work is not really necessary; because you can set the clock by merely lifting the pallets off the scape-wheel, and letting the train run till the hands point right. The regulating hand, you observe in fig. 20., turns the wrong way; because, where the dial is opposite to the back of the clock, no bevelled wheels are wanted, and the arbor leads straight off to the dial. It used to be the fashion to put clocks in the middle of the room, so that the leading-off rod might go straight up to the horizontal bevelled wheel in the middle, which drove all the dials. But the clock can be set much more firmly on stone corbels, or on cast-iron brackets built into the wall; and it is not at all necessary for the leading-off rod to be vertical; provided it is only in a vertical plane parallel to the wall, or the teeth of the bevelled wheels adapted to the inclination, the rod may stand as obliquely as you please; and when it does, it ought on no account to be made, as it generally is, with universal joints, but the pivots should go into oblique pivot-holes at the top and bottom. The joints increase the friction considerably, and are of no use whatever, except where the rod is too long to keep itself straight. Where the rod does happen to be in the middle of the room, and there are three or four dials, the two horizontal bevelled wheels at each end of it must be a little larger than all the others—both the one in the clock and those of the dial-work; for otherwise the three or four wheels in the middle will meet each other and stick fast.

When the pendulum is very long and heavy, it should be suspended from the wall, unless the clock-frame has some strong support near the middle; but a six-feet pendulum, of not more than 2 cwt., may be suspended from the clock-frame, provided it is as strong as it ought to be for the general construction of the clock, and supported on corbels or iron beams. It has generally been the practice to hang the pendulum behind the clock-frame; but inasmuch as the rope of the going part may always be thinner than that of the striking part, and that part requires less depth in other respects, a different and more compact plan is adopted in the clocks we are describing. The back pivots of the going wheels run in bushes on an intermediate bar, three or four inches from the back of the frame, joining the two cross bars, of which the ends are dotted in the drawing. The pendulum cock is set on the back frame, and the pendulum hangs within it. And in the gravity-escapement clocks there is yet another thin bar—about half way between the back frame and the bar on which the bushes of the wheels are set—the only use of which is to carry the bush of the three-legged scape-wheel, which is set behind the fly; the wheel, the fly, and the pallets, or gravity-arms, stand between these two intermediate bars; and the pallet-arbors are set in a brass cock screwed to the top of the pendulum-cock. The adjustment for beat is not made, as in fig. 12, but by short arms screwed adjustably to the pallets above the stops, and carrying the fork-pins. They are not shown in fig. 20, but may easily be imagined. The same might be done in small clocks; but from the confined space, and the lightness of the gravity arms, it is not so convenient as the beat-screws in the pendulum. The fork-pins, or the heads of the beat-screws, should be of brass, not steel, and no oil put to them.

The same general arrangement will serve for a dead escapement clock with or without a train remontoire; only the pendulum will not stand so high, and the front end of the pallet arbor must be set in a cock like those of the striking flies, on the front bar of the frame. And for a dead escapement, if there are large dials and no remontoire, the pendulum should be longer and heavier than that which is quite sufficient for a gravity escapement. The rod of a wooden pendulum should be as thin as it can conveniently be made, and varnished, to prevent its absorbing moisture.

DIALS.

The established form of dial for turret clocks is a sheet of copper made convex, to preserve its shape; and this is just the worst form which human ingenuity could have contrived for it. For, in the first place, the minute-hand, being necessarily outside of the hour hand, is thrown still farther off the minutes to which it has to point, by the convexity of the dial; and consequently, when it is in any position except nearly vertical, it is impossible to see accurately where it is pointing; and if it is bent enough to avoid this effect of *parallax*, it looks very ill. Secondly, A convex dial at a considerable height from the ground looks even more convex than it really is, because the lines of sight from the middle and the top of the dial make a smaller angle with the eye than the lines from the middle and the bottom, in proportion to the degree of convexity. Obvious as is the remedy for these defects, by simply making the dial concave instead of convex, it has, we believe, never been adopted until Mr Dent introduced this improvement also, at Mr Denison's suggestion, in some clocks for the Great Northern Railway, at Doncaster, and on the platform at the King's Cross station. As convex dials look more curved than they are, these look less curved than they are, and, in fact, might easily be taken for flat ones, though the curvature is exactly the same as usual. Old convex dials are easily altered to concave, and the improvement is very striking where it has been done. There is no reason why the same form should not be adopted in stone, cement, slate, or cast-iron, in which materials dials are sometimes, and properly enough, made with the middle part countersunk for the hour hand, so that the minute-hand may go close to the figures and avoid parallax. When dials are large, copper, or even iron or slate, is quite an useless expense, if the stonework is moderately smooth, as most kinds of stone take and retain paint very well, and the gilding will stand upon it better than it often does on copper or iron. The figures are generally made much too large. People have a pattern-dial painted; and if the figures are not as long as one third of the radius, and therefore occupying, with the minutes, about two-thirds of the whole area of the dial, they fancy they are not large enough to be read at a distance; whereas the fact is, the more the dial is occupied by the figures, the less distinct they are, and the more difficult it is to distinguish the position of the hands, which is what people really want to see, and not to read the figures, which might very well be replaced by twelve large spots. There is a clock with a dial of this kind in the London Athenæum; and though it is constantly referred to as a regulator of watches, nobody has ever complained of the want of figures, which, after all, do not mean what they say, as you read "twenty minutes to" something, when the minute-hand points to VIII. The rule which has been adopted, after various experiments, as the best for the proportions of the dial, is this:—Divide the radius into three, and leave the inner two-thirds clear and flat, and of some colour forming a strong contrast to the colour of the hands, black or dark blue if they are gilt, and white if they are black. The figures should occupy the next two-thirds of the remaining third, and the minutes be set in the remainder, near the edge, and with every fifth minute more strongly marked than the rest; and there should *not* be a rim round the dial, as there generally is, of the same colour or gilding as the figures. The worst kind of dial of all are the things called skeleton-dials, which either have no middle except the stonework, forming no contrast to the hands (to which state the authorities of

Trinity College, Cambridge, have lately altered their well-known double-striking clock, put up by the famous Dr Bentley, striking, as it used to be said, once for Trinity and once for his former college, St John's, which had no clock), or else taking special trouble to perplex the spectator by filling up the middle with radiating bars. Where a dial cannot be put without interfering with the architecture, it is much better to have none, as is the case in many cathedrals and large churches, leaving the information to be given by the striking of the hours and quarters. This also will save something, perhaps a good deal, in the size and cost of the clock; and if it is one without a train remontoire or gravity escapement, will enable it to go better. The size of public dials is often very inadequate to their height and the distance at which they are intended to be seen. They ought to be at least 1 foot in diameter for every 10 feet of height above the ground, and in many cases more, whenever the dial will be seen far off; and this rule ought to be enforced on architects, as they are often not aware of it till too late, and indeed seldom make proper provisions for the clock or the weights in building a tower.

The art of illuminating dials cannot be said to be in a satisfactory state. Where there happens to be, as there seldom is, a projecting roof at some little distance below the dial, it may be illuminated by reflection, like that at the Horse Guards—about the only merit which that superstitiously venerated and bad clock has; and perhaps the same thing might be done by moveable lamp reflectors, like those put before shop windows at night, to be turned back against the wall during the day; but such an arrangement would be expensive in working and attendance, even if it could be conveniently arranged. It has also been proposed to sink the dial within the wall, and illuminate it by jets of gas pointing inwards from a kind of projecting rim, like what is called in church windows a "hood-moulding," carried all round. But it is a great objection to sunk dials, even of less depth than would be required here, that they do not receive light enough by day, and do not get their faces washed with the rain. The common mode of illumination is by making the dials either entirely, or all except the figures and minutes and a ring to carry them, of glass, either ground or lined in the inside with linen (paint loses its colour from the gas). The gas is kept always alight, but the clock is made to turn it nearly off and full on at the proper times by a 24-hour wheel, with pins set in it by hand as the length of the day varies. Self-acting apparatus has been applied, but it is somewhat complicated, and an unnecessary expense. But these dials always look very ill by day; and it seems often to be forgotten that dials are wanted much more by day than by night; and also, that the annual expense of lighting 3 or 4 dials far exceeds the interest of the entire cost of any ordinary clock. White opaque glass with black figures has lately been introduced, and it is very superior to the common method. It is used in the great Westminster clock dials. It is somewhat of an objection to illuminating large dials from the inside, that it makes it impossible to counterpoise the hands outside, except with very short, and therefore very heavy, counterpoises. And if hands are only counterpoised inside, there is no counterpoise at all to the force of the wind, which is then constantly tending to loosen them on the arbor, and that tendency is aggravated by the hand itself pressing on the arbor one way as it ascends, and the other as it descends; and if a large hand once gets in the smallest degree loose, it becomes rapidly worse by the constant shaking. It is mentioned in Reid's book, that the minute-hand of St Paul's cathedral, which is above 8 feet long, used to fall over above a minute as it passed from the left to the right side of XII, before it was counterpoised outside. In the conditions to be followed in the Westminster clock it was expressly required that "the hands be counterpoised externally, for wind as well as weight." The long hand should be straight and plain, to distinguish it as much as possible from the hour-hand, which should end in a "heart" or swell. Many clockmakers and architects, on the contrary, seem to aim at making the hands as like each other as they can; and it is not uncommon to see even the counterpoises gilt, probably with the same object of producing apparent symmetry and real confusion.

THE GREAT WESTMINSTER CLOCK.

As this long talked-of specimen of horology, and the tower which is to hold it, are at last approaching their completion, we shall give a fuller description of the clock than was or could be given before, either in the former edition of this book, or in the *Rudimentary Treatise on Clockmaking*, in which the earlier stages of the business were related. And on account of the great interest it has excited —no less than four collections of official correspondence about it having been already published as Parliamentary papers,—and the extraordinary conduct of the government throughout the greater part of the business; and further, on account of the pertinacity with which the great body of English clockmakers have endeavoured to defeat and run down the construction of the largest clock in the world on a plan so different from anything they can appreciate or even understand (as appears from their own Memorial to the government), we shall preface the mechanical description of the clock with a short abstract of its history.

That history already extends over the almost incredible period of thirteen years; for it was so long ago as March 1844, that the architect of the Houses of Parliament represented to Her Majesty's Commissioners of Parks, Palaces, and Public Buildings (commonly called for shortness, the Board of Works), that it was time to take some steps about the clock, in order that the tower might be carried up in accordance with the plans to be adopted. He recommended application to be made to the late Mr Vulliamy, who had certainly been the best maker of large clocks in England until Mr Dent introduced the improvements already noticed in the Exchange clock, which was just then finished, and of which the astronomer royal certified that it was "superior to most astronomical clocks in the steadiness of its rate, and, he had no doubt, was the best public clock in the world." Mr Dent soon afterwards applied to be admitted as a competitor for the Westminster clock; and Mr Airy, being fortunately consulted by Lord Canning, then at the head of the Board of Works, of course recommended that he should be admitted, together with Mr Whitehurst of Derby, who had been one of the competitors for the Exchange clock, and had made some very large clocks at Liverpool and other places. A well-known Clerkenwell firm, who said they had made about 3000 turret clocks, afterwards applied. But they did not even profess to be able to comply with the conditions required by Mr Airy for securing accuracy of performance equal to an astronomical clock, and it was therefore clearly of no use to admit them.

The following were the conditions which he proposed, so far as they are now material; for some of them related to details of construction of no consequence now.

1. The escapement was to be dead-beat, or something equally accurate; and the pallets jewelled (*i. e.*, if the dead escapement was used).

2. The pendulum to be compensated.

3. The train to have a remontoire action; and it would be considered an advantage if the minute-hand had a visible motion at definite intervals (as in that at the King's Cross Station, and the Royal Exchange clock, to which the competitors were referred).

4. The striking of the first blow of the hour to be accurate to a second of time. (In reality, the object of all the

other conditions was to secure the permanent compliance of the clock with this.)

5. A spring apparatus to be attached for temporarily accelerating the pendulum (to enable the clock to be altered less than a double vibration of the pendulum without stopping it).

6. The wheels to be of bell-metal (or hard gun-metal), with epicycloidal teeth, and to be so arranged that any one can be taken out without disturbing the others.

7. The plans, and the work when completed, to be subject to the approval of the astronomer royal.

With these conditions Mr Vulliamy at once refused to comply, except as to using the dead escapement and gun-metal wheels, separately removeable, which was the case in his clocks generally. The rest he denounced as either useless or impossible, especially the 4th, which was the most important of them all. He also refused to give any estimate, or indeed to make the clock at all, except upon his own terms, and in his own way, and subject to some other referees proposed by himself, not one of whom had anything to do with horology (as the astronomer royal necessarily has), or was known to have paid any attention to it. He had also originally stipulated that he should have 200 guineas for making plans, if he was not employed, and 100 guineas if he was; and with these terms the Board of Works was foolish enough to comply, though his plans could not be of any use, as he would not comply with the conditions, nor furnish an estimate, though he had made one, and neither of the other candidates were to receive a farthing for their plans, whether adopted or not. Notwithstanding his refusal to comply with the conditions, Mr Vulliamy afterwards sent in plans, relying, we suppose, on the chances of some government office engineering, to get rid of Mr Airy and his conditions, and ultimately to make the clock in his own way. Indeed, it appears from the papers, that he was so confident of this as to predict openly that "Mr Dent would never make that clock," even after Mr Dent's plan had been approved by the astronomer royal, and his own condemned. He gave a very full and elaborate description of his clock, which was printed by both Houses of Parliament in 1847, along with a quantity of other documents, but thrown together by the Board of Works with such a blundering confusion of dates and subjects, that it is no easy matter to make out the history of the various transactions contained in them. His plan was distinguished by a number of mechanical refinements and adjustments, of no use whatever for securing the great object of accuracy of time-keeping, and some of them decidedly objectionable, and founded on mistaken and unscientific notions, as Mr Airy pointed out. Without going into details, the escapement and its appurtenances, on which the accuracy of performance all depends, were extremely coarse and heavy, and the pendulum neither compensated for temperature, nor in any way protected from the disturbances of friction, which would be enormous, with four pairs of such large and heavy hands. It is not surprising therefore, that the astronomer royal should have pronounced it nothing better than "a large village clock of superior construction," but entirely deficient in provisions for securing the accuracy of an astronomical clock. And as the going part was deficient in provisions for accuracy of going, the striking part was no less deficient in strength. For although, in some respects, the provisions for strength were ample, yet "nothing is stronger than its weakest part;" and some of the arrangements were so absurdly inadequate even for the work professed to be done, that the clock would have broken itself to pieces in a week; if indeed it could ever have been made to strike at all, with the enormous loss of power in friction that would have been involved by the defective arrangement of the levers and striking-pins, and of the ropes and pulleys. There can be little doubt, that a hammer no heavier than that of St Paul's clock, which Mr Vulliamy actually proposed to use for a bell of nearly three times the weight of that bell, would have required as many tons weight to raise it with his machinery as will raise the hammer six or eight times as heavy in the clock now made. Yet this was the plan, in the success of which the Company of Clockmakers assured the Board of Works they had the greatest confidence, in order to defeat the plan now adopted.

Mr Whitehurst's plan was very superior to Mr Vulliamy's in the strength of the striking parts. Not only did he raise his hammer from the great wheel instead of the second, but he proposed to wind up the striking parts twice a week instead of once, whereby he gained theoretically double the power with the same weight, and practically a great deal more, on account of the great saving in friction by being able to use larger pinions, and a lighter weight, with wheels of the same size. We cannot say anything of his going part arrangements, because they were very imperfectly described; and indeed he did not profess to understand the construction required to satisfy the astronomer royal's conditions, but merely offered to adopt the construction which he might prescribe. We do observe, however, that the great wheel of his going part was smaller than either Mr Vulliamy's or Mr Dent's, and obviously too small for such a clock, being only 18 inches in diameter. He proposed to omit the quarters at the striking of the hour, which, though a very good plan generally, would probably not have satisfied the public in such a clock as this. By a strange omission, neither the character of the quarters, nor even the weight of the great bell, was ever officially prescribed to the competitors, and accordingly they all assumed either different sizes or numbers of bells.

Mr Dent's plan was satisfactory to the astronomer royal in all the provisions for securing accuracy of performance; wherein it was substantially the same as he had before made at the Exchange. He seems to have doubted, however, about the strength compared with Mr Whitehurst's; but this opinion must have been formed rather hastily from the mere general aspect of the plans; since Mr Dent's great going wheel, which drives all the hands, was actually the larger of the two; and what is still more remarkable, Mr Airy did not observe that Mr Dent contemplated a bell of little more than half the weight assumed in the other two plans; and consequently his striking part was really larger and stronger in proportion to the work it was intended for than either of them, and especially Mr Vulliamy's. He also contemplated only two quarter-bells. To a certain extent, though by no means to the full extent, Mr Dent's rather smaller striking parts will account for what Mr Airy naturally called "the astonishing difference" between his tender and Mr Whitehurst's. Mr Vulliamy, as was said before, refused to send in any estimate; but he informed the Board several years afterwards that he had made one at the time for his own satisfaction; and including the 100 guineas he was to have for his drawings, even if he made the clock, the three estimates would then have stood as follows:—

Vulliamy	£3605
Whitehurst	3373
Dent	1600

This, one would think, was tolerably conclusive, especially as it was clear, from all the astronomer royal's communications, that he considered Mr Dent the most competent to execute the work, independently of all question of price. But although the expressed object of all these proceedings was to enable the architect to have "the necessary specifications and drawings, in order that the [internal] walls of the tower might be carried up in accordance with the necessary arrangement of the machinery," not a single step was taken by the Board (then under Lord Carlisle) from the reception of Mr Airy's report on the three plans in 1847, until Lord Seymour took the business up again in 1851. No intimation was given to Mr Dent that he would either be employed or not: the Board would not answer his letters until a motion was made for their production: he was put in no communication with the architect: and when the matter was resumed, it was naturally enough found that the internal walls of the tower had been carried up in a manner which was *not* in accordance with the most convenient arrangement of the machinery; and it then required a good deal of scheming to get the weights to fall straight under the clock, as it is very important they should when so large, as may be seen from their closeness to the walls of the shaft in the view of the clock given in the frontispiece; and it will be observed that the wheels of the striking parts are obliged to overlap those of the going part, and the cross bars to be kept lower than the rest of the frame to get them in at all. And, but for an alteration made by Mr Denison in the usual shape of the bell, a bell of 14 tons could not have been taken up between the walls.

After this interval of four years, Mr Airy appears to have been consulted again, with the object of really getting the clock made; and he then desired to have Mr Denison associated with him, who had, in the meantime, published the *Rudimentary Treatise on Clocks* before referred to, and had been appointed chairman of the horological jury of the Great Exhibition, and was well known to have designed the large clock there to which the council medal was awarded in the manner stated at page 79; and accordingly this was done. Most of the improvements we have noticed had been invented or introduced since the former plans were sent in, and Mr Denison at once determined to proceed on a different system from the former one. He considered it impossible that a machine, which, on account of its unusual combination of size and delicacy, must contain a variety of new features, could be properly constructed from a defined and conclusive specification made beforehand; and therefore Mr Airy and he proposed that Mr

Dent, who was obviously the person to be employed, should be asked whether he would so far confide in the reasonableness of the two referees, as to engage for a specific sum to make the clock on a plan of which only the size and general features were defined in the specification, and were to be subject to such modification and such arrangement of the details as the referees should jointly prescribe as the work went on. Mr Dent consented to do this for the sum of L.1800, which was a very moderate advance on his former tender, considering that the bells were to be of twice the weight he reckoned on, and the size of the clock increased all over, and that he was to supply some things not included before, though, on the other hand, the wheels were to be of iron instead of gun-metal, for the reasons we have already given with reference to turret clocks in general. It is possible that the success of the great cast-iron transit-circle, which had been put up at Greenwich since the former negotiations about the clock, had given the astronomer royal confidence in that material for strong and accurate work; and it is certain that no engineer in the kingdom would now make the wheels of anything but cast-iron for a machine of the size of this clock, or anything approaching to it; the weight of the wheels and other revolving parts being from three to four tons, or twenty times as much as that of a very large church clock.

The clock was to strike the hours on a bell of 14 tons, as had been intended, but not specified, in 1846, and the quarters neither on 8, 5, or 2 bells, as had been proposed before, but those commonly known as the Cambridge chimes, which have been already described at page 90; and the clock was to be completed in two years, and only to be paid for on the approval of the referees. The drawings of the clock, which had been the basis of the contract, and were printed in a parliamentary paper of 1852, were superseded by others before they were even printed, because Mr Airy and Mr Denison found, when they came to inspect the state of the tower, that the internal walls had been already built in a manner inconsistent with that design; and various other alterations were gradually made in the plan, so that those drawings have ceased to represent anything in the actual clock beyond the size of the wheels. It was of course understood, that Mr Airy's original conditions for securing the striking of the first blow of the hour correctly within a second of time were to be adhered to, as longer experience had by that time fully proved the possibility of even greater accuracy than had been attained in the Exchange clock, as at first constructed (see p. 81). It was also intended to retain the visible motion of the minute hand at every 30 seconds; and the clock was accordingly at first made with the spring remontoire of the Exhibition clock. But when the momentum of these ponderous hands, jumping 7 inches on the circumference of the 22½ feet dials was tried, it was not considered safe to retain that movement; and the gravity escapement having been invented by that time, and in use for several years, and being sufficient to prevent the variations of force and friction in the train from reaching the pendulum and disturbing the time, the train remontoire was removed; in fact, all the train remontoires may now be considered as superseded by that escapement, which is not only equally effective for time keeping, but much cheaper to make, and less likely to be spoiled by careless hands afterwards.*

No sooner was it known that Mr Dent was engaged to make the clock, than the Company of Clockmakers rose in a body, and determined to make at least one more struggle

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* A gentleman in Northumberland, writing to Mr Denison lately about the application of the gravity escapement to astronomical clocks, of which he has several, says,—" I have already had practical proof of the excellence of your gravity escapement, having had it applied to my turret clock, together with a mercurial pendulum, a year ago, in the place of an ordinary dead escapement and pendulum with a lens-shaped lob and wooden rod; with the effect, I may say, of *reducing the variation of the clock from minutes*

for their master, Mr Vulliamy, and the old brass wheel and wooden pendulum interest. Lord Seymour, who had summoned Mr Airy and Mr Denison and contracted with Mr Dent, had gone, and was succeeded by Lord John Manners; and they sent him a memorial, "signed by order of the court" (which we are sorry is too long to copy here), on the unfitness of the astronomer royal, or the chairman of the horological jury of the Great Exhibition, to superintend or design the clock, and of Mr Dent, to whom the first prize for turret clocks had been unanimously awarded, to make it. And by way of showing their sense of the value of all the modern improvements in horology, they said that the clock at the Hotel de Ville, Paris (which was made 76 years ago), was still, in their opinion, "the first public clock in Europe." "They had felt," they said, "the greatest confidence in the success of the design" sent in by Mr Vulliamy (the astronomer royal's "large village clock"), "and it was consequently a subject which created great surprise to learn that that design had been entirely departed from, ... and the least experienced of the three gentlemen who had been allowed to compete in the first instance, chosen to make this important clock." If it should really be true that "the order had been definitively given" to this inexperienced gentleman, Mr Dent, to make the clock according to the design prepared by Mr Denison, then they humbly ventured to hope, that a committee of referees might be appointed, to whom the plans and specifications should be submitted, and by whom the work should be inspected and reported on as it progressed; which committee ought, in their opinion, to consist of Sir Charles Barry (who had originally recommended Mr Vulliamy), "a limited number

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to seconds." It need hardly be remarked, that the mere compensation of the pendulum could produce no such improvement in the rate as this, especially if it be true, as Mr Vulliamy and the Clerkenwell clockmakers assert, that a wooden pendulum is as good as a compensated one.

of the profession" (which means, we suppose, in plainer English, some members of the Company of Clockmakers), and some civil engineers. The chief commissioner of works was convinced by this memorial that his predecessor had made a great mistake, and he lost no time in trying to rectify it; for without saying a word about the memorial to either the referees or Mr Dent, he summoned Mr Denison and him (Mr Airy was abroad), and proceeded to expound his views, from information he had received (as the policemen say), on the fallacy of cast-iron wheels, and on the necessity for other referees. He failed in making any impression on either point; but the clockmakers could not keep their own counsel as well as the Board of Works had kept it for them, and, by way of making a little more noise, got their memorial printed by the House of Commons, and so at once disclosed the kind of engineering which had been going on for the purpose of getting Mr Dent's contract rescinded; for it was perfectly obvious, from the nature of his contract, that the mere imposition of other referees would practically rescind it, and throw the whole affair open again, as they wanted. Thereupon Mr Denison sent in an answer, both to the clockmakers and the Board of Works, which quieted them both for some time, and in fact, until the next change of dynasty there: all which things may be read in the parliamentary paper, No. 500, of the year 1852.*

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* The clockmakers have just now been at work again, contrasting the folly of the British government in employing Mr Dent, and consulting the astronomer royal and the author of the only modern book on horology, with the wisdom of the Emperor of China and the corporation of London, both of whom have lately ordered clocks from an old-established firm in Clerkenwell. It is surprising that they should think that there is anything to contrast; for the selection is equally appropriate in all the three cases. The government here wanted a clock which could be always depended on within a second a week; and so, in a happily lucid interval of the Board of Works, they consulted their astronomer, by whose instruments

When Lord John Manners was suceeeded by Sir W. Molesworth, the anti-Dentine party thought there was another chance for them. This time, however, they went to work more secretly; and indeed the whole of their operations are not even now revealed; but so much as this was revealed when the next batch of parliamentary clock papers was published in 1855, that the Board had been engaged during the two previous years in putting the public to the expense of paying for no less than five opinions, from the attorney-general, the solicitor-general, and another of the present judges, to see if they could not by some means or other get rid of Mr Dent's contract and Mr Denison's superintendence, although they knew that the clock was then far advanced towards completion, and was only kept back because the building of the tower had been suspended instead of pressed on nearly ever since the clock was ordered. Again the attempt was unsuccessful, as their own solicitor had warned them beforehand that it would be;

the time-keeping has to be tested—engaged the superintendence of the man who invented the machinery for accomplishing the object—employed the only clockmaker in London who has had the sense to adopt it—and rejected the tenders of those who, instead of attempting to comply with the conditions, pronounced them impossible and absurd, even after the thing has been proved to be done. Nobody can wonder that the London corporation, who refused to let Sir Christopher Wren build wide streets after the narrow ones were burnt, and fought for the filth of old Smithfield with a fury worthy of the beasts they sold there, should prefer an old-fashioned clock to a new one, for the chimney-shaft called a clock-tower of the New Smithfield, which is built as if the clock was the last thing thought of. And as for the Emperor of Chins, he is at any rate not likely to be particular to a few seconds, or minutes either; and before he ordered his clock of Messrs Moore, he had no doubt ascertained, what any English engineer could tell him, that Clerkenwell is the China of England, where everybody makes clocks exactly as his grandfather did before him, and the modern innovations of machinery are resisted with a spirit and success which must make the ghosts of departed Luddites envious.

and at last the lawyers told them that even if they could legally repudiate the contract on the ground of old Mr Dent's death in 1853, they clearly ought not, inasmuch as they admitted the perfect competency to make the clock of the present Mr Frederick Dent, of the Strand and Royal Exchange (not Cockspur Street); and also knew him to be both the executor and the successor of old Mr Dent in the clock factory, and in what may be called all his scientific business. The pretext for this renewed attempt at repudiation was Mr Airy's resignation of the joint superintendence of the clock. For it appears that he had refused to act any longer with Mr Denison, not on account of any difference between them about the construction of the clock, but because Mr Denison would not make some drawings which Mr Airy wanted to be sent to the architect, and which, according to his description of them, Mr Denison knew could not be wanted, because Sir C. Barry had them already; he therefore refused to make any more, unless Mr Airy would ascertain more clearly from Sir C. Barry what drawings he really wanted—if any. It afterwards turned out, as Mr Denison expected, that he had wanted none. Mr Airy however would not ask him, and finding his colleague equally obstinate, he had no alternative but either to withdraw from his demand, or from the business. He chose the latter, and sent in his resignation to the Board, telling them that he thought Mr Denison and he could not any longer profess to act together with advantage. What further took place between him and the Board does not appear; because it does appear, from a single word which they forgot to suppress, that they suppressed no less than three of Mr Airy's letters on the subject, and probably as many of their own, in their next return to the House of Commons, professing to be a return of "*all* the papers" relating to the business since the last publication. What they were, however, is now of no consequence; for although Mr Airy's certificate had thus ceased to be legally necessary for Mr

Dent to obtain payment, he went to see the clock when it was finished, as far as it could be out of the tower, and wrote to the then chief commissioner of works, saying he approved of it.

As soon as Mr Airy refused to go on acting with Mr Denison, the Board set to work to get rid of him; and the way in which they thought to manage it was, by refusing to hold any correspondence either with him or Mr Dent without the concurrence of Mr Airy; adding that, "as far as they were aware, the position of the astronomer royal had not been altered in this matter:" which, it is obvious, was simply false. However this scheme succeeded no better than the former ones. Mr Denison told the Board very distinctly, in reply, that he had not the least intention of resigning: that he had done the whole of the work, even while Mr Airy's nominal superintendence continued: that as Mr Dent could not safely go on without further directions from the referees, and Mr Airy would not give any, he should henceforth give them alone: that as the Board did not choose to furnish either him or Mr Dent with proper information about the tower, they might take the consequences; and if they had to pay for altering the clock after it was finished (precisely what has happened), the public would have no difficulty in determining who was to blame. This letter was shortly followed by the legal opinion we have already mentioned; and thereupon Sir W. Molesworth and his Board retired from the contest in a kind of sulky despair. After some months they re-opened communications with Mr Dent, and even with Mr Denison, by Sir C. Barry's advice, about the bells, though again with no practical result, until Sir W. Molesworth went to the colonies, and Sir Benjamin Hall came in as chief commissioner, and the office was completely re-organised; since which time, it is only right to say, the business has gone on smoothly enough, and with as much rapidity as the state of the building, and the absence of the bells, has permitted.

This absence of the bells has so materially affected the construction of the clock, that it may as well be mentioned here, that very soon after it was ordered, Mr Denison told the chief commissioner, Lord J. Manners, and afterwards Sir W. Molesworth also, that the bells ought to be put in hand without delay. No notice was taken of those letters, nor was anything done about the bells until the clock was finished as far as it could be out of the tower. And even then the Board carried on the negotiations in such a way, that a year more was wasted before the specification was issued to the bell-founders, and Mr Denison, the Rev. W. Taylor, and Professor Wheatstone appointed referees. The latter gentleman had been previously commissioned, with Sir C. Barry, on his own proposal, when consulted by Sir W. Molesworth, to collect information while at Paris, for the Exhibition of 1855, "respecting the most esteemed chimes in France and Belgium, and whether there are in those countries makers acquainted with the traditions of the art, or who have applied the modern discoveries of science to the improvement of bells, or to efficient substitutes for them. He expected to find in Paris two parties from whom they might obtain some useful information on these points." The useful information however was not obtained. Mr Wheatstone afterwards communicated to Mr Denison and Mr Taylor all that he had learned on the subject, which amounted to little more than the prices charged by several foreign bell-founders, and a few other points of some curiosity and interest, but of no use whatever towards recovering, much less improving, the apparently lost art of casting *good* bells of anything like the weight required here, even for the quarters. He had truly said in his letter already quoted, that "the very unsatisfactory result of the chimes at the Royal Exchange, which have been twice recast without any ultimate advantage (*i. e.*, two peals by Messrs Mears of Whitechapel, and a third by Messrs Taylor of Loughborough), showed that no (then) known bell-founder in England could be relied on." Having thus communicated the information he had got at Paris, and having himself paid no attention to the subject of large bells, Professor Wheatstone acted no farther in the business, and never accepted the appointment of joint referee, which had been made in his absence.

We cannot enter here into the subject of bell-founding further than as it affects the construction of the clock; and we shall therefore only state, that the weight of the great bell was increased from 14 to 16 tons (within 174 lbs.), by an accidental deviation of the founders, Messrs Warner of Cripplegate, from Mr Denison's design. The composition of the metal, as prescribed by him, is also somewhat different from usual, containing 7 of tin to 22 of copper, instead of the usual modern proportion of barely 1 of tin to 4 of copper, which is considerably less tin than is given by the analysis of some celebrated old bells; and from this cause, and the successful management of the casting, the density and strength of the metal are greater than of any known bell-metal, and the bell is altogether more powerful than had been expected by anybody. The consequence is, that all the previous calculations about the weight of the hammer have turned out wrong. Mr Vulliamy had assumed that it might be from the 200th to the 160th part of the weight of the bell, probably on the analogy of the great bell of Oxford, where he had made the cathedral clock; but that is such a bad bell that no inference ought to have been drawn from it; Mr Dent put the proportion about twice as high; and Mr Denison, in his design for the clock, assumed from 4 to 5 cwt., or about 1-60th of the intended weight of the bell, which is higher than the proportion of the clock hammers of the St Paul's or Lincoln bells, and about the same as that of the Hotel de Ville at Paris, but much lower, it appears, than the proportion between the ringing clapper and the weight of some of the great foreign bells. This wide variation in the different guesses at the proper weight of the hammer, and its necessary dependence on the shape, thickness, and strength of the bell, all of which were unknown, show still more clearly the folly of the Board of Works in refusing to proceed with the bells as they were advised in 1852 and 1854, so that the great bell might be cast before the striking part of the clock was made. The result is, that it has now to be altered; as it was found in the experiments made for the purpose, that the bell went on increasing in sound as the hammer was increased up to 12 cwt., or about 1-28th of the weight of the bell. To show the difference between bad bells and good ones in this respect, we may mention, besides the Oxford bell already referred to, that with the tenor of the second condemned peal at the Exchange, which was a remarkably bad bell, full of holes from bad casting, it was found to be of no use increasing the hammer beyond the 140th part of the weight; whereas the clapper of the great bell of Notre Dame at Paris,—and a clapper hits harder than the clock hammer, and that bell is rather a thin one,—is something between a 30th and a 40th of the weight; we cannot give the exact proportion, because there are somewhat different versions given of the weights. The clappers of some of the other most famous foreign bells are stated to be of about the same proportion; and, on the whole, it is clear that either from the badness of casting, or composition, or some other cause, none of the great English bells made before that of Westminister have ever produced the proper sound for their size and weight; indeed, the weakness of the sound of all the bells in this country above 3 or 4 tons, compared with much smaller ones, has often been remarked. For an account of the experiments which were made for the Westminster bells, and various other matters relating to the casting of large bells, we must refer to the chapter on that subject in Mr Denison's *Lectures on Church-building;* and we may at last proceed to describe the construction of the clock as now altered to suit the increased weight of the hammers and the illumination of the dials, and heavier hands than were at first intended.

The frontispiece of this book may be called a transparent elevation or front view of so much of the clock as can be shown at once without confusion, representing the wheels and pinions only by circles, and showing all the parts as if they could be seen through each other, however they may really overlap. The frame is 15½ feet long, 4 feet 7 inches wide, and 19 inches deep, exclusive of the fish-belly piece at the bottom, which of course increases the strength considerably. It is designed on the principle of the trussed girders of the Crystal Palace: the top flange, on which the bushes of the wheels lie, is 2½ inches wide, and the bottom one 4 inches. The going part, which is comprehended between the two cross bars in the middle, has one end of its arbors on the back girder, but the other ends on a separate bar, which lies on the two cross bars, and is only 18 inches from the back girder, because that part requires a much less weight, and therefore a thinner rope and shorter barrel than the two striking parts. The pendulum will hang from a large cast-iron cock built into the back wall, which is about 2 feet behind the great frame, so as to leave room for a man to stand and do any work that may be required. The inside of the tower, 28 feet square, has first an air-shaft 8 feet wide, for the ventilating of the Houses of Parliament, cut off on the west side (the one farthest from the river) by a wall the whole height of the tower; and on the other side of this wall was built what is called the clock-shaft, 11 feet wide from north to south, and 8 feet 6 inches from east to west; and the clock lies over it on iron plates, also built into the back wall. This 8 feet 6 inches is more than is wanted for the clock weights, and the shaft was built originally of that size with the view of putting the staircase there. But it is very convenient for another purpose; for this is the greatest width now left in any part of the tower, and there the great bell has to be taken up sideways, in a kind of cradle, as it is 9½ feet wide, but only 7 feet 10 inches high, a lower proportion than usual, on account of a new kind of top, designed by Mr Denison, for the purpose of hanging it in a stronger way than by the common ears or *canons*, and also allowing it to be turned round when worn in one place by long-continued striking, as is more fully explained in the book just now referred to. We may add to the information there given, that the fourth quarter bell weighs nearly 4 tons, and is 6 feet in diameter, and of the note B. The other three are not yet cast, but will be about 35, 26, and 22 cwt, and ot the notes E (the octave above the great bell), F sharp, and G sharp.

The hands of the clock are now made of gun-metal instead of sheet iron or copper, as they are thicker and of more ornamental character than was intended when the contract was made, and the dials not expected to be illuminated. The dials are also rather larger than was then specified. They are not the largest in the world, as they are considerably less than the dial at Mechlin; but here there are four, and there is no other clock in the world which has to work four dials 22½ feet wide, especially a clock going 8½ days. St Paul's cathedral clock has only two 17 feet dials, and is wound up every day, which makes a vast difference in the power and strength required.* Each pair of hands weighs

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* The largest clock in the United Kingdom (except that at Westminster) is probably that put up a few years ago in Shandon church, Cork. It has four dials 16 feet wide. The frame (of the old cage pattern) is 14 feet long, and the great wheels 2½ feet wide. The scape-wheel is 12 inches wide, the maker being evidently ignorant (as they generally are) that a scape-wheel can hardly be too light, and that a heavy one requires a larger weight, and is only employed in thumping the pallets. The Westminster pendulum, though the heaviest in the world, went with a dead-escape wheel of the construction described at p. 37, weighing only ⅛th of an ounce; and the gravity-escape wheel, by which that was afterwards superseded, does not weigh above an ounce.

about 2 cwt. The hour sockets are iron tubes, 5 inches in diameter, and run on friction-wheels, and have themselves other friction-wheels running in bushes fixed to the outside of the tubes, and reaching through openings into the inside to carry the minute-hand arbors, which are 3½ inches thick. The dials are of cast-iron framework, filled with opal glass, and stand out 5 feet from the main walls, which are carried up within the swell of the tower at the dials, and bear the cast-iron roof and the bells, and will be whitened behind the dials to reflect the light, so that the gas lights will not be in the clock-room, which it is always desirable to avoid, both on account of the heat and the moisture they cause, unless the ventilation is much better than it is generally.

The sizes of all the wheels may be measured by the scale on the drawing, which is an inch to a foot, and therefore we shall not mention them; and the numbers of teeth are also inserted; so that anybody who understands a little of machinery, can see their action and velocity-ratio without further description. There is a minute-dial on the hour-wheel arbor, which carries the snails, for letting off the striking parts (only that of the quarters is shown), and a seconds dial on the 90-wheel arbor, which turns in 2 minutes. The scape-wheel necessarily turns in 12 seconds, as the pendulum is a 2-seconds one. The length of the locking-teeth or legs, is 3½ inches, which is longer than usual for the length of the pallet arms (12 inches), in order to diminish the friction on the stops at unlocking, which is quite insignificant compared with that of a common dead escapement. And in order that the action may be in the direct line of both pallets, notwithstanding their making a greater angle with each other than usual, on account of the length of the teeth, there is a double scape-wheel; that is to say, two three-legged wheels are set on the same arbor, about half an inch apart, with one set of pins between them, to lift the pallets; and one wheel locks on a stop in front of one pallet, and the other on a stop on the back of the other pallet, the legs of one standing at an angle of about 30° behind those of the other. The arms of the fly are 10½ inches long and 2 inches broad; and no amount of pressure that can be applied, even to the second wheel, by hand, will make the escapement trip. The fly is set with friction-springs, acting very nearly in a radial direction on a wheel without teeth, which is in fact a silent rachet-wheel; for the springs let the fly run forward, but it cannot run backward, nor the scape-wheel forward without the fly; just as you can drag your stick along the pavement when it is nearly upright, but cannot push it back.

It has been already stated at page 53, that a new kind of self-acting maintaining power, was invented to keep the clock going during the ten minutes, or as much more as it may take to wind. A spring apparatus was out of the question, as it would be exhausted long before the winding was done. A bolt and shutter would have to be very heavy to balance such a large weight, and would only act for some definite and not very long time; and even if it generally remained in action long enough, it would not, if the man loitered or was interrupted in the winding. The objections to Mr Airy's complicated plan, used in the Exchange clock, have been noticed already; and after various schemes had been talked of, Mr Denison contrived this, which requires the addition of no more than a single bar, with a click upon it, acting as follows. Of course, such a large clock requires an auxiliary pinion to wind it by driving a large wheel fixed to the barrel; and that wheel may as well be close to the great wheel of the train, and connected with it by the usual ratchet and clicks, as at the other end of the barrel. So that there is nothing extra in this. The only difference is, that the back end of the winding-arbor does not run in a fixed bush, but in the end of a bar which hangs obliquely from the main arbor just behind the great wheel. This bar has a click attached to it which takes into ratchet-teeth cast on the back of the great wheel, so that you cannot raise the bar any higher without pressing the wheel in the same direction in which the weight pulls it. As soon as you begin winding, you begin to produce this pressure upwards, for the point where the click acts on the great wheel becomes the fulcrum of the winding-lever or winch, and you put as much pressure on that side as you take off on the other side, by lifting or winding up the clock-weight—in fact, rather more; which is of no consequence: if it were, it would be easy to equalize it by weighting the end of the bar to the amount of the difference. As the clock goes on, the back end of the winding-arbor travels with the great wheel; but it moves so little in 5 or 10 minutes, that the corresponding angular motion of the arbor, which is 4½ feet long, does not signify; and by the time it has gone as far as it was thought safe to let it go, an arm at the end of the arbor is caught by a stop on the back frame, which stops any more winding until the man turns the handle back a little, and so lets the bar go down, and the click takes up another tooth of the rachet, and then he can go on as before, taking as long to wind as he chooses. Moreover, the stop is so placed, that its stopping the winding does not stop the clock even for an instant. The winding-pinion pulls out of gear with the barrel-wheel in the usual way. This apparatus may be applied at a very trifling expense to any clock which is large enough to require an auxiliary winding-wheel; for the angular motion of the winding-arbor in the space belonging to one tooth of the ratchet, would be very little, though the arbor would be much shorter than in this clock with a frame 4½ feet wide.

There is nothing else strictly belonging to the going part, which will not be obvious from the drawing to anybody who is likely to understand any further description. It may be mentioned however, that it is made to go 8½ days without winding, because 8 is really of no more use than a few hours above 7: if the day of winding is forgotten, another day will hardly save it. It is impossible to say at present what going weight will be required to drive the hands. The wheels are strong enough to bear far more than can possibly be required. And with reference to that point generally, it may be stated, that a segment of a wheel weaker than the new great wheels was proved up to 6 tons on the teeth ; and supposing 3 tons to be the weight on the double line of the striking part, the pressure on those teeth will be little more than 15 cwt. ; and the teeth of the new great wheels are both broader and thicker. Of course, no design can be safe against bad casting ; but as far as the design goes, and the adoption of iron instead of gun-metal, it is clear that there is no ground for apprehension of want of strength.

The setting of the hands for large alterations is by clamp-screws on the 48-wheel, which turns in the hour. For small alterations, it was noticed at p. 94, as an advantage of the gravity escapement, that by simply holding back the pallets, you may let the train run forwards or turn it backwards as you please, without disturbing the pendulum or altering any of the other adjustments. Alterations less than 4 seconds are made by means of two loose weights of about 6 lbs. each, of which one is kept in the clock-room and the other lies on the collar fixed at the top of the compensation tubes of the pendulum, because the middle of the pendulum could not be reached conveniently (see page 19). Taking this weight off for a quarter of an hour retards the clock a second, and putting the other loose weight on the top of it for the same time, accelerates it a second. This can be done without sensibly disturbing the pendulum, whereas the plan originally proposed (see 5th condition, page 102), shakes it and disturbs the time afterwards ; and moreover, it tempts the man to keep the clock at a losing rate, as that method will only accelerate it. It was given up in the Exchange clock after these shifting weights were designed by Mr Denison for the Westminster clock. The permanent regulation of the pendulum is done by still smaller weights, as explained at page 17; about an ounce laid on the collar accelerates the rate a second a day, though the pendulum weighs 6 cwt. The pendulum swings a little more than 2° from zero, or about 14 inches for the entire swing.

The 24-hour wheel, driven by a pinion on the great wheel arbor, is for turning the gas on to illuminate the dials in the evening, and turning it nearly off again in the morning. Instead of the lever of the gas valve being worked by pins on this wheel, as usual, which are put in and taken out from time to time as the length of day varies, there will be three sectors or fan-shaped pieces set close together, which can either be spread out to nearly 18 hours for winter lighting, or shut up to 6 hours for summer. The pins which are shown upon the wheel have some other work to do of a very different kind, as will be explained after we have done with the striking parts.

And first, of the quarters, as they strike first. Although there are only four quarter bells, there are five hammers, because the largest of them is struck twice in succession (as may be seen at page 90), and the same hammer could not fall quickly enough. The hammers are raised by levers, which are worked by thick wrought-iron cams with steel faces, screwed on a cast-iron barrel fixed to the great wheel. It should be observed, that all the striking levers, both of the hour and quarters, have the action and the resistance near together, so as to produce as little friction on their arbors as possible. In almost all church clocks made before Mr Dent's improvements, and as still made by the other London makers, the levers are raised by the wheel at one end and pull the hammer wire at the other, so that twice the weight of the hammer is always pressing on the arbor. With small hammers this friction does not signify, but with large ones it does. For the same reason, all the three parts of the clock are so arranged that the weights act on the same side of the barrels as the work to be done, so as to save as much friction and pressure on the great arbors as possible. In the going part, the driving of the hands will require much more power than keeping up the motion of the pendulum. In each part, the winding alone is done on what may be called the wrong side of the wheels, which of course will not increase the working friction, and in fact will do nothing, as will be seen when we come to speak of the actual mode of winding. The striking of the quarters is let off in the usual way, of which the principle has been already described at page 56. The stopping levers of both striking parts are on the third wheel arbor, because it is more convenient to set the flies on vertical arbors worked by bevelled wheels to keep them out of the way; and to diminish the shock of stopping, the stops act on a spring set in front of the lever instead of on the lever itself. (These things are omitted in the frontispiece for the hour striking part, to be shown more distinctly in fig. 21 presently). There is a contrivance (called in the drawing the *winding-stop*) for preventing the man who winds from going on when the quarters are ready to strike. It consists of a lever, whose axis is near that of the 80-wheel, with a stop at its right end, which stands in the way of a projecting piece at the back of the winding-winch, except when it is lifted on to a hook which hangs loose, but will keep hold of the lever by reason of its weight when it is hung on, but slips away when the weight is relieved. A few minutes before the quarters are going to strike, the discharging snail acting downwards on the other and lighter end of the lever, takes the weight of the heavy end off the hook, and so lets it swing away; and then, about a minute before the quarters are going to strike, the snail lets the lever drop, which immediately pulls up the man winding and warns him to push the winding wheels out of gear. It is not required for the hour part, because the striking of the quarters is warning enough for that.

It should be understood by the public that the first, second, and third quarters begin to strike at the right time, but the fourth quarter begins half a minute before the right time, to get out of the way of the hours, and act as a warning to people to take out their watches for the first blow of the hour, which is intended to be always exact within a second of Greenwich time, as originally required by the astronomer royal's conditions, but is effected by a different method from that which was originally contemplated, viz. the remontoire, which let the train move a sensible quantity at every 30th second, and therefore carried the discharging snails through a large enough angle to be sure of letting off the striking at the 60th second of the last minute of the hour.

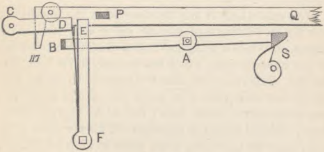

Fig. 21.

When Mr Denison determined to remove the remontoire, because it was not safe to let such heavy hands move by 7-inch jumps, he made the provision, shown in fig. 21, for securing the letting off of the hour striking work at the proper time, as the motion of the hour-snail is so small at every beat that the shake of the teeth transmitted from any of the hands pushed forward by the wind might accelerate the striking by two or even four seconds. S is a snail on the 15-minute wheel of the going part, and it lifts the heavy arm AS of a lever on a long arbor A, which reaches to the front girder of the great frame, and there has its other arm AB just under a short lever CD, which forms the second stop to the revolving arm EF of the striking part; the first stop P being on the great lifting piece PQ as usual, which is raised by the hour-snail, and "gives warning" a few minutes before the hour, and also lets the lifting piece fall again a few *seconds* before the hour. Exactly at the hour the 15-minute snail lets its lever drop, and that, both by its weight and by having a little run at CD before it reaches it, tips it up and keeps it out of the way of the pin E on the revolving arm; and so the clock strikes, the lifting piece and its stop P being lifted out of the way as usual by the roller and the small cam-wheel on the arbor of the pinion 21 (in the large drawing), and kept up by the locking-plate 117, according to the number of blows to be struck.

This cam-wheel, it may be observed in the frontispiece, has the two lifting segments cut out of it at unequal distances, one interval being one-third and the other two-thirds of the circumference, which has probably never been done before. The reason is, that it happened to be the most convenient arrangement to make this second wheel turn two-thirds round for one blow; and as the hours are alternately odd and even, the segments will always come in the right place for the lifting piece roller to drop into them if it is once set right for one o'clock.

In order further to secure precision in the time of striking the first blow, the hammer will be kept on the lift and just ready to fall, to avoid any variation in the time of raising it. For this purpose there will be, as in all clocks where this is done, a click on the 3d or 4th arbor to stop the train from running back while the clock is winding. Leaving the hammer on the lift also diminishes the constant strain on the teeth, and the force of the blow and pressure on the locking-stops: all which things are worth something where the weight is so enormous.

The great wheel has the 10 striking-cams cast upon it, which are 2½ inches thick, and faced with steel. The curves of all the cams, both here and in the quarters, are determined by the method which will be given, under the head of "Teeth of Wheels," hereafter, so that the action both begins and ends at the end of the lever. By the common method of pins which begin to act a good way from the end of the lever, the power of the clock over the hammer is least when it ought to be greatest, and so a great deal of force is wasted in the remainder of the lift. In this clock, also, the hammer head will rise more vertically than usual, because the axis of the hammer shank is near the top of the bell instead of below the mouth as usual. The rise will be nearly a foot; and as that has to be done 156 times a-day, and the hammer is 12 cwt., and the fall of the clock weight about 156 feet clear, it is evident that even if the striking part is wound up twice a-week (*i.e.* made for 4 days), the weight must be 48 cwt., without allowing anything for friction, which will probably consume about a third as much more. And such a weight as this,—say from 3 to 4 tons, will take a man at least 5 hours to wind up, supposing him not to rest at all. The quarters will take rather less; but it is clear that it would be as much as one man could do to wind up the clock in two full days out of the week; and therefore it was of no use professing to make the striking parts go a week, though it was at first intended to do so. It will be remembered that Mr Whitehurst proposed only four-day striking parts in 1846, though nobody then calculated on a hammer of half the present weight. The weight will be hung by wire ropes, the largest ·64-inch thick, the quarters ·55, and the going part ·25, or more if necessary. The striking barrels are of cast-iron, with turned grooves to guide the ropes, and the going barrel is of sheet-iron.

The mere expense of winding up such a machine by hand would be very great, and the work such as is hardly fit for anybody except convicts. Various other modes of winding have been talked about for several years. Some persons have proposed to turn the tide of the river below to account, which of course is possible enough; and if the tower had been built and the clock designed for it, it might have been done,—at an expense considerably exceeding that of the clock itself. A small steam-engine was a more practicable proposal; but that also would save nothing in the annual cost of winding, as there is not one already on the spot, from which the power could be borrowed easily when it is wanted, and it would require attendance if it were there. There remained only wind and water (not in the tidal form). Sir Charles Barry was not likely to receive with much favour a proposal to turn the spire of the tower into a windmill cupola, even if there were no other objections to the scheme of wind-winding; and so the alternatives were reduced to hand-winding, and winding by water on some modification of the hydraulic crane principle. Mr Jabez James, the engine-maker, who has been largely employed upon the Houses of Parliament, and is hanging the bells, suggested two plans of that kind, either of which would no doubt have answered. But they would have interfered with the winding by hand, whenever the water apparatus wanted any repairs or packing of the pistons, or was stopped for a time in any other way, which must of course be reckoned on. And, therefore, Mr Denison modified them into the following plan of making the clock wind itself by water, but still keeping the means of winding by hand, for which the clock was already adapted. Each striking weight, instead of going quite to the ground, will descend on to the top of a piston moving in a short cylinder, the hour-part cylinder about 14 inches in diameter, and the quarter one 12 inches. The weight falls 3 feet in striking twelve; and soon after it has struck, the 24-hour wheel, which is driven directly by a pinion on the arbor of the great wheel of the going part with very great power, will open a slide valve at the bottom of the cylinder by a lever and a long rope from the clock, and let water in from a tank about 200 feet above it, which will drive up the piston 3 feet, or a little more for safety, with the clock weight upon it; and as it rises, a comparatively small weight hung on the other side of the barrel will wind it up rather more than one turn, the quantity required for striking 12. When the piston gets very near the top of the cylinder it shuts the valve, and shuts it gradually, so as not to produce a shock of the column of water, which would probably burst the pipe; and so it remains until the pin in the 24-hour wheel opens the out-port of the cylinder, of course still keeping the in-port shut, which lets the water run away and the piston fall, leaving the weight hanging and ready to strike, just as if it had been wound by hand. The water is not turned on again till after 4 o'clock, as it is not wanted, nor again till after 6; and then it must be done every hour; but, on the whole, there is not much more than one cylinder full of water wasted in the 12 hours, and that is of no consequence. The quarter weight will be wound up in the same way every hour, which only requires a rise of less than 2 feet, and involves no waste of water. When you want to wind by hand, the small winding weights may be taken off, or their ropes will probably be arranged to drop off the barrels as soon as they have made a turn or two, and then everything goes on just as if there were no water apparatus at all. It is not worth while to apply it to the going part, as that will not take long to wind; and it is desirable that a man should visit the clock once a-week to receive the time from Greenwich by electric telegraph, and regulate the clock to that time if necessary. Otherwise it might have been made entirely self-acting, so long as the tank is kept full of water.

It was originally proposed by the astronomer royal, that the clock should report itself to Greenwich every day by galvanic action at the striking of some given hour, which may easily be done. It will therefore be subject to the most rigid test, besides the opportunity which the public will have of comparing the striking with the fall of the time-ball in the Strand, whenever the ball does not fail. But there is not the least occasion for a man to attend at the clock every day, as Mr Airy suggested, to receive the Greenwich time and set the clock, as there is no reason to expect that it will want altering, even a second a week, after it has once got fairly regulated.

TEETH OF WHEELS.

Before we leave the subject of clocks, it is necessary to say something on a very important point in their construction, viz., the teeth of wheels; for although it is more or less involved in all machines containing wheels, there is none in which it is of so much consequence as in clock-work, because there is none in which friction forms so large an ingredient in all calculations respecting its effects. At the same time we are not going to write a treatise on all the branches of the important subject of wheel-cutting; but, assuming a knowledge of the general principles of it, to apply them to the points chiefly involved in clock-making. The most comprehensive mathematical view of it is perhaps to be found in a paper by the present astronomer royal in the *Cambridge Transactions* many years ago, which is further expanded in Professor Willis's *Principles of Mechanism*. Respecting the latter book, however, we should advise the reader to be content with the *mathematical* rules there given, which are very simple, without attending much to those of the *odontograph*, which seem to us to give not less but more trouble than the mathematical, and are only approximate after all, and also do not explain themselves, or convey any knowledge of the principle to those who use them.

For all wheels that are to work together, the first thing to do is to fix the *geometrical*, or *primitive*, or *pitch circles* of the two wheels, *i.e.*, the two circles which, if they rolled perfectly together, would give the velocity-ratio you want.

Draw a straight line joining the two centres; then the action which takes place between any two teeth as they are approaching that line is said to be before the line of centres; and the action while they are separating is said to be after the line of centres. Now, with a view to reduce the friction, it is essential to have as little action before the line of centres as you can; for if you make any rude sketch, on a large scale, of a pair of wheels acting together, and *serrate* the edges of the teeth (which is an exaggeration of the roughness which produces friction), you will see that the further the contact begins before the line of centres, the more the serration will interfere with the motion, and that at a certain distance no force whatever could drive the wheels, but would only jam the teeth faster; and you will see also that this cannot happen after the line of centres. But with pinions of the numbers generally used in clocks you cannot always get rid of action before the line of centres; for it may be proved (but the proof is too long to give here), that if a pinion has less than 11 leaves, no wheel of any number of teeth can drive it without some action before the line of centres. And generally it may be stated that the greater the number of teeth the less friction there will be; as indeed is evident enough from considering that if the teeth were infinite in number, and infinitesimal in size, there would be no friction at all, but simple rolling of one pitch circle on the other. And since in clock-work the wheels always drive the pinions, except the hour pinion in the dial work, and the winding pinions in large clocks, it has long been recognised as important to have high numbered pinions, except where there is a train remontoire, or a gravity escapement, to obviate that necessity.

And with regard to this matter, the art of clock-making has positively retrograded, and the pinions which are now almost universally used in English and French clocks are of a worse form than those of several centuries ago, to which we have several times alluded under the name of *lantern* pinions, so called from their resembling a lantern with upright ribs. A sketch of one, with a cross section on a large scale, is given at fig. 23. Now, it is a property of these pinions, that when they are driven, the action begins just when the centre of the pin is on the line of centres, however few the pins may be; and thus the action of a lantern pinion of 6 is about equal to that of a leaved pinion of 10; and indeed, for some reason or other, it appears in practice to be even better, possibly from the teeth of the wheel not requiring to be cut so accurately, and from the pinion never getting clogged with dirt. Certainly the running of the American clocks, which all have these pinions, is remarkably smooth, and they require a much smaller going weight than English clocks; and it is evident that this cannot be due to any high finishing of the wheels and pinions, for these clocks are remarkable for the absence of it, though the English mechanics consider it the great merit of a piece of clock-work, just as modern builders think that good architecture consists in making stone-work smooth. Mr Dent has for some years used these pinions in the going part of his turret-clocks, and he has lately been applying them to some smaller work for the astronomer royal at Greenwich, and to regulators with the gravity escapement. It should be understood, however, that as the action upon these pinions is all after the line of centres when they are driven, it will be all before the line of centres if they drive, and therefore they are not suitable for that purpose. In some of the French clocks in the Exhibition they were wrongly used, not only for the train, but for winding pinions; and some of them also had the pins not fixed in the lantern, but rolling: a very useless refinement, and considerably diminishing the strength of the pinion. For it is one of the advantages of lantern pinions with fixed pins, that they are very strong, and there is no risk of their being broken in hardening, as there is with common pinions.

The fundamental rule for the tracing of teeth, though one of great simplicity, is, we suspect, not so well known as it ought to be, and therefore we will give it: premising that so much of a tooth as lies within the pitch circle of the wheel is called its ***root*** or ***flank;*** and the part beyond the pitch circle is called the ***point***, or the ***curve***, or the ***addendum;*** and moreover, that before the line of centres the action is always between the flanks of the driver and the points of the driven wheel or *runner* (as it may be called, more appropriately than the usual term *follower*); and after the line of centres, the action is always between the points of the driver and the flanks of the runner. Consequently, if there is no action before the line of centres, no points are required for the teeth of the runner.

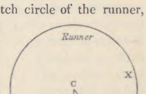

Fig. 22.

In fig. 22, let AQX be the pitch circle of the runner, and ARY that of the driver; and let GAP be any curve whatever of smaller curvature than AQX (of course a circle is always the kind of curve used); and QP the curve which is traced out by any point P in the generating circle GAP, as it rolls *in* the pitch circle AQX: and again, let RP be the curve traced by the point P, as the generating circle GAP is rolled *on* the pitch circle ARY: then RP will be the form of the point of a tooth on the driver ARY, which will drive with uniform and proper motion the flank QP of the runner; though not without some friction, because that can only be done with *involute* teeth, which are traced in a different way, and are subject to other conditions, rendering them practically useless for machinery, as may be seen in Professor Willis's book. If the motion is reversed, so that the runner becomes the driver, then the flank QP is of the proper form to drive the point RP, if any action has to take place before the line of centres.

And again, any generating curve, not even necessarily the same as before, may be used to trace the flanks of the driver and the points of the runner, by being rolled within the circle ARY, and on the circle AQX.

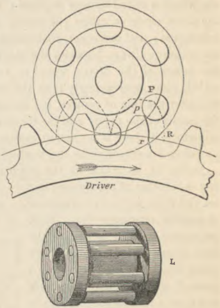

Fig. 23.

Now then, to apply this rule to particular cases. Suppose the generating circle is the same as the pitch circle of the driven pinion itself, it evidently cannot roll at all; and the tooth of the pinion is represented by the mere point P on the circumference of the pitch circle; and the tooth to drive it will be simply an *epicycloid* traced by rolling the pitch circle of the pinion on that of the wheel. And we know that in that case there is no action before the line of centres, and no necessity for any flanks on the teeth of the driver. But inasmuch as the pins of a lantern pinion must have some thickness, and cannot be mere lines, a further process is necessary to get the exact form of the teeth; thus if RP, fig. 23, is the tooth that would drive a pinion with pins of no sensible thickness, the tooth to drive a pin of the thickness 2 P*p* must have the width P*p* or R*r* gauged off it all round. This, in fact, brings it very nearly to a smaller tooth traced with the same generating circle; and therefore in practice this mode of construction is not much adhered to, and the teeth are made of the same shape, only thinner, as if the pins of the pinion had no thickness. Of course they should be thin enough to allow a little shake, for freedom of action in case of any impediment; and in clock-work the backs of the teeth never come in contact at all.

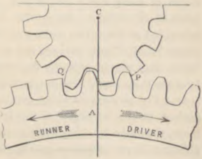

Fig. 24.

Next, suppose the generating circle to be half the size of the pitch circle of the pinion. The curve, or *hypocycloid*, traced by rolling this within the pinion, is no other than the diameter of the pinion, and consequently the flanks of the pinion teeth will be merely radii of it, and such teeth or leaves are called radial teeth; and they are far the most common; indeed, no others are ever made (except lanterns) for clock-work. The corresponding epicycloidal points of the teeth of the driver are more curved, or a less pointed arch, than those required for a lantern pinion of the same size and number. The teeth in fig. 24 are made of a different form on the opposite sides of the line of centres CA, in order to show the difference between driving and driven or running teeth, where the number of the pinion happens to be as much as 12, so that no points are required to its teeth when driven, since with that number all the action may be after the line of centres. The great Westminster clock affords a very good illustration of this. In both the striking parts the great wheel of the train and the great winding-wheel on the other end of the barrel are about the same size;

but in the train the wheel drives, and in winding the pinion drives. And therefore in the train the pinion-teeth have their points cut off, and wheel-teeth have their points on, as on the right side of fig. 24; and in the winding-wheels the converse; and thus in both cases the action is made to take place in the way in which there is the least friction. Professor Willis gives the following table, "derived organically" (*i. e.*, by actual trial with large models), of the least numbers which will work together without any action before the line of centres, provided there are no points to the teeth of the runner, assuming them to be radial teeth, as usual :—

Driver.........	54	30	24	20	17	15	14	13	12	11	10	9	8	7	6
Runner.........	11	12	13	14	15	16	17	18	19	21	23	27	35	32	176

In practice it is hardly safe to leave the driven teeth without points, unless the numbers slightly exceed these; because, if there is any irregularity in them, the square edges of those teeth would not work smoothly with the teeth of the driver. Sometimes it happens that the same wheel has to drive two pinions of different numbers. It is evident that, if both are lanterns, or both pinions with radial teeth, they cannot properly be driven by the same wheel, because they would require teeth of a different shape. It is true that on account of the greater indifference of lantern pinions to the accuracy of the teeth which are to drive them, the same wheel will drive two pinions of that kind, differing in the numbers in the ratio of even 2 to 1, with hardly any sensible shake; but that would not be so with radial pinions, and of course it is not correct. Accordingly, in clocks with Mr Denison's spring remontoire, as in fig. 19, where the scape-wheel or remontoire pinion is double the size of the fly pinion, the larger one is made with radial teeth and the smaller a lantern, which makes the same wheel teeth exactly right for both. In clocks of the same construction as fig. 20, and in the Westminster clock, there is a case of a different kind, which cannot be so accommodated; for there the great wheel has to drive both the second wheel's pinion of 10 or 12, and the hour-wheel of 40 or 48; the teeth of the great wheel are therefore made to suit the lantern pinion, and those of the hour-wheel (*i. e.*, their flanks) then depend on those of the great wheel, and they are accordingly traced by rolling a generating circle of the size of the lantern pinion on the inside of the pitch circle of the hour-wheel: the result is a tooth thicker at the bottom than usual. These are by no means unnecessary refinements; for if the teeth of a set of wheels are not properly shaped so as to work smoothly and regularly into each other, it increases their tendency to wear out in proportion to their inaccuracy, besides increasing the inequalities of force in the train. Sometimes turret clocks are worn out in a few years from the defects in their teeth, especially when they are made of brass or soft gun-metal.

In describing the striking work of a turret clock, fig. 20, and also the Westminster clock, we referred to this part of the book for the rule for constructing the cams which raise the hammer. The conditions which it is most important for them to satisfy are, that the action should begin at the greatest advantage, and therefore at the end of the lever; that, when it ceases, the face of the lever should be a tangent to the cam at both their points; and that in no part of the motion should the end of the lever scrape on the cam. In the common construction of clocks the first condition is deviated from as far as possible, by the striking pins (which are used by nearly all the clock-makers) beginning to act at some distance from the end of the lever; and consequently, at the time when the most force is required to lift the hammer there is the least given, and a great deal is wasted afterwards.

The construction of curve for the cams, which is the most perfect mathematically, is that which is described in mathematical books under the name of the *tractrix*. But there are such practical difficulties in describing it, that it is of no use. It should be observed, that in a well-known book with an appropriate name (*Camus on the Teeth of Wheels*), a rule for drawing cams has been inserted by some translator, which is quite wrong. It may be proved that epicycloidal cams described as follows, are so nearly of the proper mathematical form, that they may be used without any sensible error. Let r be the radius of the circle or barrel on which the cams are to be set theoretically, *i.e.*, allowing nothing for the clearance which must be cut out afterwards, for fear the lever should scrape the back of the cams in falling: in other words, r is the radius of the pitch circle of the cams. Call the length of the lever l. Then the epicycloidal cams may be traced by rolling on the pitch circle a smaller one, whose *diameter* $= \sqrt{r^2 + l^2} - r$ Thus, if l is 4 inches and r 8 inches (which is about the proper size for an 18-inch striking wheel with 20 cams), the radius of the tracing circle for the cams will be 0·9 inch. The advantage of cams of this kind is, that they waste as little force as possible in the lift, and keep the lever acting upon them as a tangent at its point the whole way; and the cams themselves may be of any length, according to the angle through which you want the lever to move.

Most people however prefer dealing with circles, when they can, instead of epicycloids; and drawing by compasses is safer than calculating in most hands. We therefore give another rule, suggested by Mr E. J. Lawrence, a member of the horological jury in the Great Exhibition,* which is easier to work, and satisfies the principal conditions stated just now, though it wastes rather more in lift than the epicycloidal curve; and the cams must not have their points cut off as the epicycloidal ones may, to make the lever drop

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* It is curious that all the members of that horological jury, both English and foreign, except one, were lawyers; and so is Mr Bloxam, the inventor of the escapement, fig. 11, and of the dipleidoscope; who would no doubt have been added to the jury, but for his absence from England on account of illness.

off sooner; because a short cam has to be drawn with a different radius from a long one, to work a lever of any given length. But, on the other hand, the same curve for the cams will suit a lever of any length, whereas with the epicycloidal cams you must take care to put the centre or axis of the lever at the exact distance from the centre of the wheel for which the curve was calculated,—an easy enough thing to do, of course, but for the usual disposition of English workmen to deviate from your plans, apparently for the mere pleasure of doing wrong. It is astonishing how, by continually making one machine after another, with a little deviation each time, the thing gradually assumes a form in which you can hardly recognise your original design at all. The prevention of this kind of blundering is one of the many advantages of making machines by machinery, for which no machine offers more facilities than clocks, and yet there is none to which it is less applied.

In fig. 25 let CA be a radius of the wheel, and L in the same straight line the centre of the lever; AB the space of one cam on the pitch circle of the cams, A being a little below the line of centres: AP is the arc of the lever. Draw a tangent to the two circles at A, and a tangent to the cam circle at B; then T, their point of intersection, will be the centre of the circle which is the face of the cam BP; and TB also = TA; which is a convenient test of the tangents being rightly drawn. The action begins at the point of the lever, and advances a little way up, but recedes again to the point, and ends with the lever as a tangent to the cam at P. The backs of the cams must be cut out rather

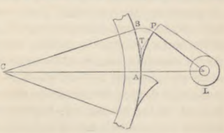

Fig. 25.

deeper than the circle AP, but retaining the point P, to allow enough for clearance of the lever, which should fall against some fixed stop or banking on the clock frame, before the next cam reaches it. The point of the lever must not be left quite sharp, for if it is, it will in time cut off the points of the cast-iron cams.

We will add a few words on the subject of oil. Olive-oil is most commonly used, sometimes purified in various ways, and sometimes not purified at all. We believe however, that animal oil is better than any of the vegetable oils, as some of them are too thin, while others soon get thick and viscid. For turret clocks and common house clocks, good sperm oil is fine enough, and is probably the best. For finer work the oil requires some purification. Even common neat's foot oil may be made extremely fine and clear by the following method:—Mix it with about the same quantity of water, and shake it in a large bottle, not full, until it becomes like a white soup; then let it stand till fine oil appears at the top, which may be skimmed off: it will take several months before it has all separated, into water at the bottom, dirt in the middle, and fine oil at the top. And it should be done in cold weather, because heat makes some oil come out as fine, which in cold would remain among the dirty oil in the middle, and in cold weather that fine oil of hot weather will become muddy. There are various vegetable oils sold at tool-shops as oil for watches, including some for which a prize medal was awarded in the Exhibition, but not by any of the mechanical juries; we have no information as to the test which was applied to it, and none but actual use for a considerable time would be of much value. We have heard of 5 per cent. in power being saved in a manufactory by the use of sperm, instead of sweet oil, to small spindles requiring constant lubrication. We have had a present of a small bottle of oil from Mr White, a clockmaker at Fredericton, who takes care of, and appreciates, the cathedral clock there, which has been several times referred to. He says it never freezes, even in the extreme cold which they have there; but he does not give any account of its nature, or mode of preparation. It has shown no signs of freezing here.

WATCHES AND CHRONOMETERS.

We said that we should defer a description of spring-clocks until we came to treat of watches, which, as we all know, have a spiral spring instead of a weight for their maintaining power. They seem to have been made as early as the sixteenth century, though Huygens, in the seventeenth, was the first discoverer of the important law respecting springs, which he enunciated in the well-known words, *ut tensio sic vis*, the force of a spring varies as the bending of it; which, however, we shall find to be subject to one somewhat inconvenient, and another very convenient exception. The most simple form of mainspring arrangement for a clock or watch is that where the spring has its inner end attached to the arbor, which ends in the winding square, having a ratchet set on it with the click in the clock-frame. The other end of the spring is fixed to the barrel containing it, and on the end of the barrel is the great wheel of the clock or watch. And one advantage of this is, that no going barrel apparatus is wanted, as there is just the same pressure on the train when you are winding up (in fact rather more) as at any other time. But then it will occur to the reader, that by virtue of the rule *ut tensio sic vis*, there must be a much greater force on the train when the watch is wound up than when it is nearly run down. And so there would be, but for that very convenient and singular exception we just now alluded to. For it is found that there is a position of every spring, in which its force does not sensibly alter for four or five turns; and if the spring is such, that this position occurs just at the right degree of tension for using it in a watch barrel, it is evident that we may use it for a mainspring without any further provision for equalizing its force. We are not sure whether this is the case yet with any of the English mainsprings, but it certainly is with many of the foreign ones; and we can testify to the fact of watches made with those mainsprings going as well as those which are made with English mainsprings and a fusee; and we believe that the late Mr Dent, who had been trying some of these watches for several years before his death, had come to the conclusion that, with a mainspring properly made and adjusted, the fusee, chain, and going ratchet are an unnecessary expense, except perhaps in large chronometers, where not only is a great force required, but a constant force throughout the day, which is not the case in watches.

Fig. 26 shows the general arrangement of a watch or chronometer (it is actually taken from a chronometer). The barrel and fusee will be recognised at once. The fusee is a sort of grooved hollow-sided cone; the more rapid swell towards the thick end is required, because one turn of the fusee, when the chain is at that end, takes much more of it off the barrel than at the thin end; and on the assumption that the force of the spring varies as its tension (except under the circumstances before mentioned), the radius of the cone must increase more rapidly, in order to make the increase of leverage keep pace with the decrease in the force of the spring as it unwinds with an increasing velocity off the thick end of the fusee. The fusee itself is connected with the great wheel by a ratchet and click and going ratchet (of which the spring and click are strongly shown in the figure), just as we described in an astronomical clock. Something is also required to prevent the watch from being overwound, or the chain strained so as to break. This is done by means of a hooked lever, set on a hinge in the upper frame-plate (which is taken off in this drawing); and when the watch is nearly wound up, the chain moving upwards reaches this lever, and moves it into such a position that its hook catches hold of the long tooth projecting from the thin end of the fusee; and thus the winding is stopped without any strain on the chain by the sudden check. In the Great Exhibition there were some watches by a Mr Jackson, in which the winding was done by a solid key fitting into a square hole in the arbor of a pinion working into a winding-wheel on the fusee, just like the winding pinion in turret clocks. The object was to reduce the size of the fusee arbor, and to avoid the inconvenience of a very short winding-square when the watch is wanted to be thin. We doubt whether the advantage is worth the additional cost. But in watches without a fusee, the solid key plan might be advantageously adopted, as it would not require the addi-

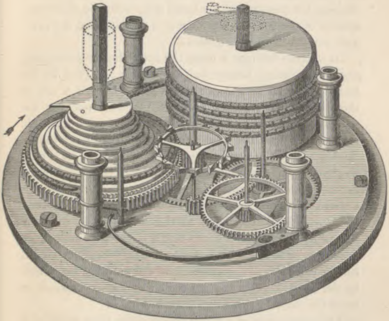

Fig. 26.

tion of a winding pinion; because the winding arbor is then the arbor of the barrel, which does not turn round except in winding, when the friction from the increased size would not signify. We are surprised that a suggestion of the late Mr Mudge for the reduction of the friction of the fusee arbor has not been adopted, viz., to make the barrel turn the opposite way to the fusee, so that the chain may act between the arbor and the centre pinion, thereby making the pressure on the fusee arbor only the difference, instead of the sum, of the force of the spring and the pressure transmitted to the pinion.

In watches without a fusee the apparatus for preventing them from being overwound is different; it goes by the name of the Geneva stop, and the principle of it is simply this; if two wheels work together, of which one has the spaces between some two or more adjacent teeth filled up, it is evident that that wheel cannot be turned quite round. And it will be the same thing if one of the wheels is only a cylinder with a single tooth in it, and the other has a certain number of notches, not going all round, through which that tooth can pass. If, therefore, a one-toothed wheel of this kind is fixed to the barrel arbor, which is turned by the key, and works into a wheel with only 4 or 5 notches in it and a blank space through which the tooth cannot pass, it will evidently allow the barrel to be wound up the 4 or 5 turns and no more; and as it unwinds it turns the stopping wheel back again with it.

The other parts of a watch do not differ from those of a clock, except in size, and the position in which they are arranged, to bring them within the circle of the dial, until we come to the escapement; and there a different state of things arises, mainly from the fact that the balance of a watch revolves through sometimes as much as 270°, while a clock pendulum only vibrates through 4° or 5°. The balance being common to all the watch escapements, it will be proper first to describe that, and the conditions to which it is subject. The two equal arms, with equal weights at each end, in fig. 4 are really a balance just as much as the wheel which is commonly used as the more convenient form. But in that figure there is not to be seen that essential element of a modern balance—the thin spiral spring, which you see opening and closing itself at every vibration when you look into a watch. The outer end of this spring is attached to the frame by a cock R (fig. 23), and the inner to the balance at S; and the time of vibration is a compound of the strength of the spring, and the moment of inertia of the balance; for if the spring is perfect, the extent of the vibration does not signify, by virtue of the before-quoted maxim *ut tensio sic vis*, and the further rule (which is one of mathematical certainty, and not empirical and approximate), that wherever the force varies as the angle of vibration, the time of the body vibrating is the same, whatever the space moved over. And as the force of a spring varies (approximately) inversely as its length, this suggests a ready method of regulating the watch; for it is easy to make a pointer or index, or "regulator" PT, turning on a ring fixed to the watch plate, concentric with the balance, and having two pins in it at P, called *curb pins*, just close enough together to embrace the spring, so that, as the index is moved one way or the other, the length of the spring which is free to vibrate may become shorter or longer. When the regulator has been moved as far as it can go towards *fast*, suppose, and the watch still loses, the spring has to be shortened at the cock R into which its outer end is pinned;

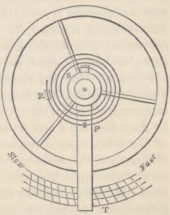

Fig. 23.

and in order that the balance may be capable of alteration, so as still to stand square with the escapement when the spring is in its neutral state, the other end is not actually pinned to the balance, but the cock S is on a small ring which is set on the axis or *verge* of the balance pretty tight by friction, but capable of being turned by hand.

It has often been complained, and very justly, that it is almost impossible to move the regulator little enough, and with sufficient accuracy, for a very small variation of rate, not merely because the point is often ill adjusted to the scale, but because the divisions themselves are necessarily very small. One way of obtaining greater accuracy, and probably the best, is to make the regulator moveable by a tangent screw acting on its end, and capable of being turned by the watch key ; and in an expensive watch, fitted with all the other modern appliances for securing accuracy of performance, the additional expense of this would be well worth incurring. We have seen several watches of this kind. Mr Dent suggests that a cheaper way of doing it, and accurate enough for most watches, would be to make the scale with oblique divisions (as shown in fig. 23), after the fashion of the old form of vernier, and the regulator itself with bevelled edges : by this means a very small motion of the edge of the regulator along the oblique divisions would be very distinctly seen, and it cannot be doubted that this would be a great improvement. In chronometers the adjustment for time is no longer made by altering the effective length of the spring after its length is once fixed, because of the other exception to the rule about the force of a spring varying as its tension, to which we alluded. For it has long been ascertained that a spring has not this isochronous property at all lengths, but only at certain intervals ; and therefore it is necessary in an accurate timekeeper to use only one of those lengths of the spring which are isochronous for different arcs of vibration ; and that being fixed, the timing of the balance can only be done by altering its moment of inertia, and this is done in chronometers by screws with heavy heads in the rim of the balance, and set farther in or out as it is wanted to go faster or slower. In marine chronometers, where there is plenty of room for it, the balance-spring is generally made in a cylindrical form, with the coils all of the same diameter, instead of the flat spiral used in watches; though it does not seem to be quite clear that the cylindrical form is materially better than the other. It is evident, however, that the goodness of this spring is a matter of primary importance; and in this respect, as well as in mainsprings, there seems some reason for apprehending that our makers are surpassed by the foreign ones. The balance-springs made by M. Lutz of Geneva (by a secret method), stood the tests which the horological jury at the Great Exhibition applied, of pulling out nearly straight, and laying on a hot plate, without altering their form; while those to which special attention was invited by Mr C. Frodsham, a chronometer-maker of reputation in London, were very much distorted under the same operations. Nevertheless the English chronometers, on the whole, enjoy a reputation superior to those of any other nation.

The timing of a watch for position, as it is called, is a matter which requires some attention. If the balance is not exactly poised on its axis, it will have a tendency to take one position when the watch is carried vertically, as it always is in the pocket; and the time of vibration will be affected by its disposition thus to act as a pendulum. The watch ought therefore to be tried with XII, IX, VI, and III, successively upwards, and if it does not keep the same rate, the balance is not properly poised. Marine chronometers, indeed, being set in *gimbals* (a ring with the two pivots into the box at right angles with the pivots which carry the chronometer), will remain horizontal, though not without some degree of motion under the motion of the ship; and this gives the balance the further advantage of having its weight resting only on the end of the axis or verge, a position in which there is much less friction than that of a watch carried in the pocket: but there it is not of so much consequence, because the balance is so much lighter than a chronometer balance.

COMPENSATED BALANCES.

The compensation of a balance for temperature is even of more importance than that of a pendulum, especially for chronometers, which are not kept, as watches are, to a tolerably equable temperature by being carried in the pocket. A pendulum requires scarcely any compensation except for its own elongation by heat; but a balance requires compensation not only for its own expansion, which increases its moment of inertia just like the pendulum, but far more on account of the decrease in the strength of the spring under increased heat. The late Mr Dent, in a pamphlet on Compensation Balances, gave the following results of some experiments with a glass balance, which he used for the purpose on account of its less expansibility than a metal one:—

Temperature.	Vibrations in an hour.
32°	3606
66°	3598·5
100°	3599

If therefore it had been adjusted to go right (or 3600 times in an hour) at 32°, it would have lost 7½ and 8½ seconds an hour, or more than three minutes a-day, for each successive increase of 34°, which is about 15 times as much as a common wire pendulum would lose under the same increase of heat, taking the decrease of elasticity of the spring into account, as well as the elongation of the rod; and if a metal balance had been used instead of a glass one, the difference would have been still greater.

The necessity for this large amount of compensation having arisen from the variation of the elasticity of the spring, the first attempts at correcting it were by acting on the spring itself in the manner of a common regulator. Harrison's compensation consisted of a compound bar of brass and steel soldered together, having one end fixed to the watch-frame, and the other carrying two curb pins which embraced the spring as we described at fig. 23. As the brass expands more than the steel, any increase of heat made the bar bend; and so, if it was set the right way, it carried the pins along the spring, so as to shorten it. This contrivance is called a *compensation curb;* and it has often been re-invented, or applied in a modified form. But there are two objections to it: first, that the motion of the curb pins does not correspond accurately enough to the variations in the force of the spring; and secondly, it disturbs the isochronism of the spring for short and long arcs, because, as we stated a little while ago, that isochronism only subsists at certain definite lengths of the spring.

The compensation which was next invented left the spring untouched, and provided for the variations of temperature by the construction of the balance itself. Fig. 24 shows the plan of the ordinary compensation balance as it has now been used for many years. Each portion of the rim of the balance is composed of an inner bar of steel with an outer one of brass soldered upon it, and carrying the weights *b*, *b*, which are screwed to it. As the temperature increases, the brass expanding must bend the steel inwards, and so carries the weights farther in, and diminishes the moment of inertia of the balance. The metals are generally soldered together by pouring melted brass round a solid steel disc, and the whole is

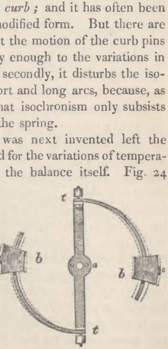

Fig. 24.

afterwards turned and filed away till it leaves only the cross-bar in the middle lying flat and the two portions of the rim standing edgeways. The first person who practised this method of uniting them appears to have been Thomas Earnshaw, who brought the chronometer to the state in which it has remained for the last eighty years, with scarcely any alteration; although (from a combination against him in his own time, and the indifference of writers on these subjects since) he has not obtained the reputation he deserves, and has been sometimes dismissed in a single sentence, while pages have been bestowed on the works of inferior artists, whose chronometers were always beaten by his whenever they came into competition, and who afterwards copied his inventions, and did their best to prevent his being rewarded for them.

The adjustment of a balance for compensation can only be done by trial, and requires a good deal of time. It must be done independently of that for time; the former by shifting the weights, because the nearer they are to the cross-bar the less distance they will move over as the rim bends with them. The timing is done by screws with heavy heads (*t*, *t*, fig. 24) which are just opposite to the ends of the cross-bar, and consequently not affected by the bending of the rim. The compensation may be done approximately by the known results of previous experience with similar balances; and many watches are sold with compensation balances which have never been tried or adjusted,—a matter which a purchaser has no means of ascertaining except by trying the watch himself in different temperatures,—and sometimes with a mere sham compensation balance.

THE CHRONOMETRICAL THERMOMETER.

If a watch or chronometer, going right at a given temperature, is transferred to a higher temperature, it will of course lose, in proportion to the excess of the new temperature above the old one, and the time it is kept there; and consequently, its difference from the true time will show the quantity of additional heat it has received during that period; and if its time is observed and registered every day or every week, it will show what has been the mean heat of that day or week. And if, instead of being furnished with a plain balance, it has one compensated the wrong way, as we may call it, its indications will become still stronger. Such an instrument is called a *chronometrical thermometer*, and is used where the quantity of heat received or lost by some other instrument or apparatus, during a giving time, is wanted to be known, without regard to the extremes which the temperature may have reached, or its fluctuations. It is therefore used at the Greenwich Observatory for trying the rate of chronometers in different temperatures.

SECONDARY COMPENSATION.

When chronometers had been brought to great perfection by the improved workmanship of modern times, and were subjected to more extreme temperatures in the annual trials at Greenwich, it was perceived that there was a residuary error, which was due to changes of temperature, but which no adjustment of the compensation would correct. For, if the compensation was adjusted for two extreme temperatures, such as 32° and 100°, then the chronometer gained at mean temperatures; and if adjusted for any two mean temperatures, it would lose for all beyond them. This error was observed, and attempts were made to correct it before anybody had pointed out how it arose: this appears to have been first done in a paper in the *Nautical Magazine* by the late Mr Dent, in the year 1833; and he gave the following illustration of it. The variation of the force of the spring proceeds uniformly in proportion to the temperature, and therefore may be represented by a straight line inclined at some angle to another straight line divided into degrees of temperature. But the inertia of a balance of the common construction cannot be made to vary uniformly according to the temperature, but will vary more rapidly in cold than heat; and consequently its rate of variation can only be represented by a curve, and the curve can only be made to coincide with the straight line representing the rate of variation of the spring, in two points, whether two extremes or two means, or one extreme and one mean point. The same thing may be shown mathematically, as follows: Let r be the distance of the compensation weights b, b, in fig. 24 (which we may assume for convenience to be the whole mass M of the balance) from the centre at some mean temperature, and let dr be their increase of distance due to a decrease of some given number of degree of heat, under the action of the compensation bars. Then the new moment of inertia will be $M\ (r^2 + 2r\ dr + dr^2)$, and the ratio of the new to the old will be $1 + \frac{2dr}{r} + \left(\frac{dr}{r}\right)^2$; and the term $\left(\frac{dr}{r}\right)^2$ is now too large to be disregarded, as it might be in pendulums, where, as we saw, the compensation $\frac{dl}{l}$ is only required to be about $\frac{1}{20}$th of the $\left(\frac{dr}{r}\right)$ in a balance. It is found that an equal increase of temperature will produce an equal, or rather a less motion $(-dr)$ of the weights towards the centre than from it at any given point; but calling it only equal, the ratio of the decreased moment of inertia to the original one will be $1 - \frac{2dr}{r} + \left(\frac{dr}{r}\right)^2$; so that the increase and the decrease from the mean amount differ by twice $\left(\frac{dr}{r}\right)^2$; in other words, the moment of inertia of the balance varies less in passing from mean to hot temperature than from mean to cold; and consequently if it is adjusted for mean and cold, it will not have decreased enough at an equal increase from mean to hot, or the chronometer will lose; and if adjusted for the two extremes it will gain at mean temperatures.

The correction of this error is called the *secondary com-*

pensation ; and it was a few years ago the subject of a rather warm controversy, carried on in memorials to the Admiralty, published by Parliament, and subsequently in the *Journal of the Society of Arts* for the year 1853, arising from a claim by Mr Loseby (whose name has been mentioned in connexion with another invention of no use at page 32) to be rewarded by Government for an invention of this kind, which he asserted to be superior to the many others for the same purpose, some earlier and some later than his own. The astronomer royal four times reported against Mr Loseby's claim, though admitting the general excellence of his chronometers; and it appears from other examinations of the reports of the annual trials at Greenwich, in the above papers and journal, that when proper means are taken to distinguish the errors of compensation from the general errors which have nothing to do with temperature, the apparent superiority of Mr Loseby's compensation vanishes altogether. It is obvious that the mere fact of one chronometer going better than another for a certain time proves nothing as to the value of any particular invention it contains, unless some means are taken to distinguish the effects of the error which that invention is designed to correct. We shall give a short description of the principal classes of inventions for this purpose, as several of them are exactly the same in principle.

The first that was disclosed was Mr Eiffe's, who communicated several methods for effecting this object to the astronomer royal in 1835. They were afterwards described in a paper edited by Mr Airy for the Admiralty; and they, or some of them, were sufficiently successful to obtain for Mr Eiffe a reward of L.300 as being the first inventor, and having disclosed his invention without a patent. In one of them a compensation curb was used; and though, for the reasons we gave before, this will not answer for the primary compensation, it may for the secondary, where the motion required is very much smaller. In another the primary compensation bar, or a screw in it, was made to reach a spring set within it with a small weight attached, at some mean temperature, and as it bent further in, it carried this secondary compensation weight along with it. The obvious objection to this is (as Mr Loseby remarks), that it is discontinuous; but the whole motion is so small, not more than the thickness of a piece of paper, that this and other compensations on the same principle appear to have been on some occasions quite as successful as his own. Mr Eiffe seems to have made some improvements since that time, but the nature of them is not disclosed in any of the papers we have referred to. Shortly after this Mr Molyneux took a patent for a secondary compensation exactly the same as this of Mr Eiffe's, then before the astronomer royal.

Another large class of balances, all more or less alike, may be represented by Mr Dent's, which came the next in order of time after the two we have mentioned. He also described several forms of his invention in a pamphlet which he published; and it should be observed, that the one which he there specified as the best of them is not the one which Mr Loseby afterwards selected and described as "Dent's balance," for the purposes of his memorial to the Admiralty. The following is the proper description :—

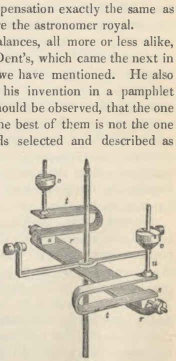

Fig. 25.

In fig. 25, the flat cross-bar *rr* is itself a compensation bar which bends upwards under increased heat; so that if the weights *v*, *v* were merely set upon upright stems rising from the ends of the cross-bar, they would approach the axis when that bar bends upwards. But instead of the stems rising from the cross-bar, they rise from the two secondary compensation pieces *st*, *u*, in the form of staples, which are set on the cross-bar; and as these secondary pieces themselves also bend upwards, they make the weights approach the axis more rapidly as the heat increases; and by a proper adjustment of the height of the weights on the stems, the moment of inertia of the balance can be made to vary in the proper ratio to the variation of the intensity of the spring. The cylindrical spring stands above the cross-bar and between the staples.

Fig. 26 represents Mr Loseby's mercurial compensation

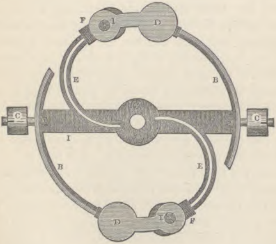

Fig. 26.

balance. Besides the weights D, D, set near the end of the primary compensation bars B, B, there are small bent tubes FE, FE with mercury in them, like a thermometer, the bulbs being at F, F. As the heat increases, not only do the primary weights D, D and the bulbs F, F approach the centre of the balance, but some of the mercury is driven along the tube, thus carrying some more of the weight towards the centre, at a ratio increasing more rapidly than the temperature. The tubes are sealed at the thin end, with a little air included. The action is here equally continuous with Mr Dent's, and the adjustment for primary and secondary compensation are apparently more independent of each other; and this modification of Le Roy's use of mercury for compensated balances (which does not appear to have answered), is certainly very elegant and ingenious. Nevertheless, it is clear, from the analysis of the Greenwich lists for the last seven years of Mr Loseby's trials, that the advantages of this method over the others is more theoretical than practical; for it appears, that if the six months of trial are divided into three periods, one containing all the coldest weeks, another the hottest, and the third those of moderate temperature only, and whether the division is arbitrarily made into equal periods of eight weeks, or into periods of six weeks of the most extreme temperatures, and twelve of the mean, or is made just where the printed register of the temperature shows the greatest breaks to have occurred in each year, still the result is the same, that Dent's compensation was the most successful of all in three years out of the seven, and Loseby's in only one. And further, it is evident that the high place which Loseby's chronometers had frequently obtained in the Greenwich lists, not being borne out in that particular respect for which his invention is designed, must be attributed to his personal care and skill in getting up a single chronometer for trial in each year; which, however creditable to him, is clearly rather an argument against the value of his invention than in favour of it; and makes it probable that the same care and skill bestowed upon some of the other inventions for secondary compensation would have rendered them still more successful. It is remarkable also, that it has never been adopted by any other chronometer-maker; for although he afterwards included it in a patent, it was well known and open to the adoption of everybody for several years before:

whereas the principles both of Mr Eiffe's and Mr Dent's methods have been adopted by several other makers.

Chronometers have been made with glass balance-springs; and the published rate of one which was tried some years ago at the Royal Observatory was very good. They have the advantage of requiring very little primary and no secondary compensation, on account of the very small variation in their elasticity, compared with springs of steel or any other metal. We cannot ascertain any good reason why the use of them has not been extended, except that it is said the workmen resisted their introduction, as they often do resist any improvement involving a material departure from the established modes of construction. It was also remarked, in a discussion at the Society of Arts, that glass springs change their rate after a few months: but so do steel springs; indeed, it is expressly stated in Mr Eiffe's pamphlet before referred to, that chronometers always gain after a few months' working. But whatever is the cause, very few of these glass spring chronometers appear to have been made even by Mr Dent, who was the author of the one whose rate we have mentioned.

But about a year before his death he invented a very different method of effecting the primary and secondary compensation at once, and without any additional appendage to the balance, or addition to the cost. He called it the *prismatic balance*, from the shape of the steel rim, of which the section is shown in fig. 27, BC being the brass, and the dark triangle within it the section of the steel part of the rim. A prism of cast-steel will bend more easily from the edge than the other way, and consequently the motion is greater when it is being curved by heat than when it is

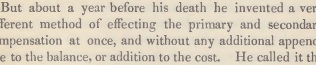

Fig 27.

pulled straighter by cold; which is exactly what is wanted. It is true that the difference is not quite so great as it ought to be for complete secondary compensation for a very wide range of temperature, such as the present astronomer royal has for the last few years subjected all the chronometers which are sent for public trial; a practice which seems very likely to withdraw the attention of the makers from points of greater practical importance, and confine it to this one of secondary compensation for variations of temperature, such as not one in a hundred of them will have to undergo in real use, and which is therefore of quite secondary importance. It is remarkable that when the chronometer rates were sent to Greenwich after a late arctic expedition, the astronomer royal had to report to the Admiralty that the chronometers had all been kept so *warm* that they did not afford the means of arriving at any conclusion as to the relative merits of the different kinds of secondary compensation; in other words, that it had not come into action, even in an arctic voyage, to any sensible extent. But, although it would be of no use to send a chronometer of this kind to be tried against others in artificial changes of temperature from 21° to 115°, the present Mr Dent (of the Strand) says he has found them quite near enough to the requisite compensation for all ordinary variations of temperature, and also more than usually steady in their rate; for even in the best chronometers there appear every now and then quite capricious variations, which show that there is yet ample room for improvement in other things besides compensation for an excessive range of temperature.

It ought to be understood better than it generally is, that the best chronometers, with all these improvements, cannot be made to keep a rate equal to that of some of the turret clocks we have described, or even of a good astronomical clock of the usual kind. The chronometer which stood highest in the Greenwich trials in the best of the seven years before referred to, exhibits a difference of rate of 4·5 seconds between two successive *weeks*, and a difference of 8·6 seconds between the greatest and least "weekly sums of daily rates;" whereas, we saw that turret clocks with cast-iron wheels and a proper escapement, can now be made to go with a variation of rate of less than one second a *month* for several months together.

WATCH ESCAPEMENTS.

There is a greater variety of escapements in use in watches than in clocks. In the Austrian department of the Great Exhibition there was a large watch movement to which thirteen different escapements could be fitted for the purpose of illustration: not that anything like all this number can be said to be in use. The only ones that can be so described are,—(1.) The old *vertical* escapement, now almost disused; (2.) The *lever*, very much the most common in English watches; (3.) The *horizontal* or *cylinder*, which is equally common in foreign watches, though of English invention; (4.) The *duplex*, which used to be more in fashion for first-rate watches than it is now; and (5.) The *detached* or *chronometer* escapement, so called because it is always used in marine chronometers. Of course every watch is in one sense a chronometer; but the term is conventionally applied only to marine chronometers, and to watches of the same construction, which are thence called pocket chronometers. Besides these five standard movements, we have already mentioned that Macdowall's single-pin escapement (fig. 8) has been applied to watches, and that it is in some respects superior to the lever; but it is more expensive on account of the two additional wheels in the train; and that, like the *virgule* or *comma* escapement (which is described in most of the French treatises on watches), can hardly be added to the list of escapements in general use, though it is entitled to stand above many others of the thirteen before alluded to.

The vertical escapement is simply the original clock escapement of fig. 4 adapted to the position of the wheels in a watch and the balance, in the manner here exhibited in fig. 28. It is, as we saw before, a recoil escapement, and the only one of those we have mentioned which is; and besides that, it requires considerable thickness in the watch to hold the wheel which stands vertically when all the others are horizontal. It is also inferior in going to all the others, and no cheaper than the lever escapement can now be made; and for these reasons it is no wonder that it has gone out of use.

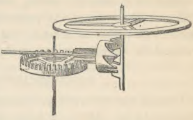

Fig. 28.

The lever escapement, as it is now universally made, was invented by Thomas Mudge, a London watchmaker, to whom (or to his son for him), in 1793, a committee of the House of Commons, in opposition to the opinion of the Board of Longitude, and apparently not understanding the evidence they took, gave a reward of L.3000 for inventing a remontoire escapement for chronometers, not worth a farthing, and indeed, as it turned out, worth a good deal less than that to his son, who proceeded to make the chronometers. However, if the reward is considered as given for the invention of the lever escapement, which is now used in all the best watches in the world (except chronometers), it may be said to be well deserved. It is strange that Graham, the inventor of the dead escapement in clocks, did not hit upon this application of it to watches; an application, too, which avoids the great defect of that escapement in clocks, viz., the dead friction, or the friction on the dead faces of the pallets beyond what is necessary for the locking. Fig. 29 shows its action; of course the position of the lever with reference to the pallets is im-

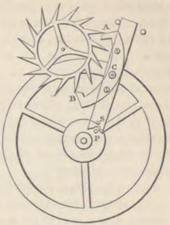

Fig. 29.

material in principle, and is only a question of convenience in the arrangement; but it is generally such as we have given it. If you turn back to fig. 6, the dead escapement in clocks, you will see that this is just the same as if the pallets there vibrated no farther with the pendulum than just enough to let the teeth escape, and left the pendulum free during all the rest of its swing, or "excursion," beyond the angle of escape. The reason why that cannot be done with a pendulum is, that its arc of vibration is so small that the requisite depth of intersection cannot be got between the two circles described by the end S of the lever and any pin in the pendulum which would work into it; whereas, in a watch, the pin P, which is set in a cylinder on the verge of the balance, does not generally slip out of the nick in the end of the lever until the balance has got 15° past its middle position. The pallets are under-cut a little, as it is called, *i.e.*, the dead faces are so sloped as to give a little recoil the wrong way, or slightly to resist the unlocking; because otherwise there would be a risk that a shake of the watch would let a tooth escape while the pin is disengaged from the lever. There is also a further provision added for safety. In the cylinder which carries the impulse pin P, there is a notch just in front of P, into which the other pin S on the lever fits as they pass; but when the notch has got past the cylinder, it would prevent the lever from returning, because the safety-pin S cannot pass except through the notch, which is only in the position for letting it pass at the same time that the impulse-pin is engaged in the lever. The pallets in a lever escapement (except bad and cheap ones) are always jewelled, and the scape-wheel is of brass. The staff of the lever also has jewelled pivot-holes in expensive watches, and the scape-wheel has in all good ones. The holes for the balance-pivots are now always jewelled, if nothing else is. The scape-wheel in this and most of the watch escapements generally beats five times in a second; in large chronometers four times; and the wheel next to the scape-wheel carries the seconds-hand. Macdowall's single-pin escapement is adapted to watches exactly as the dead escapement of clocks is turned into the lever escapement of watches.

Fig. 30 is a plan of the *horizontal* or *cylinder* escapement, cutting through the cylinder, which is on the verge of the balance, at the level of the tops of the teeth of the escape-wheel; for the triangular pieces AB are not flat projections in the same plane as the teeth, but are raised on short stems above the plane of the wheel; and still more of the cylinder than the portion shown at ACD is cut away where the wheel itself has to pass. The author of this escapement was Graham, and it resembles the dead escapement in clocks in principle more than the lever escapement does, though much less in appearance; because in this escapement there is the dead friction of the teeth against the cylinder, first on the outside, as here represented, and then on the inside, as shown by the dotted lines, during the whole vibration of the balance, except that portion which belongs to the impulse; whereas in the lever escapement there is not the dead

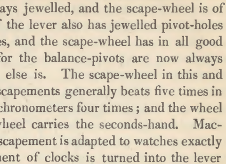

Fig. 30.

friction, as we explained just now. The impulse is given by the oblique outside edges A*a*, B*b* of the teeth against the edges A, D of the cylinder alternately. The portion of the cylinder which is cut away at the point of action is about 30° less than the semicircle. The cylinder itself is made either of steel or ruby, and from the small quantity of it which is left at the level of the wheel, it is evidently a very delicate affair; and probably this has been the main reason why, although it is an English invention, it has been almost entirely abandoned by the English watchmakers in favour of the lever, which was originally a French invention, though very much improved, as we have said, by Mudge; for before his invention the lever had a rack or portion of a toothed wheel on its end, working into a pinion on the balance verge, and consequently it was affected by the dead friction, and that of this wheel and pinion besides. This used to be called the rack lever, and Mudge's the detached lever; but the rack lever being now quite obsolete, the word *detached* has become detached from the lever escapement, and confined to the chronometer, to which it is more appropriate, as will be seen presently. The Swiss watches have almost universally the horizontal escapement. It is found that—for some reason which is apparently unknown, as the rule certainly does not hold in cases apparently analogous—a steel scape-wheel acts better in this escapement than a brass one, although in some other cases steel upon steel, or even upon a ruby, very soon throws off a film of rust, unless they are kept well oiled, while brass and steel, or stone, will act with scarcely any oil at all, and in some cases with none.

The *duplex* escapement (fig. 31) is probably so called because there is a double set of teeth in the scape-wheel; the long ones (like those of the lever escapement in shape) for locking only, and short ones (or rather upright pins on the rim of the wheel) for giving the impulse to the pallet P on the verge of the balance. The action of this escapement is very peculiar, and requires some attention to understand it. It is a single-beat escapement, *i. e.*, the balance only receives the impulse one way, or at every alternate beat, as in the chronometer escapement, and in a few clock escapements which we have not described because they have never come into use. When the balance is turning in the direction marked by the arrow, and arrives at the position in which the dotted tooth *b* has its point against the triangular notch V, the tooth end slips into the notch, and as the verge turns farther round, the tooth goes on with it till at last it escapes when the tooth has got into the position A; and by that time the long tooth or pallet which projects from the verge has moved from *p* to P, and just come in front of the pin T, which stands on the rim of the scape-wheel, and which now begins to push against P, and so gives the impulse until it also escapes when it has arrived at *t;* and the wheel is then stopped by the next tooth B having got into the position *b*, with its point resting against the verge, and there is evidently what we have called dead friction between them; but as the verge is smaller than the cylinder of the horizontal escapement, and is also made of a jewel, the friction does not seriously affect the motion of the balance. The impulse is also given very directly across the line of centres, and therefore with very little friction,

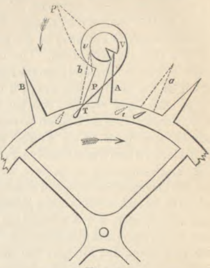

Fig. 31.

as in the three-legged dead escapement for clocks before described, and in the chronometer escapement, which will be next described. A little impulse is also received from the long teeth on the notch; but the greatest part of that motion is wasted. As the balance turns back, the nick V goes past the end of the tooth *b*, and in consequence of its smallness, it passes without visibly affecting the motion of the scape-wheel, though of course it does produce a very slight shake in passing. It is evident that, if it did not pass, the tooth could not get into the nick for the next escape. The objection to this escapement is, that it requires very great delicacy of adjustment, and the watch also requires to be worn carefully; for if, by accident, the balance is once stopped from swinging back far enough to carry the nick V past the tooth end, it will stop altogether, as it will lose still more of its vibration the next time from receiving no impulse. The performance of this escapement, when well made, and its independence of oil, are nearly equal to those of the detached escapement; but as lever watches are now made sufficiently good for all but astronomical purposes, for which chronometers are used, and they are cheaper both to make and to mend than duplex ones, the manufacture of duplex watches has decreased a good deal of late.

The *chronometer*, or *detached* escapement is shown at fig. 32, in the form to which it was brought by Earnshaw nearly eighty years ago, and in which it has remained ever since, with the very slight difference that the pallet P, on which the impulse is given (corresponding exactly to the pallet P in the duplex escapement), is now generally set in a radial direction from the verge, whereas Earnshaw made it sloped backward, or under-cut, like the scape-wheel teeth. The early history of escapements on this principle does not seem to be very clear. They appear to have originated in France; but there is no doubt that they were considerably improved by the first Arnold, who died in

1799; (the second, who died in 1842, owed his reputation to his father in the first instance, and afterwards to his partner, the late Mr Dent). He received several government rewards for improvements in chronometers, though it cannot be said that he deserved them all; for the last and largest of them he got solely through the influence of his friend Sir Joseph Banks, who, after failing to persuade the Board of Longitude to disregard the certificates of the astronomer royal, and the farther evidence taken by themselves in consequence of Banks's opposition to the grant to Earnshaw, at last, by the help of the First Lord of the Admiralty, Lord Melville, extorted from a majority of the Board a further grant of L.1680 to Arnold, for no further invention whatever, but simply to make him equal with Earnshaw, who had been voted L.3000 for the improvements which enabled his ordinary and cheap chronometers to beat the picked ones of Arnold and other makers. For, among the other proofs of Earnshaw's genius, it may be mentioned that he boldly set at defiance the common and stupid prejudice for what is called "high finish," *i.e.*, the polishing up of surfaces which have no action, and therefore no friction on them. In this we are sorry to find that he has not been followed, in chronometers at least, by anybody; and Mr Dent, who has adopted the same system in turret clockwork, has on that account met with the same obloquy, on grounds still more absurd; for nothing can be a more ridiculous waste of money than polishing non-acting surfaces, which are never seen after they leave the shop, and besides that, necessarily lose their polish by dirt, oil, and sometimes rust, in the course of a few months. But it is time we should describe the detached escapement, as it has been made ever since the time of Earnshaw, with the slight difference in the shape of the pallet before alluded to.

In fig. 32 the small tooth or cam V, on the verge of the balance, is just on the point of unlocking the detent

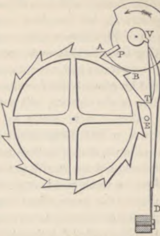

Fig. 32.

DT from the tooth T of the scape-wheel; and the tooth A will immediately begin to give the impulse on the pallet P, which, in good chronometers, is always a jewel set in the cylinder; and the tooth V is also a jewel. This part of the action is so evident as to require no further notice. When the balance returns, the tooth V has to get past the end of the detent, without disturbing it; for, as soon as it has been unlocked, it falls against the banking-pin E, and is ready to receive the next tooth B, and must stay there until it is again unlocked. It ends, or rather begins, in a stiffish spring, which is screwed to the block D on the watch frame, so that it moves without any friction of pivots like a pendulum. The passing is done by means of another spring TV, called the passing spring, which can be pushed away from the body of the detent towards the left, but cannot be pushed the other way without carrying the detent with it. In the back vibration, therefore, as in the duplex escapement, the balance receives no impulse, and it has to overcome the slight resistance of the passing spring besides; but it has no other friction, and is entirely *detached* from the scape-wheel the whole time, except when receiving the impulse. That is also the case in the lever escapement; but the impulse in that escapement is given obliquely, and consequently with a good deal of friction; and besides, the scape-wheel only acts on the balance through the intervention of the lever, which has the friction of its own pivots and of the impulse pin. The locking-pallet T is under-cut a little for safety, and is also a jewel in the best chronometers; and the passing spring is of gold, as steel will rust. In the duplex and the detached escapements, the timing of the action of the different parts requires great care, *i.e.*, the adjusting them so that each may be ready to act exactly at the right time; and it is curious that the arrangement which would be geometrically correct, or suitable for a very slow motion of the balance, will not do for the real motion. If the pallet P were really set so as just to point to the tooth A in both escapements at the moment of unlocking (as we have drawn it, because otherwise it would look as if it could not act at all), it would run away some distance before the tooth could catch it; because in the duplex escapement the scape-wheel is then only moving slowly, and in the detached it is not moving at all, and has to start from rest. The pallet P is therefore, in fact, set a little further back, so that it may arrive at the tooth A just at the time when A is ready for it, without wasting time and force in running after it. The detached escapement has also been made on the duplex plan, of having long teeth for the locking, and short ones or pins nearer the centre for the impulse; but the advantages do not appear to be worth the additional trouble, and the force required for unlocking is not sensibly diminished by the arrangement, as the spring D must in any case be pretty stiff, to provide against the watch being carried in the position in which the weight of the detent helps to unlock it.

There have been several contrivances for remontoire escapements, some of them certainly far better than Mudge's parliamentary reward escapement; but there are defects in all of them; and there is, after all, not the same advantage to be obtained by giving the impulse to a watch-balance by means of some other spring instead of the mainspring, as there is in turret-clocks, where the force of the train is liable to very much greater variations than in chronometers or small clocks. We are, however, far from pronouncing, as some persons have done,—on the very insufficient ground of these inventions having failed hitherto, —that no remontoire escapement for watches can ever succeed. It was predicted with equal confidence, that it could never succeed in clocks; whereas we now see, that both a train remontoire and a remontoire escapement have succeeded perfectly, and make the clocks keep better time than had ever been known before.

REPEATERS, KEYLESS WATCHES, &C.

Among the pieces of watch-work which have gone very much out of fashion may be mentioned repeating-watches, *i.e.*, watches which strike the hours and quarters on pushing in the handle. They are now scarcely ever made in England, and with very good reason; for it is almost impossible to crowd into the space of even a large-sized watch the quantity of wheels and other things required for the repeating work, without unduly interfering with the going part; and besides that, the striking work itself is very liable to get out of order. We have therefore thought it better to omit the descriptions of the various inventions of this kind, especially as they are too complicated to be easily understood from drawings.

The winding of watches without a key is an object for which there have been several inventions, and it possesses a considerable advantage, besides the mere convenience of being independent of a key; for as there is then no occasion to open it, the case may be made to fit more closely, and the air is more completely excluded, and consequently the watch will go longer without cleaning; and it also saves the thickness and the cost of a double back to the case. The first plan of the kind was that of pulling out the knob of the handle, which went into the watch, and had a gathering click attached to it which wound up the fusee, or the barrel, by means of a ratchet. But this was not found to answer; it was liable to get out of order, and moreover, at every time of winding you pumped fresh air into the watch, which soon produced injurious effects. A far better plan is that which was noticed in the horological report of the Great Exhibition as exhibited by Mr Dent, as the proprietor, though not the author of the invention. It combines the two objects of winding and setting the hands by means of the handle, in the manner we shall now describe. In fig. 33, *d* is a wheel on the barrel, with bevelled teeth, and there is another small bevelled wheel on a spindle *b*, which ends in a milled head *a*, within the handle or *pendant;* these two wheels cannot conveniently be arranged so as to work into each other without the intervention of a third between them, which is marked *e* in the left hand of the three figures 33. It is easy to see that turning the milled head will wind up the barrel. The same arrangement might of course be applied to the fusee, though it would increase the size; but in fact these watches are made without one, and we know from those who have

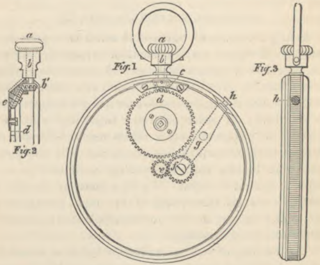

Fig. 33.

worn them for some years that the absence of a fusee could certainly not be discovered from any defect in their performance; on this point we have expressed our own opinion some pages back. The winding wheel *d* is also made with the well-known contrivance of Breguet, known here by the name of the "tipsy key," when applied to a common winding key, which enables you to turn the handle the wrong way without doing anything except moving a ratchet-wheel over its click, and consequently without straining the watch in attempting to wind it the wrong way. The same handle and wheels are also made use of to set the hands, thus: There is a small wheel *f* which turns on a stud at the end of the lever *fgh*, and as the lever turns on a pivot at *g*, when its end *h*, which just projects through the rim of the watch, is pushed on one side, the wheel *f* will then be thrown into gear with the winding wheel *d* and the hour pinion in the middle of the watch; and consequently, if the handle is then turned, it will alter the hands, just as they are usually altered from the back by a key in foreign watches, so that the face need never be opened. Of course, while this is doing, you do at the same time wind up the watch a little if the handle has to be turned the way for winding; but that is of no consequence, except that you cannot put the hands forward immediately after you have completely wound up the watch. (The arrangement of the lever and the wheel *f* is not quite the same in Mr Dent's later watches as that given above, and taken from one of his pamphlets; but the principle being the same, we have not thought it worth while to alter the drawing.)

The Emperor Napoleon I. had a watch which wound itself up by means of a weighted lever, which rose and fell at every step he took, and, having a gathering click to it, it wound up a ratchet attached to the barrel, if it was not then fully wound up. The instrument called the *pedometer* is on the same principle, though its object is different, being merely to count the number of steps you take while the instrument is in your pocket. It is capable of adjustment according to the number of steps which the wearer usually takes in a mile, which he must first count, and set the instrument accordingly, and then it will indicate the distance walked; but without such adjustment it affords no measure of distance at all, and it is on the whole of very little use.

There is a very elegant invention of M. Redier of Paris (to whom a prize medal was awarded in the Great Exhibition), for enabling you to mark the exact time of any observation, without immediately looking off the object, and without the trouble of counting the beats by ear from the watch. In fig. 34, DD is the dial of a large watch (not

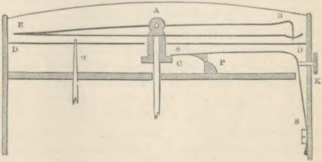

Fig. 34.

intended for the pocket, though not so large as a box chronometer). The seconds-hand arbor is in the middle, so as to get the usual space of a minute for the seconds on the dial, and the spaces may be still further divided if necessary. The watch should not have a duplex or a detached escapement, because in them the hand only moves at every other beat, and the quicker the balance beats the more accurate the observations may be. Very perfect going is not necessary for it, any more than for what is called in observatories a *journeyman clock*, *i.e.*, a clock, made for very loud beats (which is not generally consistent with very good going), and only set going from another clock a short time before it is wanted. The seconds-hand is double, the lower one ending in a little cup at B, with a small hole in the bottom; and the upper one EAB is a spring fixed to the other at E, and the end B a point just going through the hole in the cup. A drop of thick ink is put in the cup, and it is evident that when the upper hand is pulled down, its point will make a mark on the dial. The pulling down is done thus:—At A there is a kind of link hung to the marking-hand, moving very freely on the arbor of the main seconds-hand, and ending in a ring C, very near the end of the spring SS, which is fixed to the watch-case, and can be pushed in by a knob K from the outside. It would be difficult to exhibit in a drawing the peculiar form of the pin P, and the inclined plane which passes over it; but it is such that, as soon as the knob is pushed in far enough the inclined plane drops over the end of P, and then the spring strikes down the ring C, and so pulls down the marking-hand, and then the inclined plane is brought back sideways past P, so as to be thrown out of the ring immediately, and to leave only a momentary contact with the dial; it is in fact so momentary that the ink-spot is never *run* the least, but is always a distinct and small speck, which gives the time of pushing in the knob within the nearest beat of the balance; and for the minute, the minute-hand M must be looked at, either a little before or a little after the observation.

Watches have also been made with what are called *split seconds*-hands; the two hands being in their ordinary state together and appearing as one; but when you push in a knob, one of them is stopped, while the other goes on: the time shown by the stopped one is of course the time of the observation. Sometimes this is done by merely connecting the hands by a very slight spiral spring, which will allow itself to be untwisted one or two coils without stopping the watch; and as it cannot be of any use to stop the seconds-hand longer than a minute, this seems to answer. There is however another plan, in which these two hands, or at least the socket of one and the arbor of the other, are connected by a pair of discs set obliquely on the arbor and the socket respectively, so that whenever the spring which keeps them together is allowed to act, it brings the loose hand up to the hand fixed on the arbor; and it does not signify how long it may be stopped by throwing the discs out of contact.

MERIDIAN INSTRUMENTS.

It is of little use having the best clock in the world, unless you have some means, still more invariable and incapable of getting out of order than the clock itself, for occasionally testing and correcting it. The most perfect is of course a transit instrument; which, however, is not useable by many persons who can easily manage a more simple instrument, and have only the sun to deal with, and not the stars.

The DIPLEIDOSCOPE is an instrument invented by Mr Bloxam, whose name has already been mentioned several times, for ascertaining the time of solar noon much more exactly than can be done by a common sun-dial. It can also be used when the sun is covered with thin clouds, not thick enough to hide it, though sufficient to prevent it casting a distinct shadow. The name is compounded of διπλόος double, εἶδος an image, and σκοπέω to see, because in all positions except one it presents a double image of the sun. The instrument is to be fixed at first by a chronometer, so that it may be in the position of showing the single image of the sun exactly at noon; and then, at about a minute before noon, the two images make their first contact, and at the same time after noon they completely separate; and the times of these contacts, and also of the complete coincidence, can be observed within two or three seconds. The following is the principle of the construction :—

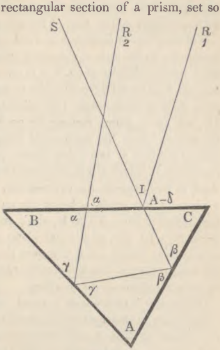

Fig. 37.

Let ABC be the rectangular section of a prism, set so that a ray of the sun SI, and its reflected ray IR$_1$, lie in the plane perpendicular to the axis of the prism. It is not solid, but composed of three small glasses, of which AB, AC., are mirrors, but BC is only a plain glass not silvered. Consequently, the ray SI will be partly reflected from BC in the direction IR$_1$, but part of it will pass through the glass, and be reflected by the mirror AC on to AB, and there reflected again and sent through BC in the direction of αR_2, making some angle α with BC. Suppose the angle of incidence, and therefore of first reflection, to R$_1$, to be $A - \delta$ (A being the opposite angle of the prism), and the other angles as marked in the figure; and let us see what α the angle of the twice reflected ray will be. Now, $\beta = \pi - (C + A - \delta)$, in the small triangle near C; therefore, in the one near A, $\gamma = \pi - (A + \beta) = C - \delta$; and in the triangle near B, $\alpha = \pi - (B + C - \delta) = A + \delta$. And therefore the difference between the directions of the once reflected and the twice reflected rays is $2\,\delta$; and if the prism is so placed that the angle of incidence = the opposite angle of the prism at noon, the rays will then emerge parallel at noon, and the two images of the sun will be seen as one; as noon approaches the images converge, and after noon diverge, with a velocity double that of the sun itself.

But the plane of incidence and reflection can only be perpendicular to the axis of the prism twice a-year. Still the same result will take place if it is once set properly. For suppose it to be set perpendicular to that plane at the equinox, then at midsummer the incident and reflected ray IR_1 will lie in planes making the angle ω (the obliquity of the ecliptic) with the equinoctial plane; but SI and IR_1 will be sections of two other planes parallel to the axis of the prism, in which the incident and reflected rays also lie. And, in like manner, the ray reflected from AC will lie in a plane at the angle ω below the equinoctial plane; and that reflected from AB to R_2 also; and the projections of these rays on the equinoctial plane will lie in the same direction as before; and therefore the twice reflected and the once reflected rays will emerge parallel, as before, when SI is in the plane of the meridian.

The prism is inclosed in a small, solid brass box, in the shape of an irregular pyramid, about two inches high; and it is made so that it only requires fixing on a horizontal bed. They are only made by Mr Dent, as he is the proprietor of Mr Bloxam's patent. Instead of fixing them and so leaving them exposed to the air, he has lately adopted the plan of fixing a brass plate on the window-sill where the instrument is to stand, with a raised edge, against which one side of the dipleidoscope is laid when it is first set by the chronometer, and afterwards whenever it is used. It is generally necessary either to smoke the front glass, or to look at it through a piece of smoked or coloured glass, which is supplied with it, as well as the necessary table of the times of first and last contact for every day in the year. He has also lately made some of them to revolve on an axis parallel to the earth's axis, and with a graduated hour-circle, so that they may be used for any other hour as well as noon. But in this case the instrument can only be used (except at noon) for the latitude for which it is constructed, like a sun-dial, unless it has an adjustment for latitude also, as some of them have.

But some persons find a difficulty in using the dipleidoscope, easy as it seems to us, probably because they will not take the trouble once to learn how to look into it, which does require a little attention. We therefore add a description of a still more simple instrument, which does not profess to be an invention, but merely a convenient arrangement for getting what has been used for ages in different forms, viz., a meridian mark perfectly obvious and unmistakable.

On a level slab of a fine stone or slate, erect (in any way you please) an upright plate, rather near the south edge of the slab, and facing south, and with a very narrow vertical slit in it, reaching 8 or 9 inches from the slab. The edges which form the slit should be rather sharp. It may be set near enough to the south by marking the shadow, or rather the bright line, of the slit on the slab at the time of solar noon, and setting the plate at right angles to this line. When this *gnomon* is fixed, with the slit quite vertical by looking at a plum-line through it, you may get your meridian mark in either of two ways. If you are within reach of any reliable source of accurate time, and have a watch that will carry it within a second or two, the shortest way is just to prick the middle of the bright line on the slab exactly when the watch tells you it is solar noon. Then draw a straight line through that point to the bottom of the slit, and that is the meridian line, or place of the bright line at solar noon for ever.

But if you cannot be sure of getting the exact time second hand, you may find it for yourself without any watch at all; for in this respect it differs from the dipleidoscope. At about 10.30 A.M. mark on the slab the exact end of the bright line. You can only do it in summer, because the line will reach beyond the slab in winter, unless it is very large: 15 inches from north to south is quite wide enough, and about 20 inches from east to west leaves plenty of room to engrave an equation table upon it for intervals of about a minute. The longitude difference from Greenwich time should be incorporated in the table, making the clock time before the solar in all the west of England. Call this first mark A; and make two or three more marks B, C, up to about 11.30, and with one leg of the compasses at the bottom of the slit exactly, draw arcs of different circles through A, B, C. At some time after noon the end of the bright line will fall again upon each of these circles, say at *a*, *b*, *c*. Bisect the arcs A*a*, B*b*, C*c*; and if you can draw a straight line from the bottom of the slit through all these bisections, you may be pretty sure they are right, and that line is the meridian line. If all the bisections do not fall on the line, some of the marks have been wrong, or the slab not level, or the slit not upright, and you must try again another day. Indeed, it is better not to cut the line in strongly until you have tried it on several days. Mr Denison first put up one of these instruments about twenty years ago, and it happened to be afterwards visited by the Plumian professor of astronomy at Cambridge; and though it was not very well made, and the slit too wide, he found the exact time could be taken from it within three or four seconds, which is near enough for keeping any clock in order at moderate intervals. With a fine slit the time can be taken within two or three seconds, which is as near as it can be done with certainty by the dipleidoscope. Mr Dent now makes these *gnomons* in a convenient form for setting, of cast-iron with zinc or copper plates screwed on, leaving the slit between them, and they cost very little. Of course a firm foundation is essential.

PART II.

LOCKS.

A **Lock** may be defined to be any kind of fastening which is intended not to be opened except by one particular instrument, called the key, or by some secret method of manipulation. The earliest lock of which the construction is known is the Egyptian, which was used 4000 years ago. In this drawing (fig. 1), *aa* is the body of the lock, *bb* the bolt, and *cc* the key. The three pins *p*, *p*, *p* drop into three holes in the bolt when it is pushed in, and so hold it fast; and they are raised again by putting in the key through the large hole in the bolt, and raising it a little, so that the pins in the key push the locking-pins up out of the way of the bolt. The security of this is very small, as it is easy enough to find the places of the pins by pushing in a bit of wood covered with clay or tallow, on which the holes will mark themselves; and the depth can easily be got by trial.

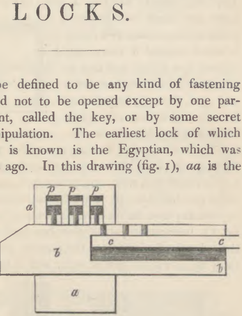

Fig. 1.

Mr Chubb, the well known lock-maker, has shown us a wooden Chinese lock which is very superior to the Egyptian, and, in fact, founded on exactly the same principle as the Bramah lock, which long enjoyed the reputation of being the most secure lock ever invented; for it has sliders or tumblers of different lengths, and cannot be opened unless they are all raised to the proper heights, and no higher. Until about eighty years ago, we had no lock so good as this in England. The locks then in use (fig. 2) were nothing better than a mere bolt held in its place, either shut or open, by a spring *b*, which pressed it down, and so held it at either one end or the other of the convex notch *aa*; and the only impediment to opening it was the wards which the key had to pass before it could turn in the keyhole. But you could always find the shape of the wards by merely putting in a blank key covered with wax, and pressing it against them; and when you had done so, it was by no means necessary to cut out the key into the complicated form of the wards (such as fig. 3), because no part of that key does any work except the edge *bc* farthest from the pipe *a*; and so a key of the form fig. 4 will do just as well; and a small collection of skeleton keys, as they are called, of a few different patterns, were all the stock-in-trade that a lock-picker would require.

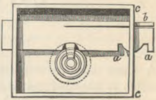

Fig. 2.

Fig. 3.

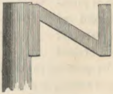

Fig. 4.

The common single-tumbler lock (fig. 5) was rather better than this, as it requires two operations, instead of one, to open it. The tumbler *at* turns on a pivot at *t*, and has a square pin at *a*, which drops into a notch in the bolt *bb*, either when it is quite open or quite shut, and the tumbler must be lifted by the key before the bolt can be moved again. But this, also, is very easy, unless the lock is so made that the tumbler will go into another notch in the bolt if it is lifted too high, as in the lock we shall now describe, and which is the foundation of all the modern improvements in lock-making.

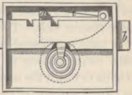

Fig. 5.

Barron's Lock.—Fig. 6 is a front view, and fig. 7 a horizontal section, of Barron's lock, which was patented in the year 1778. First consider it with reference to one tumbler, *at*, only. You see that unless the square pin *a* is lifted by the key to the proper height, and no higher, the bolt cannot move, and that alone adds very considerably to the difficulty of picking, except by a method not discovered for many years after.

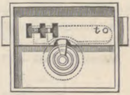

Fig. 6.

But besides that, Mr Barron added another tumbler, and unless both were raised at once to the proper height, and no higher, the lock could not be opened. We are not aware that Barron himself ever went beyond two tumblers; but the principle of the many-tumblered lock is undoubtedly his, and nothing that was added to it for nearly eighty years afterwards made any material addition to its security. But instead of making a separate pin to

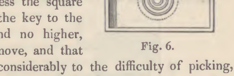

Fig. 7.

each tumbler, and a corresponding number of notches in the bolt, the simpler plan was adopted by other makers of putting what is called the *gating*, in the tumblers, and a single pin in the bolt, which is then called the ***stump;*** this will be shown presently in the drawing of Chubb's still more famous lock. The face, or working edge, of the key of a many-tumblered lock assumes this form (fig. 8), the steps corresponding to the different heights to which the tumblers have to be raised, and one of them acting on the bolt, and they may have a much wider range of difference than in this figure. The key here drawn is also one with the wards of such a shape that no skeleton except itself can pass them. The form, however, can be got in the usual way by a wax impression ; and as it weakens the key very much, and is expensive to cut, it is not often used.

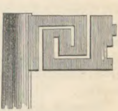

Fig. 8.

Bramah's Lock.—The next lock of any importance was

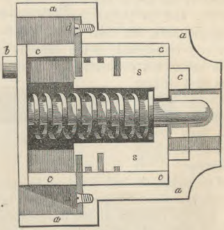

Fig. 9.

the celebrated lock originally patented, just ten years after

Barron's, by the late Mr Joseph Bramah, who came up to London from Barnsley as a joiner, and raised himself to eminence by the invention of this lock, of the machine for numbering bank-notes, the beer-engine, the water-closet, the pencil-cases called "ever-pointed," and, above all, the hydraulic press—an invention which, like Nasmyth's steam hammer, extended the powers of man beyond what before had been conceived possible. In figures 9 and 10, *aaaa*

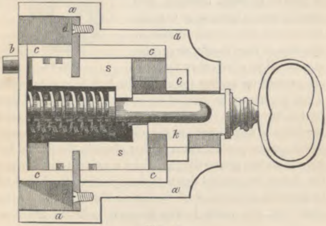

Fig. 10.

is the outer barrel of the lock, which is screwed to, or cast with the plate; *cccc* is a cylinder, or inner barrel, turning within the other. It is shown separately at fig.

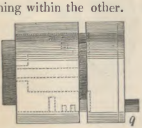

Fig. 11.

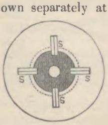

Fig 12.

11; and fig. 12 is a cross section of it, the black ring being the keyhole, and the light spot in the middle the *drill-pin*, which goes into the key. The short pin *b*, in figs. 9, 10, 11, is set in the end of the cylinder, near its edge; and when the cylinder turns round, that pin shoots or draws the bolt, by acting in a slit of the form shown in fig. 13. The security of the lock depends upon a number of sliders, *s*, *s*, of which the shape is shown in fig. 14, and the cross section in fig. 12. They are made of plates of steel doubled, and sprung open a little, so as to make them move with a little friction in the slits of the cylinder or revolving barrel in which they lie, and are pressed up against the cap of the lock by a spiral spring. They are shown so pressed up in fig 9, and pressed down by the key in fig. 10. There is a deep groove cut round the barrel; and in each of the sliders there is a deep notch which can be pushed down to that place in the barrel by a key slit to the proper depth; and it is evident that when all the sliders are pushed down to that position, the barrel will present the appearance of having no sliders in it. A steel plate (fig. 15), made in two pieces in order to get it on, embraces the barrel at the place where the groove is, having notches in it corresponding to the sliders, and is fixed to the body of the lock by two screws marked *d*, *d* in figs. 9,

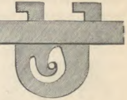

Fig. 13.

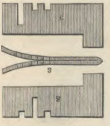

Fig. 14.

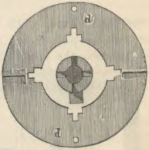

Fig. 15.

10, and 15. When the sliders are pushed up by the spring, they fill the notches in the plate, and prevent the barrel from turning; but when they are pushed down by the key, the notches in the sliders all lie in the plane of the plate, and so the barrel can turn with the key, and the pin *b* in the end of it drives the bolt as before described. The key, as every one knows who has seen a Bramah key, has a *bit*, *k*, sticking out from the pipe, the use of which is to fix the depth to which it is to be pushed in, and then, as the bit slips under the cap of the lock, it keeps the key at the same depth while you are turning it.

This was the construction of the lock for a good many years, and Mr Bramah pronounced it in that state "not to be within the range of art to produce a key, or other instrument, by which a lock on this principle can be opened." It was found, however, long before the defeat of the improved challenge Bramah Lock by Mr Hobbs in 1851, that the inventor had made the common mistake of pronouncing that to be impossible which he only did not see how to do himself. As it has been generally supposed that what is called the tentative method of lock-picking was unknown here before it came over from America in the year of the great Exhibition, we must remind our readers that it was described in the last edition of this work nearly thirty years ago; though, no less fortunately than strangely, the lock-picking fraternity were not of sufficiently literary habits to make themselves acquainted with it. Mr Hobbs, it is true, carried the process farther than had been supposed possible before; but all the Barron and Chubb, and other many-tumblered locks, which were supposed impregnable, might long ago have been opened by anybody who had paid attention to the method by which the Bramah locks were known to have been picked some forty years ago, before the introduction of the *false notches*, designed by Mr Russell in 1817, then one of Mr Bramah's workmen. If you apply backward pressure to the bolt of a tumbler lock when locked, or twisting pressure to the barrel of a Bramah lock, first pressing down the spiral spring, there will be a greater pressure felt against some of the tumblers or sliders than against others, in consequence of inevitable inequalities of workmanship; and if you keep the pressure up, and gently move any of the tumblers or sliders on which the pressure is felt, you will at last get it to some point where it feels loose. That may or may not be the exact place to which the key ought to lift it; but as soon as you feel it loose, leave it alone; it will not fall again, as the friction is sufficient to prevent it; and, if necessary, you may fix it there by a proper instrument, or measure the depth, and keep the measure till you begin again. Then try another tumbler which feels tight, and raise it till it also feels loose. And if you go on in that way, always leaving the loose tumblers alone, and raising the one which feels tight, they will at last all be got into the position of complete freedom, *i.e.*, to the place where the stump of the bolt can pass them. The operation is just the same in principle in the Bramah lock and in tumbler locks: only, as all the sliders are acted on by one spring in the Bramah as now made, you need only just push down that spring, and hold it there, and then the sliders may be moved freely either way by means of a hook or a small pair of self-acting forceps to pull them up if they accidentally get pushed too far. At first each slider had a separate spring.

But if the sliders have some false notches in them not so deep as the true ones (see fig. 14), and the corners of the notches in the plate *dd* are cut out a little (as in fig. 15), then you might by trial get all the sliders into such a position that the barrel could turn a very little, but no more; and when it is turned that little, you cannot push the sliders in any farther, and so (as was long supposed) the tentative process is defeated; and undoubtedly it is made much more troublesome, but it only requires more time and patience. You can still feel that the pressure is greater against some one or more of the tumblers or sliders than against others; and wherever that is the case, you know that it must be at a false notch, and not the true one, for a true one gives no pressure at all. Proceeding in this way, Mr Hobbs opened the challenge-lock with eighteen sliders, or guards, which had hung in Messrs Bramah's window for many years, in nineteen hours, and would have done it sooner, but that one of his instruments broke in the lock. He afterwards repeated the operation three times within the hour, in the presence of the arbitrators; and we have seen him open a more recent one with eight sliders in four minutes, by means of an instrument which is equivalent to a Bramah key with adjustable slits, which are set to the sliders as he goes on feeling them and getting their depths. It has been stated as an advantage of the Bramah lock, that an impression cannot be taken from it. This is a great mistake. Mr Chubb showed us a small instrument, which a man could hold in his hand without it being seen, and by which an exact impression of the depths of any Bramah key, whose number of slits is known beforehand, can be taken in a moment, and the other end of the instrument then becomes a key which will open the lock at once.

It is moreover to be remembered, that thieves do not always confine themselves to the conditions of a challenge, in which force and injury to the lock are of course prohibited; and if a lock can be easily opened by tearing out its entrails, it is of very little use to say that it would have defied all the arts of polite lock-picking; and in this respect the Bramah lock is singularly deficient; for if the exposed cap or nozzle of the key-hole is cut off, as it easily may be, or the hole widened out by a centre-bit, the sliders can all be pulled out, and there is an end of the lock. But, as a protection against picking by pressure without violence, Mr Denison suggested an alteration, of which a specimen was made in 1853 by Messrs Mordan (who are now the largest manufacturers of Bramah locks), on the principle of Mr Hobbs's moveable stump for tumbler locks. The locking-plate is not screwed to the body of the lock but is left free to turn a little; and if it is turned by putting any pressure on it from the sliders, it pushes a click CC (fig. 16) into a notch in the barrel and holds it fast, and so no pressure of the sliders can be felt. In this case, the locking-plate is made in one piece, and the barrel in two. If that contrivance had existed in Messrs Bramah's challenge-lock, it could not have been picked by Mr Hobbs's method. However, locks for securing property well worth stealing must be safe against rude as well as polite lock-picking, and this the Bramah lock hardly can be made; and therefore it must be admitted, that, even with the above-mentioned improvement, it is now behind the requirements of the age, though the smallness of the key, and the cheapness with which they can be manufactured and sold to the trade (though they are not yet sold by retail as cheap as some other better locks), will probably enable them to keep their place for some time.

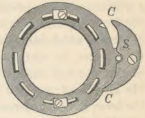

Fig. 16.

Inside and Outside Locks.—Locks for drawers, closets, iron chests, and the like, are only required to lock on one side, and their keys are therefore made with a pipe, which slips on to, and turns on a pin in the lock, called the *drill-pin.* But doors which have to be locked sometimes on one side, and sometimes on the other, cannot have their keys made in this way; but the key is solid, and its plug or stem being thicker than the flat part or web, it acts as an axis fitting into the upper part of the key-hole, though that hole does not completely inclose it. All keys for these inside and outside locks must be symmetrical, or alike on each side of a line through their middle, in order to fit the lock either way, which limits the variety of the tumblers in the case of many-tumblered locks. A Bramah lock, to open on both sides, must be made double, with one set of sliders to push in from one side of the door, and the other set from the other side; and, consequently, they are very seldom used for this purpose. It may be convenient to observe, that when we use the term Bramah lock, we mean a lock of that construction; for the patent having long ago expired, they may be made by anybody, just as Chubb's lock may, though nobody but the representatives of the original patentees has a right to apply the name *Bramah* or *Chubb* to them; and therefore Messrs Mordan, for instance, rightly call them by their own name, though their locks are the same as Bramah's, except that they generally make the number of sliders odd, while Messrs Bramah make it even.

Cotterill's Lock.—The lock of Mr Cotterill of Birmingham is on the same principle as Bramah's, the difference being, that the sliders are pushed out radially by a very thick key with inclined slits in it. The locking-plate is a ring instead of a flat plate, and the notches in the sliders have all to be brought into the same circle, to be able to pass along the ring. Some of the sliders are made into what are called detectors, being held by a spring catch, if they are pushed out too far. This is the primary form of Cotterill's lock; and in that form it is evidently quite as easy to pick as the commonest form of Bramah lock, and easier, because the range of the sliders is necessarily very small, as the extreme range can be no more than the thickness (not the diameter) of the key-pipe. But Mr Cotterill afterwards added a second ring X (fig. 17) outside the fixed locking-ring RR; and in that outer ring you observe that the notches are not quite opposite to the ends of the sliders, some of which are bevelled; and therefore, when pushed out by the key, they will force themselves into the notches of the outer ring, and turn it a little against the resistance of a spring, which tends to keep it in the position shown in the drawing with reference to the cylinders and sliders. When it is so pushed a little out of the way by the bevelled sliders, the square-ended ones

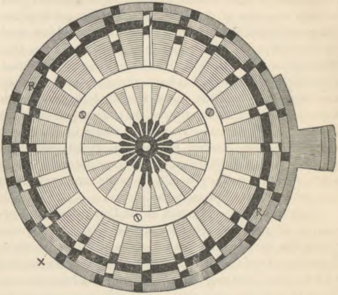

Fig. 17.

can enter the holes then opposite to them, and so carry their own notches into the position to pass the inner or fixed ring, and then the cylinder can turn, and it carries the outer ring with it. Moreover, in the latest form of this lock, the inner ring is not absolutely fixed, but has a little play, like the plate of the improved Bramah lock in fig. 16; and by the side of it there is a click, CC, which any slight turning of the ring brings into action, and makes it lock the ring fast. This appears, from Mr Cotterill's description and drawing, to be just the same contrivance which we have already described as being applied by Mr Denison to the Bramah lock to prevent feeling the pressure of the sliders on the locking-plate; only this appears to lock into the ring itself, and therefore would not prevent the pressure from being felt;

whereas Mr Denison's click for the Bramah lock fastens the barrel, and does prevent the pressure. But that could easily be done in the same way in Mr Cotterill's lock; and if so done, it would, as far as we can see, be of much more value than the second ring, as we shall explain presently. The entrails of this lock could not be taken out, like Bramah's, by merely cutting off the nozzle.

This lock acquired some celebrity, from having defeated Mr Hobbs in a challenge to pick it. But from the printed account of the affair, sent to us by Mr Cotterill himself, it is clear that that failure proved nothing, except that Mr Hobbs was taken by surprise, and supposed that he was picking one of Cotterill's locks as they had been made before the invention of the second ring, and such as he had publicly exhibited a mode of picking with merely a piece of wood; whereas the lock in the trial contained these other arrangements, which Mr Hobbs knew nothing of. It is certainly added, in the printed account, that when he did see the additions, he confessed that he did not then see how such a lock was to be picked, and declined to try it. Whether it really is invincible in its present state we are not able to say, not professing to be lock-pickers ourselves; but it does appear to us that the inventor considerably overstates the difficulty when he says all the sliders must be moved together; for it seems plain that pushing out any two nearly opposite sliders with the bevelled ends would turn the outer ring as well as a dozen; and as soon as it is turned a little it is of no further use. No doubt all the sliders must be at last brought together into the proper position, as they must in any other lock; but that is a very different thing from requiring them all to move simultaneously into that position. And whether the lock is impregnable or not, we should imagine that the great thickness and weight of the key, which is necessary to get even a moderate range in the sliders, would generally be considered an objection to it, as we have the best authority for saying, that in some other cases the highest amount of supposed security will not induce even bankers to adopt locks with large keys.

Letter Locks.—It used to be supposed, some years ago, that locks which could only be opened by setting a number of rings or discs to a particular combination of letters could not possibly be opened by anybody who was not in possession of the secret; and hence they were also called *puzzle*-locks. At first they were made with a fixed combination, which could not be changed. Afterwards the rings were made double, the inner one having the notch in it which the bolt had to pass, and the outer one capable of being fitted on to the inner in any position, by unscrewing some part of the lock, so that you might set them to any combination you like. This was the first instance of a changeable lock, of which we shall have more to say at the end of this article. But it was afterwards found that these puzzle-locks have just the same vulnerable point as all our locks had until lately, viz., that the pressure of the bolt can be felt on some of the rings more than on the others; and Mr Hobbs says emphatically, in the *Rudimentary Treatise on Locks*, "wherever that is the case, that lock can be picked." We have heard an amusing account of his opening, in a few minutes, a great dial lock on an iron door at Liverpool; and also opening a French lock in the Great Exhibition, and setting it to a new combination, so that the exhibitor himself could not open it. Besides this defect, these locks have very much gone out of use on account of their being troublesome to handle, and perhaps also from the risk of forgetting the combination to which it was set last, if the lock has been left for some time; and therefore we do not think it necessary to go further into the details of their construction: the principle of it we have described sufficiently to make it intelligible.

Chubb's Locks—Of the multitude of locks which have been made on the many-tumbler principle, originally invented by Barron, none have enjoyed so much celebrity as Chubb's, partly from their superior workmanship and the use of more tumblers than usual, and perhaps still more from the late Mr Chubb, or his brother, who took out their first patent in 1818, having had the good fortune to hit upon the name *Detector* for a certain part of the machinery, which, besides adding to the security against any mode of picking then known, also captivated the public with the idea of discovering if anybody had been tampering with the lock, though the operator might depart in ignorance that he had left any trace of his attempt behind him. It is remarkable that the detector was not even then a new invention; for a lock exactly the same in principle, but slightly different in arrangement, had been previously made by a Mr Ruxton. In the same way false notches were used in Strutt's tumbler lock above thirty years before they were re-invented by Chubb and others, with the idea of defeating the tentative method of picking by them. The original form of this invention is shown in fig. 18 by the lever DT,

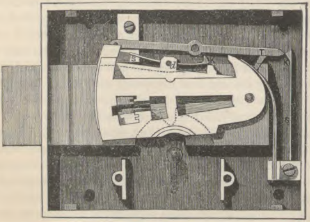

Fig. 18.

which turns on a pin in the middle, and is acted upon at its end T by a spring S, which will evidently allow some play to the lever on either side of the corner X, but the moment it is pushed past that point, the spring will carry it farther in the same direction, like what is called in clock-work a *jumper*. In its proper position that end always remains above the turning-point; but if any one of the tumblers is raised too high, the other end D of the detector, which reaches over all the tumblers, is lifted so far that the end T is sent down below the corner, and the tooth T then falls into a notch in the bolt, and so prevents it from being drawn back, even though all the tumblers are raised properly by the right key, which at once reveals that somebody has been trying to pick the lock. The way to open it then is to turn the key the other way, as if to overlock the bolt: you observe a short piece of gating near the end of the tumblers, to allow the bolt to advance a little, *i.e.*, just far enough to push the tooth of the detector up again by means of its inclination there, and then the lock can be opened as usual. In Mr Chubb's more recent locks the tumbler is made in another form. The back tumbler, or the one which has to be raised highest, has a pin *d* reaching over all the others, and if any of them are overlifted, that back tumbler is also, and then a square corner *k* in it gets past the end of the detector spring *ks*, and is held up. It is set right by overlocking the bolt as before, the bolt itself raising the end *k* of the spring, and letting the tumbler fall. This form of detector is, however, inferior to the other, as it informs the picker what he has done, by the back tumbler itself being held up, which he can feel directly.

But since Mr Hobbs's mode of picking locks became known, all these detectors have become useless. Some persons have even gone so far as to say that the detector may be made a guide to picking. Whether this be so or not, the detector does not act unless some of the tumblers are raised too high, which they never are by a skilful operator on this plan, nor does it act (even if thrown by accident) against picking backwards, or feeling the way to shoot the bolt a little farther, as if to free the detector; and in this way, at any rate, the measure of the key can be taken without any hindrance from the detector. Before 1851 tumbler locks were seldom made with false notches; we remember, however, seeing a lock on an iron door, invented by Mr Strutt many years ago, in which the tumblers were in the form of quadrants, with a very large angular motion, and a number of short or false notches, and one deep one. But since that year Mr Chubb and some other makers of tumbler locks have adopted false notches in all their best locks, together with revolving curtains, which cover the straight part of the key-hole as soon as the key is turned; and barrels going down from the back of the curtain to prevent a false key or pick from turning without turning the curtain; and other obstacles, of which the object is in all cases to prevent the maintaining of pressure of the stump upon the tumblers at the same time that the tumblers themselves are moved, or, as Mr Hobbs has called it, "tickled," by some other instrument. These provisions, and especially a number of small false notches (which may be got with a thick stump by serrating the end of it), undoubtedly make the locks much more difficult to pick; in fact so difficult, and requiring such nicety of instruments and manipulation, that they may be considered practically safe, except under extraordinary circumstances. But then it must be remembered that all the great robberies, of which there are several every year, do present extraordinary circumstances, and that they are never attempted except where the temptation has been made great, by the thieves seeing that they had unexpected facilities offered them. It is therefore by no means safe to assume that a lock will never be picked, merely because it would take a first-rate hand a long time to do it. The process need not be continuous. A good hand will do part of his work, and measure it, or mark it off upon his false key, one day, and more another, until it is all done, and his key ready for action at the first convenient opportunity. Recent experience has shown that your own officers, clerks, and servants are the people from whom you have most to apprehend, and they are just the people who have the most time and opportunity to perform their key-making operations undisturbed. Without going into all the mechanical details (which it is perhaps as well not to publish), it is enough to say, that the lock of the United States Bank, which was almost as complicated as the famous one of Day and Newell, and contained all the false notches, revolving curtains, and other provisions which have been several times re-invented or put out as novelties here, was nevertheless picked for a wager.

We shall now describe the principal inventions that have been made within the last few years, with the view of defeating that tentative method of picking to which all our locks, as constructed before 1851, were and are liable; and we shall point out which of them really do effect that object, and may be regarded as absolutely secure against any mode of picking at present known; and which of them may be regarded as safe enough for ordinary purposes, though not coming up to the mark of absolute security.

Hobbs's Lock.—The invention which most directly meets the defect of all previous locks is Mr Hobbs's moveable stump, which, it must be observed, is a totally different thing from the great twenty-guinea American lock of Day and Newell, which also goes by his name here, because he makes and sells them. In Hobbs's lock, the stump is not rivetted into the bolt as usual, but is set on the end S of a bent lever STP (fig. 19), which lies in a hollow of the bolt behind it, turning on a pivot in the bolt itself, and kept steady by a small friction-spring, not shown in the drawing. The stump comes through a hole in the bolt large enough

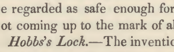

Fig. 19.

to let it have a little play; and the long end P of the lever stands just above the edge of a square pin, which is fixed in the back plate of the lock. When the lock is locked, if you push the bolt back, you produce no sensible pressure on the tumblers, but only just enough to turn this *protector* lever, as Mr Hobbs calls it, on its pivot T, and so bring down its end P in front of the square pin, and then the bolt can no more be pushed back than when held by Chubb's detector. The protector is set free again by merely pushing the bolt forward with the key, without reference to the tumblers. It was found however, that in this state, the protector could be prevented from acting by a method used by Mr Hobbs himself for another purpose, viz., pushing a piece of watch-spring through or again, by pushing up the watch-spring between any two the key-hole, and up behind the bolt, so as to reach the protector at P, and keep it up while you push the bolt back; of the tumblers, and holding the end S of the protector with it, so as to press the stump against the tumblers. Both these devices, however, are prevented now by letting in a *feather* FF in a groove between the bolt and the back of the lock, which no watch-spring can pass, and also bringing a piece of the feather forward through the front gating of the tumblers just under the stump. In this form the lock is safe against any mode of picking at present known, unless the key-hole happens to be large enough to admit the inspecting method, which is this:—A person intending to pick the lock goes beforehand and smokes the *bellies*, or lower edges of the tumblers, through the key-hole. When the key comes, it wipes off the black on each tumbler, according to the length of the bit which raises it; and then, when the picker returns, he throws a strong light into the key-hole, and, by means of a narrow reflector put into it, reads off, as it were, the length of bit required to raise each tumbler to the proper height. This operation may sound impossible; but it is an established method of lock-picking, at least in America, where they seem to be considerably a head of us in these matters. It requires a largish key-hole, however; and it may be prevented by any kind of revolving cylinder, which will conceal the view of the tumblers while the key-hole is open. The one that does it most completely is the eccentric cylinder, which will be described in the great American lock. The inspecting method might also be frustrated by making the acting part of the bellies of all the tumblers no longer than would be reached by the shortest bit in the key. In that case, the long bits would not begin to act at their points, but on their sides, and would leave no measure of their length upon the tumblers.

There is another lock invented by Mr Hobbs, also belonging (as far as we can see) to the absolutely secure class; but it will be more conveniently described after we have noticed the changeable-key locks.

Parnell's Locks.—The next contrivance for preventing the tentative mode of picking is that invented by Mr Parnell (fig. 20), and now sold by Mr Puckridge, with whom Parnell was in partnership for some time, but has now left that firm, and set up for himself at another shop, with a later invention of his own, which we shall describe presently. His first lock acquired some celebrity from a trial at law, in which it appeared that a certain Mr Goater, who worked for

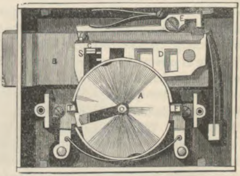

Fig. 20.

Mr Chubb, had claimed 200 guineas for picking a challenge lock of Parnell's,—the fact being, that he had first clandestinely taken the cap off and made a false key, and then pretended to pick it. But the trial proved no more in favour of it than the pretended picking proved against it; for there was no proof that the lock could not be picked by other means; and we cannot think it would present much difficulty to those who can pick such locks as Jones's American bank-lock, before alluded to, though it would probably defeat the ordinary race of lock-pickers.

The most important features in this lock are, the lever E at the top, which is called a *double-action latch*. It is, in fact, Chubb's detector, with the addition of the tooth on the left hand, which falls into the bolt and prevents it from being pushed back against the tumblers, except when it is raised by them, or any one of them, just enough to clear the bolt, and no more; for if raised too high, it locks into the bolt at the other end, like Chubb's first detector. But it is evident that this is worth very little by itself; for you have only to put the pressure on the bolt, and then gently raise the lever by one of the tumblers until the bolt will either clear it completely, or, at any rate, press against some of the tumblers, and then proceed as usual. But then another lever is added. You observe a line across what appears to be the stump S. The part below the line is the real stump; but the part above it is a kind of second stump set on a tumbler behind the others, and not touched by the key, but pressed upwards by a weak spring, so that it can only rise when all the tumblers are lifted. This *self-acting lever* also ends in a square corner, which butts against the real stump when it is down; so that, if you push the bolt back, you bring the stump against the self-acting lever, and not against the tumblers. All this looks very formidable; but on examining one of these locks, it occurred to us at once, that if you only lift all the tumblers a little, so as to let the self-acting lever rise out of the way of the stump, and then (but not before) push the bolt back, you have disposed of the lever just as much as if it did not exist; and on trying it, we found the operation perfectly easy. Of course, it would require more care and delicacy to manage the "double-action latch" and the "self-acting lever" together than either of them separately; but they are only used together in the most expensive of these locks; and, moreover, it is a maxim in lock-picking, that a mere multiplication of difficulties does not produce impossibility, and that no number of approximate or partial securities amount to absolute security.

The mode of operation just now described will defeat equally well a self-acting tumbler, on the same principle, which Mr Chubb added to his locks soon after Mr Hobbs's demonstration, in 1851, of the insecurity of his and Bramah's, and indeed of all the then existing English locks. Mr Parnell (or Puckridge) also uses, in his large locks, a revolving curtain and cylinder, or barrel, which covers part of the key-hole, and the web of the key expands as it turns; for, when the key is out of the lock, it looks like a blank, with no bits projecting. But all these things, and the double-action latch too, are all old inventions, as may be seen in the *Rudimentary Treatise*, and more fully in Mr Price's large book on *Fire-proof Safes, Locks, and Keys* (published since this article was written), which is the most complete treatise on the subject ever published in this country; though even in that some of the descriptions are so brief as to be hardly intelligible, in consequence of the enormous number of inventions—nearly all patented, and most of them useless—which have been made for the improvement of locks within the last forty years. Besides being an old invention, an expanding key is very limited in the range or variety of the bits, expensive, and unpleasant to work on account of the increased friction. The pieces marked FF (in fig. 20) are called *sentinels* by the inventor, and they are intended to prevent the cylinder from turning beyond a certain point with a false key, and also to prevent the false key from getting out again. This, too, has been done before, and on the same plan, of preventing any key, whether true or false, from returning; and so, if it cannot go forward and open the lock, it is held fast, as evidence of its own intrusion, like Cassim in the cave of the Forty Thieves. But when the inventors of these things talk of the "frightful consequences" of having to smash the door in order to get the false key out, they forget that the key is not the thief, and that these consequences are rather amusing than frightful to the person who left it there, and who will have the satisfaction of knowing that he has, at any rate, done as much mischief as possible, by way of paying off the owner for not providing him with a lock more easy to pick. It is also to be remembered, that if the owner himself carelessly puts a wrong key into the lock, or if there is a piece of dirt sticking to it, which may prevent it from opening the lock, the consequences are equally unpleasant. The detention apparatus clearly adds nothing to the security. If the "sentinels" really do their other duty of preventing the cylinder from turning beyond a certain point except with the true key, you want nothing more, and get nothing more, by detaining an intruding key; and if they can be held or thrown out of action (as we rather suspect they can), that, of course, would be the first thing a skilful lock-picker would do. We do not mean to say that a lock with all these complicated provisions could be picked under several hours, if at all. But it does not seem to us in the least degree more secure than Mr Hobbs' much simpler and cheaper contrivance of the moveable stump, or than some others which we have not yet described. And it is necessary to caution the public against *shop-window* locks in general, with large wagers set upon them; for unless you know that the lock exhibited in the window is the same as those usually sold in the shop at a moderate price, and unless the conditions of the challenge (which are generally "to be had within") are fair—and we have seen some that were utterly unfair and absurd, the offer of "200 guineas to the artist who can pick this lock" does not prove that any other lock in the shop is worth 200 pence; and it is, in fact, nothing but a mere advertising trick.

Mr Parnell's other lock, sold by himself only, has the advantage of being much cheaper, and at least as secure as the one with the self-acting lever and expanding key, which is the ordinary construction of the locks under his former patent. This lock has also the revolving curtain’ and there is a small ring B (fig. 21) on the under side’

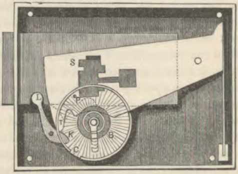

Fig. 21.

which incloses a deep circular ward set in the back of the lock, which requires a very deep cut in the key, so that there would be very little room for a pick to play in. These two features are not claimed by Mr Parnell as novelties, and, in fact, they are old enough to be open to any body. The curtain has another ring near its edge, which just comes over a pin P in the uppermost tumbler when it is down, and prevents it from rising, except when the curtain is turned far enough round to bring the gap at C in the ring over this pin, which happens just when the key begins to lift the tumblers. But the real peculiarity of the lock is this: In locking, just before the key leaves the tumblers, it delivers the stump, not into the place where it is now shown lying, but into the notch S; but before it leaves the lock the key encounters the end of a lever KL, which pushes the bolt back a little, and so lets the tumblers drop a little lower, with the stump in the position shown here. When the key opens the lock again, it passes by the end K of the lever, and first lifts the tumblers a little by their corners, near K, at the same time that the gap C in the curtain-ring comes over the pin P; then it encounters a piece that comes down from the bolt near T, and shoots the bolt forward a little, without which the tumblers cannot be fully raised (as will be seen from the shape of the false notches), and then the key operates as usual. Nevertheless, this certainly cannot be placed in the class of absolutely secure locks; for if a pick can be got to work over the neck-ward and curtain-ring or barrel, which is well known to be possible, it does not appear to us that there would be more difficulty in picking this lock than any other with false notches; for it makes no difference that the bolt has first to move forwards a little and then backwards, and the curtain could easily be got into the position to free the tumbler which it holds. However, these locks are sold a good deal cheaper than other locks with much less security used to be, and, if not absolutely secure, they are sufficiently so for all common purposes.

This reduction in the price of good locks, besides the improvement in the quality, is plainly the consequence of the exposure of the defects of all the existing English locks in the Great Exhibition, which some persons endeavoured to smother as dangerous, and others to explain away as proving nothing against the character of our locks. Not only have we got Mr Hobbs's own improvements in construction, and reduction in price, by the introduction of machinery for lock-making to an extent hitherto unknown, but there is now in the market a variety of what may be called very good locks, even though most of them could be picked by an expert hand with plenty of time, and at lower prices than were charged for the only two locks which had any reputation until the last few years, viz., the Bramah and the Chubb locks. And the mere variety of locks is in itself a source of security, because a thief no longer knows by the look of a key-hole what kind of machinery he has got to deal with inside.

Restell's Lock.—There is only one other modification of the old many-tumblered lock that we need notice, and that is Mr Restell's. The only peculiarity in it (for the revolving curtain and barrel are much too old to be so designated) is the addition of a disc at the bottom of the barrel, in the same plane as the bolt. The bolt can only pass when the disc is in one position, *i.e.*, when a piece which is cut out of it is just under a kind of tooth in the bolt; and at all other times the disc, lying partly within the bolt, holds it fast, and prevents any pressure being put on the tumblers. But this, again, proceeds on the erroneous but common assumption that the instrument for feeling and lifting the tumblers a little at a time cannot be used when the key-hole is closed, except at the centre, by the curtain and barrel; whereas it is, in fact, worked through a kind of hollow key, which presses on the bolt while the pick works the tumblers, and it can be done in locks with far greater impediments to it than this, although we say of this, as of Mr Parnell's, that it is an improvement upon any of the locks made before 1851.

Locks without Tumbler-springs.—We now come to a class of locks in which the tumblers or slides are no longer moved one way by springs and the other way by the key; for we shall postpone the description of the complicated American changeable-key locks until we have taken the reader through the easier matters. In the locks we are now going to describe, the tumblers, or slides, or discs, which stop the bolt, are kept in their places by friction only, and will stand anywhere, having thin plates lying between them, and being pushed or turned one way in locking and the other way in unlocking.

In the Exhibition of 1851 there was a disc or wheel lock exhibited by an American named Jennings, who used to expound it with great eloquence as cheaper and better than any other lock in the world. It had also a changeable key, *i.e.*, the key was a mere stalk or shank, fitted with small rings, each with a bit projecting from it, and they could be transposed, together with the corresponding parts in the lock. This of course can be done, and had been done before, with the key of any tumbler-lock, if you take the lock off and change the tumblers, provided the bits are made to fit into the key, instead of being part of it as usual; but we shall have to say more of this hereafter. We have been unable to learn what has become of Mr Jennings or his lock, except that Mr Hobbs showed us a very simple way of picking it, by poking a piece of watch-spring, with a hook at the end, between the discs, and feeling for the notch in the circumference, and then bringing it round to the right place for the lock to open.

Andrews's Lock.—Another American lock on the disc

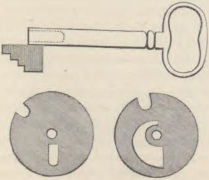

Fig. 22.

principle, by Dr Andrews, was exhibited at the Society of

Arts in 1853, with some others that we shall notice, when that sagacious body awarded its premium to a lock made by a Mr Saxby, which Mr Hobbs forthwith picked in three minutes with a bit of wire, and then reminded them that he had himself exhibited a drawing of an old lock of the same construction at a lecture in that very place only about a year before. Dr Andrews's is called the snail-wheel lock, because all the discs except the upper one have snail-shaped holes in them, as in the last of these figures (fig. 22). The upper disc has only a square hole (except that for the drill-pin on which they all turn), which is the key-hole, and that disc always travels with the key ; the others only begin to move in one direction as soon as the key encounters the spiral edge of the hole, and of course they are carried to different distances, according as the corresponding bit of the key is shorter or longer. They are separated by loose, thin plates, which cannot turn with them, and act as friction plates. Each disc has a notch in it, and it is only when all these notches are brought together under the end of a spring lever, called a "toggle," that it can drop into them. As soon as you feel or hear that take place, you have to turn the key back again, and the discs still keep together, because the toggle fills up all the notches, until it is worked out, as they revolve, and it carries the bolt with it ; and then the discs no longer move together, but some lag behind until the key reaches the square end of all the snail-holes, and so brings them all into the original position, with the notches standing in different places, and then the key can come out. We do not know by what method this lock can be picked, as it can hardly be possible to distinguish between the pressure of the toggle on the edges of the discs and the absence of pressure when it is over a notch, on account of the great amount of constant friction ; and the smallness and eccentricity of the key-hole would make the watch-spring method extremely difficult, if not impracticable. But besides the key being thick and clumsy, on account of the great friction which it has to overcome, the lock is uncomfortable to work, and it is therefore not likely to come into use against the easier locks with smaller keys, and equal, or at any rate sufficient security, which are now made.

Tucker's Locks.—There have been several locks on the disc principle invented in succession by Mr Tucker, of Fleet Street, the first two of which had revolving discs; and in the last and more simple one, patented in 1855, though the discs no longer revolve, they slide between fixed plates without springs, and do not turn on a pin like common tumblers, and will stand indifferently anywhere. It will be sufficient to describe the last of these inventions, as Mr Tucker himself states it to possess all the elements of security of the former ones, with the advantage of being much cheaper, because more simple in construction. In fig. 23, T T is one of the sliding tumblers, which are separated by thin fixed plates, and slide upon the guide-pins at T T, and have also friction-springs X, pressing on them to keep them steady. S is the bolt stump, which can only enter I, the

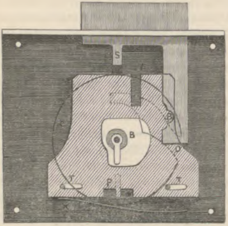

Fig. 23.

gating of the tumblers, when they are pushed the proper distance towards the left, which the key will do as soon as it turns towards the left, in the usual way of unlocking. But something else still prevents the bolt from falling, and that is the flat curtain C, which turns with the key, and has also a barrel B, as in several of the other locks we have described. This curtain also prevents the stump from being pressed against the tumblers, being just big enough to keep it from touching them until it has turned nearly three-quarters round, when the pin S, which stands up on the stump, can enter the opening D in the curtain (shown by a dotted line in the drawing, to prevent confusion). But by the time the curtain has got so far round, any instrument in the key-hole would be prevented by the barrel from reaching the tumblers so as to push them back and feel the pressure of the stump; at least so the inventor asserts, and we do not venture to contradict him; though it must be remembered that no revolving curtain and barrel have yet been able to prevent the instruments of the American lock-pickers from reaching and moving the tumblers, at the same time that the barrel is being pressed the other way in order to keep up pressure on the bolt. The only way (so far as we can see) to prevent this is by a contrivance, such as Mr Denison's lock (described below) was first made with, of a kind of door between the tumblers and the key-hole, which opens for the key just before it reaches them, and closes again after it has moved the tumblers, and before any action at all upon the bolt begins. It will be seen hereafter that in that lock this shutting off the tumblers from the key-hole was afterwards carried still further, as the key there does not operate on the bolt at all, but must be thrown out of the key-hole, and the hole completely closed, before the bolt can be drawn back; but the first arrangement may very well be used in cases where the key is wanted to operate on the bolt.

We have not yet explained how the bolt in this lock is drawn back when the curtain has got into the proper position for it. It is not done by the last bit in the key acting directly on the bolt, as usual, but by a bit P fixed on the curtain itself, which acts upon the notch B in the bolt, as the key usually does. And this same bit P performs another function in locking, viz., shooting all the tumblers into the position here shown by striking against a pin which is set in the bottom one, and comes up to the curtain, and so carries all the others with it by means of the square notch which is cut in all of them, except the one which has the pin in it. It must be observed that the curtain does not lie close upon the tumblers, but there is the thickness of the bolt, or of the bit P, between them. A spring locks into the curtain and prevents it from being turned, except when this spring is pressed down by putting a key into the key-hole. One object of making the curtain, and not the key, to lock and unlock the bolt is, that you guard against the risk of what is called short-locking; *i.e.*, sending the bolt in any common tumbler-lock not quite far enough for the tumblers to drop. There are means by which a person intending afterwards to pick a lock might cause it to lock short, if he had previous access to it, or possession of the key, at least as locks are generally made, and then, of course, he has only to pull the bolt back, the tumblers having never fallen. Moreover this arrangement in Tucker's lock allows it to be locked by any key that will turn in the key-hole, though it cannot be unlocked by any but the true key, or one which will move all the tumblers to the right place for the stump to enter them. Mr Tucker has also applied the curtain in his padlocks in such a way that the shackle has a tail reaching inwards, and resting against the curtain at all times, except when it is in the proper position for opening; *i.e.*, when this tail is opposite to a segment cut out of the curtain corresponding to the opening D in the lock just now described, but much larger. The object of this is to obtain greater strength than usual to resist all attempts to force the shackle open. The cheapness of these locks is due to the circumstance that all the principal parts can be stamped out of sheet brass, the curtain alone being cast, with the barrel and bit P on it, and its face turned, which is a cheaper operation than filing. In this respect it approaches to Mr Hobbs's style of lock-making; only he has carried the stamping and machine-finishing system much farther; indeed, it is hardly exaggerating to say that he has abolished the use of the file, and left nothing to hand labour except the mere fitting of the pieces together, and putting the tumblers in the right position to have the gating cut according to the key.

Nettlefold's Bolt.—We have just now alluded to padlocks, and we shall do so no farther, because they are generally of exactly the same internal construction as other locks of the same maker. And, for the same reason, it is unnecessary to describe the various modifications of the fastening part of locks to adapt them to peculiar uses or positions; but there is one which does seem to be worth a short notice, viz., an invention of Mr Nettlefold, patented in 1839, for making the bolt hook into the striking plate, against which it locks. This drawing of it (fig. 24) will explain the nature of the contrivance at once. We have inserted no tumblers, because it may be used with one kind of lock as well as another. It is convenient for writing-desks, sliding cupboards, and even for drawers, which can often be prized open by merely putting in a screw-driver above the lock, and forcing up the piece over it just enough to let the bolt pass, which is generally short. There are other ways of doing the same thing, such as making the bolt itself hooked, and giving it two motions, first vertical, to

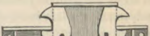

Fig. 24.

shoot it out, and then horizontal, to hook it into the striking plate; and some Bramah locks are made with a kind of annular bolt, which forms a rim to the cylinder, with a segment cut off in one place to let the striking plate come down, which is then taken hold of by the other part of the ring as it revolves. Bramah locks of portfolios, and articles of that kind, are usually made in this way, which is very cheap and simple.

Master-Keys.—It is often convenient to have a set of locks so arranged that the key of one will open none of the others, and yet the owner of the whole may have one master-key that will open them all. In the old locks with fixed wards this was done by making the wards of a slightly different form, and yet such that one skeleton will pass them all, just as the skeleton-key in fig. 4 will serve for the warded key of fig. 3, and a multitude of others. In locks with sliders or tumblers, the way is to make one tumbler in each lock with a wider gating, so as not to require lifting so high as it does in the other locks of the set; then the key of that lock will raise that tumbler in that lock high enough to clear the stump, and yet the master-key, which has a longer bit in that place, will not raise it too high, because the gating is wide enough for both; but the special key of that lock will not open any other of the set which has not the same tumbler widened in the gating. Mr Chubb, some years ago, made a set of locks for the Westminster Bridewell, with keys for the different grades of officers. The owner of the head key can stop out any of the under keys; and if any attempt is made to pick any lock, and the detector is thrown, it cannot be released by any of the subordinate keys, though they can open the lock in its normal state, and consequently the governor must be acquainted with it. There are a variety of other forms of many-tumblered locks, some with the tumblers acting upwards at one end and downwards at the other (Parson's lock); and others with some of the tumblers pulled down by bits cut within the web of the key, besides the usual ones to be pushed up by the key (Somerford's); and some with a combination of the Bramah plan in the pipe of the key, with the Chubb plan in the bits, and so on; but none of them involve any novelty in principle, and they are all capable of being dealt with in the same way: and therefore we shall at once pass on to another class of locks, viz., those which shut of themselves, and are called—

Spring or Latch Locks.—These locks we chiefly notice because they require a particular provision to make them in the smallest degree secure, and are, nevertheless, often left without it, by way of saving a shilling or two in their price, and multitudes of street-door robberies are committed in consequence. The former of these two names is generally used for a lock which shuts of itself on a box or drawer, or articles of that kind; and the latter for street or room-door locks, which shut of themselves, and open with a handle on the inside, but only with a key on the outside. In the simplest and cheapest form of these locks there is no pretence of any security except a few fixed wards, which the key has to pass; and, as before explained, that is no security at all against anybody with the smallest dexterity, and with a serious intention of opening the lock. Next to them, or rather below, because pretending to be what they are not, come the locks which lock a certain distance themselves by means of a spring, but can be locked farther by the key, and having tumblers, but no fixed wards (which a good tumbler-lock does not require). But though this kind of lock cannot be opened when it is thus double locked, except by the key, or some efficient mode of picking, yet when they are only self-locked (which is the most they are ever locked in 99 cases out of 100), the tumblers are of no more use than if they did not exist, and the lock can be opened by any bit of bent wire that will go into the key-hole. It should be remarked however, that the Bramah lock is just as secure as usual when used for a spring or latch lock, because the key cannot turn at all without pushing in the sliders properly. But in this, as in all latch-locks, it is very unsafe to have a handle which pulls back, as it can easily be reached by a wire put through a hole in the door; the handle should always be made to turn, like a common room-door handle.

There are two ways in which spring-locks with tumblers may be made as safe as the same lock with an ordinary bolt. One is to make a click or catch fall into the bolt when it is drawn back, and not to make the tumblers to fall when the bolt is drawn back: in the shutting of the door this catch is pushed back by some knob projecting for the purpose, and then the tumblers fall and hold it fast. But this will not do for a latch-lock which is intended to open by a handle on one side of the door. For that purpose the proper plan is that which is now adopted in all good latch-locks, not to let the key act directly on the bolt, which has no stump, but on a false bolt which lies on the top of the real one, and has the stump fixed in it. When the real bolt is shut by the spring it carries the false one with it, and that is then locked by the tumblers. But the real bolt can be pushed back by the door shutting, or pulled back by the handle, without moving the false bolt, though it cannot be reached through the key-hole. In buying a lock, the test of this is to see whether the stump moves as you push or pull the bolt back. If it does, the lock is good for nothing, unless it is on the peculiar construction to be described immediately.

Chubb's Latch-Lock.—In order to prevent the bolt from being pushed back by a piece of wire poked in between the door and the staple into which it locks, Mr Chubb has made the following ingenious modification of the common latch-lock. In fig. 25 the bolt is drawn back by turning a handle H as usual, but the handle also raises all the tumblers like a key. But the back tumbler T is not set on a fixed pin as usual, but on a pin in the bolt, and so travels with it; and when it is drawn back far enough, *i.e.*, about half way, the spring S falls in front of that tumbler at T, and so, when you leave hold of the handle again the bolt only goes about

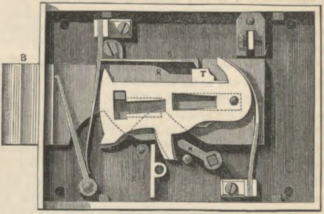

Fig. 25.

half way out, as far as B, the point to which its face is bevelled. But when you push the door to, the sloped corner of the bolt at R raises the spring S, and the tumbler T not being then held up by the handle, it falls and clears the spring, and so the bolt shoots the whole way out, and the other tumblers fall upon its stump, and it can only be opened either by the key K or the handle H raising all the tumblers to the proper height.

To prevent confusion, we may observe that there is another lock called Chubb's *latch*, in which the bolt consists of a number of tumblers prolonged. But this is a very inferior article to the *latch-lock* just now described, or even to a latch-lock made in the second of the methods above mentioned. We understand the latch-lock is used extensively in prisons (of course without the handle), where it is not only desirable to avoid the necessity of having to lock the cell doors by a key, but also to provide against the ingenuity of the inmates in pushing back the bolt of a spring-lock. It has been suggested however, that this provision may be defeated by a prisoner, or any other thief not yet in prison, putting something into the bolt-hole which will prevent the bolt from shooting full out, and then the tumblers will not fall, and the bolt can be pushed back easily. A safer lock for this purpose is one which we shall describe presently, and which locks by merely turning the handle, but cannot be opened without the key.

We may observe also with reference to these latch-locks for house doors, that they very soon get spoiled, at least so far as to impede their action, and render them unsafe, by the dirty atmosphere of a large town. This might easily be prevented by using a spring curtain like that which we shall describe in Mr Denison's smaller lock. If purchasers of locks would insist on having such an addition made, it could be done without increasing the cost by more than a shilling, and it would save its price many times over, by the length of time the lock would go without cleaning, and last without being spoilt. But unless purchasers insist upon having it, it is not likely that the lockmakers will volunteer such an improvement. The curtain should slide easily on the drill-pin and on another pin, just below the lower end of the key-hole, and be pressed up by a long thin spring acting upon it near the drill-pin. We suggested this some time ago to a celebrated London lockmaker, and he undertook to get it done. After some months he produced a lock, with a spring curtain certainly, but (with that peculiar ingenuity for baffling any new invention which English mechanics generally display) the curtain made to slide on two pins set at some distance on each side of the drill-pin, instead of a single pin below it; and the consequence of course was, that there being nothing like the web of the key to push the curtain down straight, it generally went obliquely, and generally jammed itself fast upon the pins, and then (as usual in such cases) was pronounced impracticable, and thrown aside; and all this with one of Mr Denison's small locks as a model to copy, in which the curtain slides up and down quite easily. It has since been done properly by Mr Hobbs; and there is plenty of room to add it to any existing lock which has a false bolt lying above the true bolt for the key to act on, as every good latch-lock must have; for otherwise the tumblers are of no value whatever, as explained above.

Safe Locks with small Keys.—In all the locks we have yet mentioned, the bolt is acted on by the key, even though the key may not touch it; and the key must therefore be strong enough to move the bolt besides lifting the tumblers, or whatever is substituted for them; and this makes the key for a large lock too large and heavy to be conveniently carried in the pocket, and a bunch of such keys impossible. To get over this difficulty, most of the makers of iron safes have adopted the plan (we do not know by whom invented) of shooting a large bolt, or a number of bolts, by means of a handle, and then a small lock with a small key locks into one of them, and thus fastens them all. The security then depends upon the impregnability of the small lock against fraudulent picking or forcible evisceration. And it may be mentioned here that there are certain thieves' instruments, by which a force sufficient to tear open the inside of a lock can be inserted through a key-hole of the common size. This, however, is now defeated by cutting out a piece of the back plate, and then screwing it on again, with only a few small screws; and so that alone gives way under any bursting pressure, whether from the instrument called the jack-in-the-box, or from gunpowder, which is another of the thieves' methods for cutting the knot which they cannot untie. If the small lock, therefore, cannot be picked, or forced, this mode of locking the bolts of a large door is quite safe, and you have the advantage of a very powerful lock with nothing to carry in your pocket larger than a small desk key.

Denison's Lock.—A lock was invented however, in 1852, but not patented, which combines the advantages of large and strong works, with a key-hole so narrow, that no instrument strong enough to injure the lock could be got in, nor a reflector to observe the bellies of the tumblers; and the bolt is not only shot by turning the handle, but locked besides, without using any key at all. But it cannot be opened without the key; consequently, there is no occasion to entrust the keys to clerks, or other persons who may be left to close the boxes or doors, provided the owner, or some one confidential person, is there in the morning to open them. This lock enjoys the distinction of being the only one of English invention which is pronounced secure, —at least against any known method of picking,—by Messrs Hobbs and Tomlinson, in the treatise before referred to. It was invented by Mr E. B. Denison, Q.C., whose name has been frequently mentioned already in the article on Clocks; and the following is its construction :—

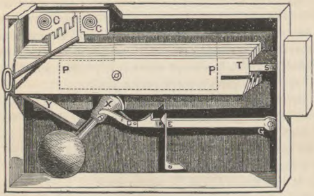

Fig. 26.

In fig. 26 are shown the tumblers T, turning on a pin at or near the middle of their length, so as to be nearly balanced, though in small locks this is unnecessary. Between every two adjacent tumblers, and between the bolt and the tumbler next to it, there is a thin steel plate, which occupies the position shown by the dotted lines PP. These plates have one edge lying against the upper side of the lock, so that they cannot turn at all on the tumbler-pin, which goes through them quite loosely. One or two of the plates should be bent a little to make them act as friction springs on the tumblers when the cap of the lock is on, so that they will stand indifferently in any position. In the figure they are drawn all pressed down, so as to prevent the stump S from entering the gating, and this has been done by the long tail Y of the handle, which, it is easy to see, will raise the left end of the tumblers, and depress the right, after the fan-tailed piece X of the handle has shut the bolt. After the tumblers have been raised to the proper height by turning the key half round (where it may be stopped by the plates P, P), the stump can enter the gatings, and the bolt can be drawn back by the handle, the tail Y then doing nothing. So far as we have gone yet, the lock would possess no greater security than any other many-tumblered lock; but there is a steel curtain CC, which does not revolve as usual, but slides on two pins set in the back of the lock, and is pressed up against the front plate by two spiral springs, so as to close the key-hole completely, except when it is pressed in. From the back of the curtain there goes a kind of square plug (shown in section at fig. 27), which can be pushed through a hole in the back plate, and has a notch in it just in the plane of the bolt, and the bolt itself has a corner there; so that when the curtain is up, the bolt can be drawn back through the notch in the curtain plug; but when the plug is pushed in ever so little, the bolt cannot be drawn back, because its corner cannot pass the curtain plug; and in this position the stump cannot be made to touch the tumblers, except one of them, which is made a little longer than the rest (as shown at T in fig. 26), in order to keep the bolt steady. It is evident then, that as soon as you push in the curtain to admit any instrument what-

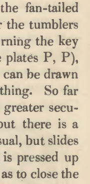

Fig. 27.

ever, the bolt is held fast, and it becomes impossible to put any pressure of the stump upon the tumblers ; in other words, the tentative mode of picking is impossible. In small locks the curtain has no plug, but merely works against the edge of a second stump of the bolt, which can only pass when the curtain is up, and it slides on the drill-pin and another pin below it.

The security of the lock is further increased by the addition of what may be called a detector DEG, as it does detect if the bolt has not been shot far enough by the person who locked it; and what is of more consequence, prevents it from being opened in that state. It turns on a hinge or pin at G, and is held up or down by a jumper-spring at E, as in Chubb's first detector. In fig. 26 it is shown as held down, or out of the way of the bolt; but as the handle turns back again and draws back the bolt, the pin below X raises the detector a little, and then the spring is ready to throw its tooth into the notch in the bolt as soon as it is shot only about half way; and in that state the bolt cannot be drawn back without turning the handle far enough for the fan-tail X to send the detector down again below the corner of the spring, and by doing that you will also have locked all the tumblers, and so made the lock fast until the key comes to open it. And it is to be observed, that the curtain cannot be pushed in until the bolt is fully shot, so that no exploration of the lock can take place while it is open, or even partially open. It may be arranged, if required, that the curtain could not be pushed in, not only until the bolt is shot, but until the tumblers are locked also, by adding a spring catch under the curtain, to be freed by one of the tumblers when it is fully locked.

The following, therefore, are the advantages of this lock:—
1. A very large lock, with all its parts strong, only requires a very small key, not weighing above a quarter of an ounce.
2. No key is required to lock it, and you cannot leave the key in the lock (a fruitful source of mischief), and yet it is free from the inconvenience of spring-locks, which sometimes

shut themselves when not intended; and moreover, a large spring-lock requires a large and strong key to open it. 3. It cannot get out of order from the usual causes of the tumblers sticking together, or tumbler-springs breaking, because there are none, and the tumblers do not touch each other, but the friction-plates between them. 4. The key-hole being always quite closed by the curtain, except while the key is in, the lock is protected from dirt and from the effects of a damp or smoky atmosphere, which injures other locks. 5. The smallness of the key-hole prevents the insertion of any instrument strong enough to force the lock, and also prevents inspection. 6. It is pronounced by the highest authority to be secure against any known mode of picking. 7. It requires no delicacy of construction or high finish in any of the parts; and the moving parts are few; in fact, the whole of them together are fewer than the number of springs alone in the great American lock which we shall next describe. 8. It is free from the incumbrance of a patent, the inventor being one of those who agree with the opinion of the Jury on Philosophical Instruments in the Great Exhibition, and with many of the first engineers and most scientific men, that "patents are a great obstruction to the progress of science," and waste, on the whole, more money than they gain for real inventors.

Notwithstanding these advantages, we cannot learn that any of the lockmakers have taken up the manufacture of this lock, all of them having a settled course of manufacture of their own articles, which they find they can sell sufficiently; and unless some large order should be given for this lock (as for a set of prison doors, for which it seems peculiarly adapted, with a master-key arrangement) it seems not likely to be adopted until some startling event makes the public open their eyes to the insecurity of the established forms of English locks which they have long believed in. We now proceed to describe what has been considered the great triumph of transatlantic skill, viz.:—

Day and Newell's Parautoptic Lock.—This formidable name has nothing to do with the chief peculiarity of this lock, viz., the power of changing the key and the state of the lock without taking it off the door, which might have been indicated by an equally imposing title—*parallactic.* Parautoptic only means that it cannot be examined through the key-hole, which is not peculiar to this lock. In order to understand this complicated machine it will be better to consider the provisions for security against picking, and those relating to the changeability of the key, independently of each other, as they have nothing to do with each other, and either might be used without the other. The object of the changeable key is merely to provide against the risk of its falling into the hands of somebody who may have taken an impression, and made a false key from it: a risk which is perhaps rather more likely to be increased than diminished by the great size of this key, and the disposition of people not to carry such a large instrument in their pockets more than they can help, and the probability of their not taking the trouble to unscrew the bits and change the form of the key every time they use it. Assum-

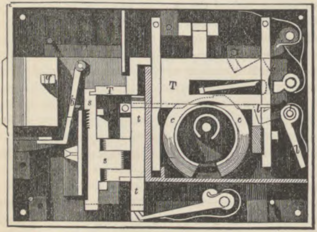

Fig. 28.

ing then, for the present, the key not to be made with moveable bits, the security of the lock depends on the following points:—The stump *ss*, which for the present must be assumed to be attached to the bolt, does not act against the tumblers TT, which are raised by the key, and may be called the primary tumblers, but on a set of secondary ones *tt*, which are made to follow the primaries whenever they are raised by a set of springs under them, which are not strong enough to resist the primary tumbler-springs, but are strong enough to lift the secondaries when the pressure of the others is taken off. But even this does not fully represent the independence of the secondary tumblers, for each secondary tumbler *tt* really consists of two pieces, of which one is pushed up by the spring and lifts the other with it, which has the gating or jaws to receive the stump, but can rise without the carrying piece being lifted. The consequence is, that supposing pressure to be applied to the bolt so as to hold fast one (or more) of the secondary tumblers, it only holds the gating piece, and the corresponding primary tumbler remains as free to move up and down as if there were no pressure, and therefore the pressure cannot be felt. Moreover, there is a fixed wall in the lock between the key-hole and the secondary tumblers, so that it is impossible to reach them from the key-hole. All the tumblers move between parallel guides, instead of turning on pins as usual; and the primary ones are also separated by thin loose strips of iron, which prevent them from sticking together. The secondaries, however, would be the most likely to stick, as their springs are weaker; and as their action depends entirely on the springs, which are comparatively weak, we cannot help thinking there is some risk of their getting stuck together by rust forming between them, or by a drop of thickened oil, as sometimes happens in Chubb's, or any other spring tumbler-lock.

The primary tumblers are also prevented from being inspected through the key-hole by a curtain *cc*, which is not the ordinary flat curtain with a small barrel close to the key-pipe, but a large ring or barrel turning in a circular groove in both the lock-plates. Moreover, this curtain is not concentric with the key-hole; and therefore, although the bits of the key do not project beyond the curtain when it is put into the key-hole, yet by the time it has got nearly half round, they project considerably, and raise the tumblers as if there were no curtain at all in the way. On the front edge of the curtain there is a broadish flange, with a segment cut off at the top, and on that segment there lies another tumbler (covering the primary tumblers, and supposed to be taken off in fig. 28, but shown in fig. 29); and any raising of this tumbler by turning the curtain, brings over the straight part of the key-hole (through which alone any inspection could be made) a revolving plate (fig. 30), which lies outside the front plate of the lock, by means of a pin *p*, which comes through the front plate, and works in a hole in the revolving plate. This revolving plate is called the detector plate, but with no good reason; for, like many other so-called detectors, it detects nothing, though it does pre-

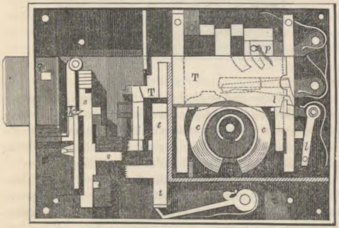

Fig. 29.

sent additional obstacles to opening the lock with anything except the right key. For, when the lock is locked, it has hold of a pin *q* in the bolt, which can only be freed by the plate revolving, and so closing all the key-hole, except the hole in the middle, which is occupied by the key. There is also a kind of spring-lever *ll*, which locks upwards into the bolt, and is also only freed by the tail *m* of the revolving plate as it moves to the left under the action of the key.

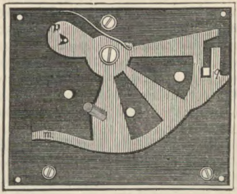

Fig. 30.[1]

In spite of all these accumulated securities, one of these locks was lately picked in America by a totally unexpected method. There is no great difficulty in getting an instrument into the lock which will deposit a little printing-ink, or other black grease, on the bellies of the tumblers just over the key-hole. This was done a short time before the owner was going to lock the lock; and the effect of his doing so was to spread the ink along each of the tumblers just as far as the key happens to touch it. If you can get now another instrument, or succession of instruments, into the lock, which will take off the impressions made on the

---

[1] **In this figure, which is copied from Mr Hobbs's *Rudimentary Treatise on Locks*, the *detector plate* is drawn the reverse way of the two figures of the lock; for what reason we are not aware.**

tumblers, or measure the length of them, you can make a key from it; and the great size of the key-hole enables this to be done by putting in a wooden key of this shape; the rounded surface allowing the black on the tumblers to mark its own length thereon. Mr Hobbs however has defeated this contrivance, by adding a wiper to the revolving curtain, which always passes over all the tumblers after the key, and so wipes the ink along them all equally, and prevents the length of sweep of the key-bits from being distinguished. We may observe here, that the opening of a six-tumblered Newell's lock in this country, a few years ago, which the English lock-makers made a great deal of, proved nothing at all, as it was done by merely working through the permutations of the key, which are only 720 for 6 tumblers; and the right one was, by good luck, hit upon long before they were all gone through. An expensive lock of this kind ought not to have less than 8 tumblers, which would give 40,320 changes, and take a man four months to work through, at the rate of one every two minutes for twelve hours a-day. Besides that, it is possible still further to increase the number of changes by having some spare bits to the key beyond the number of tumblers, so that the number of changes may be increased enormously, as nobody finding (say) 12 bits loose could tell which eight of them had been used to form the key to lock the lock.

Fig. 31.

In order to understand the principle of the changeable key machinery, suppose that you could shift the position of the stump in an ordinary tumbler-lock, then all the bits of the key would require making shorter or longer in order to raise the tumblers to the proper height. Suppose next that each tumbler had a stump of its own screwed to the bolt, but capable of being unscrewed and shifted at pleasure, then every bit of the key would require altering whenever you alter the position of the corresponding stump. And again, suppose these separate stumps to be so attached to the bolt, by a ratchet and click, or some similar contrivance, that when the bolt is back and the stumps lying in the jaws of the tumblers, the tumblers will carry the stumps with them to whatever height they may be raised by a key, and leave them sticking to the bolt at that height when the bolt is shot, and the stumps pass out of the jaws of the tumblers,—then it is clear that the lock can only be opened by the same key which raised the tumblers and stumps to that particular height; and yet, as soon as it is opened, the stumps again come under the dominion of the tumblers, and any other key will do to lock the lock again just as well as the one which was used before. In other words, such a lock is perfectly neutral and indifferent as to the key which may be used to lock it, but it cannot be unlocked by any key except the one which locked it last; and therefore, by changing the key, or the arrangement of a given set of bits on one stem, you change the lock also while it is locked.

We may observe, that a key with transposable bits is by no means new; but then it always before required the lock to be taken off, or the tumblers transposed by some other operation, to suit the alteration of the key. Fig. 32 shows the construction of any changeable key, the bits being put in in any order, and fastened by a screw going through them all.

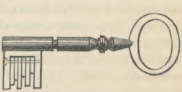

Fig. 32.

Now, to apply this to Newell's lock. In fig. 28 it is shown unlocked, and the moveable stumps *ss* are then lying within the jaws of the secondary tumblers *tt;* and besides that, they are now taken hold of near the top by the long pieces projecting from the primary tumblers TT. Consequently, when the primaries are raised by the key for locking, the sliding stumps *ss* are lifted with them; and as they slide up and down between guides fixed to the bolt, they are carried forwards, and out of connexion with the primary tumblers when the bolt is shot; but just before the connexion ceases, a click *k* falls into the back of the stumps (which are notched for the purpose), and holds them at the same height until they return. There are as many notches in the stumps as there are different lengths in the key-bits; and, as before stated, there may be any number of bits capable of fitting on to the same key, whether of the same or different lengths, so as to increase the variations in the lock without increasing the number of the tumblers.

These locks do not appear to have been as yet much adopted in England: whether from the cost, the ponderousness of the key, and the trouble involved in taking it to pieces frequently (for without that, the changeability is no security whatever), or merely from the national antipathy to novelties, and the national confidence in our own security, we do not pretend to say. It is certain that in America both the thieves are more dexterous, and the owners of property spend much more upon locks and safes than we do. A New York watchmaker told us lately that he locks up all his valuable goods every night in a cast and wrought iron safe two inches thick, with a lock that cost L.50. There are however some of them used in the Bank of England, and a few other banks.

The French Changeable-key Lock, though very inferior to the American ones in security, has this advantage, that nobody can lock or change it for mischievous or fraudulent purposes without possession of the key that last locked it. The primary tumblers which are raised by the key do not contain the gatings for the stump, but work a second set of tumblers which do, by means of teeth, like two toothed wheels working together. In order to change the lock, you overlock it backwards a little with the key that will open it (*i.e.*, which locked it last), and, by turning a small handle, you throw the two sets of tumblers out of gear with each other. Then change the bits of the key as you please, and put it into the lock again and turn it, as before, half way round, and bring the tumblers together again by the handle. They will join by a different set of teeth from before, and the altered key alone will open the lock. This plan may be adapted to any kind of tumbler-lock; and if it is one of a secure construction, it would be just as good as the more complicated American lock. Mr Chubb has lately made some of these locks; but in this instance also, the necessary size and weight of the key seems to be an impediment to their use; and probably any one who was inclined to spend a largish sum on a changeable lock, would buy the American one, which is undoubtedly very superior to the French in security both against picking and violence.

In order to get over this disadvantage of a large key, Mr Hobbs invented another lock, which is equally changeable, and still more parautoptic, or secure from inspection, than Newell's. The key that you have to carry is, in fact, nothing but the web or bits of a key, which may be either fixed or changeable, according to the nature of the lock. The key-hole has no centre of motion within it; but when this web of key is pushed into a hole in the lock, you turn a handle in another place, and that carries the key round quite invisibly, closing the hole completely; and as it turns, it opens the lock in the usual way, and returns. There is no possibility of feeling or examining its action, as no handle can go with it into the lock. The only objection to it is, that it is troublesome to put such a key in, and still more so to get it out again; and consequently, it has not taken with the public, nor do we believe that any lock will, which does not admit of a moderate-sized key of the usual form, and to be used with no more trouble than usual. We cannot help thinking that some spring action might be contrived, which would enable this very neat and small key to be pushed into the lock and shot out again, with no more trouble than is involved in turning a key and then a handle, as in the now common arrangement for large safe locks.

In fact, after we had written this, Mr Hobbs sent us a new American lock, invented by Mr Linus Yale of Philadelphia, in which this very thing is done; the bits of the key being taken off the shank or handle, and carried away into the inside of the lock, where they perform their work, and rejoin the key shank before the revolution is completed. But the key itself is so large and thick, that it is far from realizing the advantages just now suggested in Mr Hobbs's travelling key-bits. The description sent with it is unfortunately quite unintelligible without an inspection of the lock itself, and the lock is so complicated, that we despair of being able to convey any idea of more than the general principles of its construction. It is a changeable lock, like Newell's, and with this great point of superiority over that lock, that it is entirely independent of the action of tumbler-springs; the moveable stumps, and the sliders or tumblers which act upon them, all lying between friction plates, as in Denison's and Tucker's locks, and standing indifferently anywhere. The only spring is a long spiral spring in the shank of the key (fig. 33), which drives a pin through the bits (which are all screwed together just in whatever order you please), and that pin yields to another pin in the lock, which meets it as you push the key in; so that the bits then become attached to this lock pin, which itself moves on a sliding stud, which carries off the bits into the acting part of the lock against the ends of the sliding tumblers. This part of the lock, viz., the box containing the sliders, is shown in fig. 34. Any of the primary sliders T, when pushed by the key, carries along with it the corresponding stump-slider S, and these sliders correspond to what we called the stump-tumblers in Newell's lock. After that is done, the box BB, which contains those sliders, is moved upwards, and delivers them all to the tooth Q, which holds them in whichever of their notches it happens to receive them. The primary sliders having

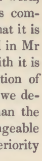

Fig. 33.

been brought back by other motions in the lock to their original or neutral position, the box BB cannot be brought

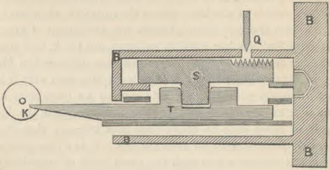

Fig. 34.

down again until all the primary sliders are pushed by the proper key into exactly the same position as they were when they parted with the stump-sliders. This part of the lock is really very simple, and involves no delicate or difficult work, as all the tumblers, all the stump-sliders, and all the little plates which lie between them both, are, or ought to be, exactly alike, and may be stamped out of sheet-iron and brass; and the whole thing goes into a very small compass, although the lock itself is very large. We may observe here, that if you were to take the key out of the lock (filing off the small bit like that in the Bramah key, which goes under the cap to keep it in), after the bits are cut off and carried away into the lock, you would not find the key-hole open, but closed at the depth which takes in the bits by a hard steel plate, which slides over it as soon as the box or "carriage" of the tumblers begins to move.

It would be natural to suppose that the cross piece BB at the end of the slider-box is the bolt, as it is prevented from moving down as a bolt usually is, until the stumps can enter the jaws of the tumblers; and this cross piece is, in fact, lifted by a kind of talon turned by the key, just like an ordinary bolt. But, nevertheless, it is not the bolt, but merely locks into the bolt, or rather lifts a lever which does, so that no amount of force which could be brought to bear on the bolt has any tendency to crush the tumblers or sliders; and this is the reason why they can be so small while the lock is very large. The key however cannot be said to be small, for it is even thicker than Newell's; but you might carry only the bits in your pocket, and stick them on to the handle or shank of the key, which may be left anywhere near the lock. Another singular provision is introduced in this lock. The bolt or bolts are not square-cornered as usual, but large round cylinders, case-hardened, so that if you attempt to cut them with a saw they will only roll under it. Figure 35, which is copied from a paper called the *Scientific American*, shows the general aspect of the lock when the front plate is taken off. All that box marked *bb*, which is as large as an ordinary lock, moves to the left, and carries the bolts with it when the lock is locked, leaving, of course, some of its parts behind under the key-hole. The piece here marked *ii* is that which we called BB in fig. 34, and it works the lever *b*, which butts against the horizontal piece lying under the tooth-wheel *f*, when the lock-carriage is shot out. It will be understood perhaps by those who are conversant with machinery, how the different parts of this carriage, and the plates which cover it, may be carried backwards and forwards by the toothed wheels and pins shown in this figure; but, as we are convinced that any attempt to explain the details of this machinery, without having the lock itself before you, would be useless, we shall content ourselves with the attempt we have made to give some idea of the general principles of its action. We will only add, that the casting of both these American locks (which have all their heavy parts of cast-iron) is vastly superior to any iron casting we have ever seen made in England; and, on the whole, the United States are evidently far ahead of us in the manufacture of both good and cheap locks; and all because our people are too stupid to substitute machinery for hand-work, and because (as Mr Hobbs said in the discussion at the Society of Arts, on the establishment lately set up by the government for the manufacture of arms at Woolwich), "if the English workmen can do anything to make a machine go wrong, they will; whereas in America they will do all they can to help it." In the same way the American and French manufacturers of clocks have driven our makers both of common clocks and of ornamental clocks out of our own market; and any enterprising manufacturer might very soon finish the business by making both church and house clocks at half the price which is paid for the old-fashioned hand-work of Clerkenwell, and of far better quality.

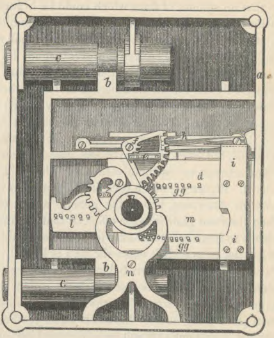

Fig. 35.

Tucker's last Patent.—Since the publication of this article in the *Encyclopædia*, Mr Tucker has brought out another better lock cheaper than those on the principle described at page 207, and apparently no less secure than any other modern lock. In order to prevent picking by pressure (otherwise called the tentative method), he makes the guide-slot of the bolt with a notch near the end, cut downwards, so that any backward pressure applied to the bolt through the key-hole has the effect of raising it against a slight spring (only another of the usual *comb* of tumbler-springs), and bringing the corner of the notch against the guide-pin, which then prevents any pressure of the stump on the tumblers from being felt by trial. This really does what the somewhat similar and less simple contrivances of Parnell and Chubb's "double-action latches" (pp. 199, 200) profess to do, but do not; and it adds practically nothing to the cost. In fact, these locks are sold for less than half the prices of Chubb's *detector* and Hobbs' *protector* locks of the same size, and are certainly more secure than Chubb's. The tumblers have only a single gating in them, like those in Denison's lock (p. 217), except the uppermost one, which has a notch at the end of the gating, just enough to keep the bolt steady when it is unlocked; and therefore this, like Tucker's other lock before described, can be locked by an almost blank key, which will not open it, as only one of the tumblers requires raising a little and the bolt shooting. This also makes the stump stronger, as it extends directly up to the thick part of the bolt, and it gives a greater range for tumblers of any given size.

Another of Mr Tucker's new inventions is a latch or spring-door lock, which does not, however, present the opposition of the spring to opening by the key, though it does to opening by the handle. This is done by setting the tumblers on a pin fixed to a sliding piece, which is pressed forward by the great bolt spring. When you draw the bolt back by the handle, the tumblers and their pin are all pushed back together by the bolt-stump; and they are so made as to cover the key-hole when pushed back. When you open by the key, it lifts the tumblers, and draws back the bolt, just as if there were no bolt-spring, because then the pivot does not move. And if the tumblers are not raised to the proper height for the stump to pass them, the bolt cannot get back without pushing the tumblers over the key-hole, which they cannot pass while any kind of key is in it; and so the bolt cannot be pushed back by means of any instrument in the key-hole except the proper key. The chief advantage of this lock is, not so much its security (which we have reason to believe not very great) as its cheapness, and its avoiding the common objection to large spring-door locks, that they require so large a key and so much force to open them that few people will encounter it. The key is solid, as in Denison's lock, and is consequently stronger for the same size, and escapes being filled up with dirt, and is rather cheaper than a pipe-key. He has also patented a new kind of piano, or desk, or sliding door lock, in which the hooked bolt is first lifted and then advanced by the key, without any other moving piece in the lock except, of course, the tumblers. This is obviously much simpler and stronger than that described at page 210, or than any other lock yet made for the same purpose, and consequently very cheap also. There are several other contrivances in his new specification, but they are not of so much importance as these, which we are glad to have received just in time to notice them, as it appears to us that these are decidedly the best cheap locks of any that have yet been brought out.

POSTSCRIPT TO PART I.

It has become necessary to correct the statement at page 77 respecting the clock for what is called the "Department of Science and Art" at South Kensington. At the time that was written and printed, it was understood to be settled that Mr Dent was to make the clock on the plan which is there described and has been fully proved to be the best, and is no dearer than any other, assuming the work to be equally well done in both cases. Mr Cole, the general manager or superintendent of the said department, went to Mr Dent's factory, and professed himself anxious to have the best possible clock, and made no objection to the usual price. Indeed, so little did he consider the price of consequence, that I had some difficulty in making him understand that it would be a foolish waste of money to have a clock of that size made as a model of the great Westminster clock, for the inspection of the public, as he wanted it to be, after seeing that clock, inasmuch as many things must be introduced into a clock with weights of three or four tons which would be absurd and unmechanical in one of the common size. Soon afterwards, however, it seems to have occurred to him that he might either get a clock out of Mr Dent on the same principle as a celebrated dandy is said to have got his clothes from a first-rate tailor, or else get a plausible excuse for throwing him over in favour of somebody else whom he had been persuaded to employ instead; for he went again to Mr Dent, and intimated to him that it might be worth his while to put up a clock at that place at a low price, *for the sake of* *the advertisement*, and if he would not, there was somebody else who would. Mr Dent declined to do business on those terms; and so Mr Cole ordered the clock of a maker, of whom he must have known, having been himself one of the managers of the Exhibition of 1851, that he had some turret-clocks there, and was not even among the fifty-one makers rewarded or publicly mentioned by the jury, though indeed it was proposed in joke to give him a special medal for his clocks—not on account of their goodness.

If this is the way in which science and art are to be encouraged at Kensington, they would not suffer much if Mr Cole and his "Department" were (as Mr Carlyle says) "swept into the dust-bin with all possible expedition."

THE END.

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