CLOCK AND WATCHMAKERS' MANUAL.

NEW AND COMPLETE

CLOCK AND WATCHMAKERS'

MANUAL.

COMPRISING DESCRIPTIONS OF

THE VARIOUS GEARINGS, ESCAPEMENTS, AND COMPENSATIONS NOW IN USE IN FRENCH, SWISS, AND ENGLISH CLOCKS AND WATCHES, PATENTS, TOOLS, ETC. WITH DIRECTIONS FOR CLEANING AND REPAIRING.

With Numerous Engravings, Compiled from the French.

WITH AN APPENDIX CONTAINING A HISTORY OF

CLOCK AND WATCHMAKING IN AMERICA.

BY M. L. BOOTH,

TRANSLATOR OF THE MARBLE WORKERS' MANUAL, ETC.

NEW YORK:

JOHN WILEY, 56 WALKER STREET.

1860.

R. CRAIGHEAD,
Stereotyper and Electrotyper,
Caxton Building,
81, 83, *and* 85 *Centre Street.*

TO

HENRY FITZ, ESQ.,

OF

NEW YORK CITY,

AS A TOKEN OF APPRECIATION OF HIS KINDLY INTEREST AND AID,

This Work is Inscribed.

GENERAL INDEX.

COMPILER'S PREFACE.

AMONG the mechanical arts, there is none more useful than that of horology, yet there are few less understood, or less practised in this country. Notwithstanding the great demand for time-pieces of various kinds, and the very general interest manifested in them by their owners, there are but few treatises on the subject in the English language, and those few too costly to be accessible to the million, while the most of the movements are imported from Europe instead of being manufactured by our own mechanics. But of late, more interest has been manifested, American clocks have won a world-wide reputation, and the manufacture of American watches has been attempted with a marked success, which augurs well for the future. It cannot be doubted that there is native ability enough among our artisans to execute superior workmanship; the point in question is to afford it facilities for development equal to those enjoyed by other nations.

The art of watchmaking requires as much theoretical as practical knowledge, and in Europe, where it has attained its greatest perfection, the workmen are instructed by numerous treatises, published under the supervision of distinguished mechanicians appointed by the government, which detail the mode of operation with scientific precision. These books are invaluable to the European artisans; and such is the interest which they manifest in the subject that the most costly and elaborate treatises on the specialities of the art find a ready sale. The most of these are written in the French language—the universal language of the continent—and to them may be attributed much of the superior skill possessed by European artisans.

The increasing interest manifested in the subject by our mechanics, together with the new impetus given to the trade by our manufacturing establishments, has led us, at the suggestion of a distinguished scientific man of this city, to compile a translation from the works before mentioned, for the use of American watchmakers. As the basis of our work we have selected M. Magnier's revised and enlarged edition of Le Normand and Janvier's *Manuel de l'Horloger*, recently published, and forming one of the volumes of the well-known *Encyclopédie Roret*—a condensed treatise on the art of horology which enjoys a high reputation in France. For the benefit of our numerous foreign workmen, we have endeavored to retain a literal translation of technical terms, so far as has been practicable without rendering the sense obscure to our native mechanics, adding a vocabulary of definitions of terms and synonyms of technicalities.

The design has been to furnish to our artisans a comprehensive treatise on watchmaking, which, without being confined to an elaborate description of a single speciality, should yet furnish details enough to be of real use to the *workman* as well as of interest to the *amateur*. The plan of the work, beginning with a glance at the watches of Berthoud and Breguet, the principles of which still constitute the base of horological science, comprises descriptions and plates of the various gearings, escapements, and compensations in use among watchmakers, tools, patents, etc.; together with instructions for cleaning and repairing watches and keeping them in order; with such practical information as may render it useful to the general reader. Nothing has been adopted that has not been sanctioned by approved authority, and it is hoped that the present volume, without conflicting with other treatises, will prove a valuable addition to our mechanical literature.

The idea of the measurement of time dates back almost as far as Time itself; though its measure by mechanical means is of more modern origin, it is still so far distant as to be very uncertain. Four hundred years before the Christian era, Plato invented the clepsydra, the first clock of which we have any record, which marked the lapse of time by the falling of water, and indicated the hours by the sound of a flute. Since this time, the progress of watchmaking may be divided into nine distinct epochs, a sketch of which may not be out of place here.

The first of these was marked by the invention of toothed wheels. But this must have been very ancient, for Ctesibius, who lived two hundred and fifty years B. C., used them in his clepsydra, and they were probably also employed in the moving sphere of Archimedes.

In the second epoch, toothed-wheeled clocks were regulated by a balance whose alternate vibrations were produced by an escapement, and whose motive-power was a weight.

This invention is attributed to Pacificus, who lived about the ninth century; but it seems more probable that it was discovered in Germany, and that it only dates back to the thirteenth or fourteenth century.

In the third epoch, which may be fixed at the close of the fifteenth century, balance-clocks were constructed which marked the seconds of time, and were designed for astronomical observations. These were used by Tycho Brahe, and also by Valtherus.

The fourth epoch presented the valuable invention of the spring formed by a band, which, bent in a spiral form and enclosed in a barrel, serves as the motive-power, and is a substitute for the weight; to this invention we owe the portable clocks, or watches, which were first made towards the middle of the sixteenth century. In this epoch, the striking-clocks, alarm-clocks, etc. were first constructed.

The discovery of the pendulum by Galileo, about the commencement of the seventeenth century, marked the fifth epoch, which has become especially memorable by the application of this pendulum to the clock as a substitute for the balance. This application was first made by Huyghens towards the middle of the same century.

The sixth epoch was marked by the application of the spring to the balance-regulator of watches; by means of which this regulator acquires the property of making oscillations which are independent of the escapement, so that the elastic force of this spring is to the balance what the weight or gravity is to the pendulum. This successful application was made in 1660, by Dr. Hook. In 1674, the Abbé d'Hautefeuille made use of a straight spring, which Huyghens improved upon in 1675, by giving it a spiral form. Shortly after this time, the repeater was invented in England. It was first applied to clocks in 1676 by Mr. Barlow, and afterwards to watches by Messrs. Barlow, Tompion, and Quarle.

The seventh epoch may be dated at the close of the seventeenth century. Towards this period, considerable variations were perceived in the pendulum-clocks constructed by Huyghens, and a new escapement, called the *anchor*, was substituted for the Huyghens escapement, which possessed the property of causing the pendulum to describe small isochronal arcs, thus rendering the ingenious invention of the cycloid of Huyghens wholly useless.

The eighth epoch was ushered in just before the middle of the eighteenth century, when a mechanism was adjusted to clocks which corrected the variations caused in them by the changes of temperature. At this epoch, the astronomical clocks had attained a high degree of perfection.

The ninth epoch is that of the invention of chronometers, which seem to dispute its greatest advantages with the pendulum by a most valuable property discovered in the spiral-spring—that of rendering the unequal arcs described by the balance isochronal, or of equal duration. The execution of the different parts composing the clock has also been carried to a high degree of precision in this epoch, by the invention of various instruments and tools. The epoch of which we speak dates from the middle of the eighteenth century to the present time.

Horology embraces within its province, first, public clocks, mantel clocks, and watches; second, astronomical clocks, and, thirdly, marine chronometers. We have endeavored to give as clear and succinct descriptions of the principles on which these are constructed, together with the mechanical execution, as our limits will allow; and we trust that these may enable our workmen not only to copy them, but also to apply them to new and superior mechanisms, and thus achieve a triumph for American manufactures.

We would tender, in conclusion, our cordial thanks to the many friends who have kindly aided us in the work; especially to Henry Fitz, Esq., of New York city, to whom we are indebted for many valuable suggestions, and also for his revision of the proof-sheets of the present volume. Trusting that our work may sometimes prove a useful friend, we submit it to all who are interested in the subject of its commentary.

NEW YORK, *December* 1, 1859.

EXPLANATION OF PLATES.

PLATE I.

Fig. 1 and 2.—Berthoud's caliber for an improved balance-wheel watch.

Fig. 3.—Works of the same watch represented on a right line.

Fig. 4. Description of the construction of the improved fusee-arbor·

Fig. 5, 6, 7, 8, and 9.—Details of the parts of the fusee.

Fig. 10 and 11.—Arrangement of the pieces of the balance-wheel watch, placed in the case in their true positions.

Fig. 12 and 13.—Details of the potance and the pallet, with the steel plates, after the improvements of Berthoud, Sully, and Leroi.

Fig. 14.—Description of the barrel-arbor with the curb of the spring.

Fig. 15.—Caliber of the Breguet and the demi-Breguet watches.

PLATE II.

Fig. 1.—Interior of the pillar-plate of a demi-Breguet watch, with all its wheels, bridges, and the balance.

Fig. 2.—Exterior of the same pillar-plate, beneath the dial, the bridges and the slide for regulating the escapement.

Fig. 3.—Construction of the demi-Breguet arbor.

Fig. 4, 5, 6, 7, 8, and 9.—Breguet barrel-arbor and bridge with all the component pieces.

Fig. 10.—Description of a repeating-watch with all the pieces of the dial-work.

Fig. 11.—Large repeating-hammer carrying the knob and pins.

Fig. 12.—The knob of the hour-hammer seen separately.

Fig. 13.—Canon pinion of a repeater with its quarter-snail and the surprise.

Fig. 14 and 15.—Alarm watch with the two hands for the alarm-detent.

Fig. 16 and 17.—Regulator of Le Normand's machine for cogs.

PLATE III.

Fig. 1 and 2.—Pendulum-clock striking the quarters and repeating by the same train.

Fig. 3.—Description of a new method for suppressing the fusee in watches without altering the equality of the force of the main-spring.

Fig. 4, 5, and 6.—Different stop-works of the winding-up arbor for supplying the place of the chain-guard.

Fig. 7, 8, 9, and 10.—Demonstration of the theory of the gearings.

Fig. 11, 12, 13, 14, 15, and 16.—Demonstration and theory of the cylinder-escapement with the steel cylinder.

Fig. 17.—Steel apparatus for supporting the jewel substituted for the steel cylinder.

Fig. 18.—Form of the cylinder-wheel adopted by Breguet.

Fig. 19, 20, and 21.—Mounting of the stone cylinder by Breguet. Figure 20 shows the form which he gives the pivots.

Fig. 22.—Duplex escapement.

PLATE IV.

Fig. 1, 2, 3, and 4.—Hork escapement of M. Pons de Paul.

Fig. 5, 6, 7, and 8.—Spiral escapement of the same artist.

Fig. 9, 10, 11, 12, and 13.—Gearing escapement of the same.

Fig. 13, *bis*, 14, 15, and 16.—Inclined-plane escapement of the same.

Fig. 17.—Arnold's detached escapement.

Fig. 18, 19, 20, 21, and 22.—Detached escapement of Seb. Le Normand.

Fig. 23, 24, and 25.—Different anchor escapements, two of which (*Fig.* 23 and 25) are dead beat, while *Fig.* 24 is recoiling.

Fig. 26.—Lepaute's pin-escapement, for regulators and belfry-clocks.

Fig. 27.—Breguet's compensation for watches.

Fig. 28 and 29.—Destigny's compensation for clocks.

Fig. 30 ana 31.—Seb. Le Normand's improvement upon the compensation of M. Destigny.

Fig. 32 and 33.—Chronometer-balance of MM. Leroi and Arnold.

PLATE V.

Fig. 1.—Compensation for watches, by M. Perron, Jr.

Fig. 2.—Compensation for watches, by M. Robert.

Fig. 3, 4, and 5.—Compensation for clocks, by M. Charles Zademach.

Fig. 6.—Berthoud's instrument for regulating clocks.

Fig. 7, 8, and 9.—Parts of the space-column tool of M. Roger.

Fig. 10.—Lever of Berthoud, for calculating the force of mainsprings of watches.

Fig. 11.—Plane of the files for rounding cogs.

Fig. 12.—Plane of the hand invented by Seb. Le Normand, adjusted to ordinary machines for finishing cogs.

Fig. 13.—Section of the same hand.

Fig. 14.—Wheel-click-pin placed on the sides of the machine for finishing cogs, and designed to change the backward and forward movement of the hand to an alternate circular movement.

Fig. 15.—Geometrical demonstration of the causes which necessitate a progressive movement of the slide which carries the rack, E, F, according as the rounding file encircles one or several teeth in its action.

Fig. 16.—Forms of the teeth of the wheel.

Fig. 17 and 18.—Elevation and plane of the space-column tool.

Fig. 19, 20, and 25.—Elevation and plane of the inclined-plane tool.

PLATE VI.

Fig. 1 and 2.—Profile of a lathe-rest for rounding pinions.

Fig. 3.—New lathe for the pivots.

Fig. 4, 5, and 6.—Elevation, plane, and detail of a new pivot-compass.

Fig. 7 and 8.—Plan and separate piece on a larger scale of an instrument for cylindrical turning.

Fig. 9, 10, 11, 12, and 13.—Tool for inclining the teeth of cylinder-wheels equally, represented in five different positions.

Fig. 14, 15, and 16.—Tool for equalizing the teeth of cylinder-wheels and forming the inclination of the back of the tooth.

Fig. 17, 18, and 19.—Tool for polishing the columns of the cylinder-wheel.

NEW AND COMPLETE

WATCHMAKER'S MANUAL.

INTRODUCTION.

GLANCE AT THE PRESENT STATE OF THE ART—PLAN OF THE WORK.

THE art of Horology, or of measuring time by clocks and watches, unquestionably ranks among the most wonderful productions of the mechanical arts. Through the improvements made in it during the last century, it has now reached so high a degree of perfection, that it is safe to believe that it will not advance much further, either in the construction and perfect execution of the different parts of time-pieces, or in the invention of tools designed to abridge the labor and to ensure perfect accuracy and regularity of movement. We shall therefore render an important service to intelligent workmen who are anxious to avail themselves of all the modern improvements, by offering to their notice a description of the methods employed by the best artisans in the manufacture of their clocks and watches.

Our plan more particularly embraces a description of the workmanship executed in Paris, which is justly thought to excel that of the Swiss manufacturers. We shall enter into the details necessary to the exact description of all the manipulations employed by the most celebrated watchmakers, show the improvements which have been introduced in the manufacture of watches, mantel and belfry clocks, and chronometers, and describe the various tools which have recently been invented both for abridging the manipulations and rendering them more exact. We shall give valuable instructions in respect to repairing and regulating clocks and watches, and keeping them in order when they are thus regulated. These are very important, for excellent watches are often spoiled by inexperienced workmen to whom they are entrusted for repairs, or greatly injured by a want of care or knowledge on the part of their owners. We have endeavored to remedy this, by giving full and minute directions as to the care and management of timepieces, which cannot fail to be valuable to all who own them. We have also described the various escapements now in use, together with the most important gearings, and several useful tools which have lately been invented.

The Manual is divided into chapters, in which we shall treat successively: first, of the manufacture of watches; second, of apartment clocks; and third, of belfry clocks; and in these we shall avoid describing any workmanship which is not approved by the best artisans.

Machines for Measuring Time.

The general name of "clock" is given to any machine that divides time into equal parts and indicates these divisions. Clocks are made of different sizes, to adapt them to the various demands, and are distinguished by names suggestive of their uses. These are, first, portable clocks, or watches; second, stationary clocks, which are used in apartments; and third, belfry-clocks, intended for public uses. Besides these are the marine chronometers, a chapter on which will be found in the volume.

The mechanism of a clock, to whatever use it may be applied, is composed of several essential parts, which, by their correspondence, secure an exact measurement of time. These are: first, the regulator; second, the escapement; third, the train; fourth, the motive power; fifth, the click-and-spring work, or means of winding up the motive power; and sixth, the dial and hands which mark the time measured by the clock.

The regulator is a most important feature of the mechanism, and is the true instrument of the measure of time, dividing it, as it does, by its quick and regular movements. By aid of the escapement, to which it is joined, it regulates the velocity of the wheels, whose functions are, in turn, to mark the movements of the regulator; and, by a double effect of the escapement, these same wheels, by their action upon it, transmit to the regulator the force of the motive power, so as to sustain the vibratory movement which the friction and the resistance of the air tend to destroy.

CHAPTER I.

WATCHES.

The watchmaking of the present day may be divided into two distinct systems, the more ancient of which is distinguished by two pillar-plates, which are separated by four pillars of equal length, and between which are placed the wheels and other parts of the mechanism. This system was greatly improved by Ferdinand Berthoud. The details of his improvements will be found in the following section.

The second system belongs to the well known Breguet, who has suppressed one of the pillar plates, and consequently the pillars forming the frame, besides making various other simplifications which will be noticed hereafter. We shall speak first of the common watches, and afterwards describe the improvements which Breguet has introduced into the pocket repeaters.

I.—PILLAR-PLATE WATCHES AS IMPROVED BY BERTHOUD.

The improvements introduced by this skilful artisan into the construction of balance-wheel watches were the fruits of constant observations, guided by a long-continued and profound study of the mechanical sciences. Yet no authority can be considered final; and while we acknowledge his profound science and the general excellence of his system, we shall proceed, in our description of it, to point out the further improvements which have been suggested by later experience.

He preferred the verge to the dead-beat escapement, because this escapement gives a great movement to the balance-wheel, while a very small space in the escapement is passed over, and but a slight friction is obtained. In this we must differ from him; for we can easily prove, both from long experience and daily use, that the balance-wheel or verge escapement, although more easily made by ordinary workmen, has not the accuracy of the dead-beat escapement, that its recoil can never be entirely obviated, and that this cause, in itself, is sufficient to deprive it of the regularity essential to this part of the watch; and that the many attempts which have been made to render this escapement isochronal have all proved futile. But we shall speak further on this subject in our chapter on Escapements.

Berthoud seems to attribute the wearing of the pallets solely to the communication of the thick oil to this part of the escapement, without taking the quality of the brass employed in the wheels at all into account; yet no observing eye can have failed to perceive that this is the principal cause, and that if the wheels are made of good brass, the friction will have little or no effect on them.

Yet the verge or balance-wheel watches should not be utterly proscribed for several reasons. In the first place, they are more easily made and repaired by ordinary workmen; secondly, they are of a much lower price, and consequently within the reach of those who do not care for extreme accuracy in a watch; and thirdly, they do not require as frequent attention as watches with dead-beat escapements, which need fresh oil often. For the balance-wheel watches as improved by Berthoud, see Plate I.

Common Balance-wheel Watches.

Figures 1 and 2 represent the caliber. To trace this, take a piece of brass, a line in thickness and a little smaller than is required for the caliber, forge this carefully until it is reduced to one-half its original thickness, and is about nineteen lines in breadth. After smoothing both surfaces with the file, and after removing all the strokes of the rough file with the smooth one, pierce a small hole in the middle, exactly perpendicular to the surface of the plate, with a spring compass; trace the circle of a radius of $9\frac{1}{2}$ lines, then fix it with sealing-wax upon an arbor, taking care to place it as truly as possible upon the lathe; this can easily be done by heating the caliber by means of a blow-pipe and the flame of a candle. Then profit by the heat imparted to the brass plate to adjust it properly, by lightly pressing against its surface a piece of wood, held firmly on the rest of the lathe, while the mandrel is turned by the drill-bow. It is then left to cool in its place, still turning the drill-bow. When the caliber is quite cold, it may be turned on its edge to reduce the circle to nineteen lines in diameter, which is the dimension required for the large pillar-plate. Care must be taken that the outline of this circle be cylindrical instead of conical. Then, with the burin, give to both surfaces, and the edge, strokes extending across them, or rather, somewhat bevelling; remove the plate from the mandrel and warm it slightly with the blow-pipe; and finally, file off both surfaces upon a cork cylinder, so as to level down the strokes which have been given it, without removing them entirely, even of the smooth file, these are afterwards effaced with water-stone. An equal thickness is thus given to the plate.

It now only remains to trace the position and dimensions of the wheels and necessary pieces upon the two surfaces. A great degree of skill is required to do this from memory, and artisans generally copy the best executed works in their possession.

Upon one of the surfaces of the caliber trace all the pieces belonging to the interior of the watch, and those which are to be placed on the small pillar-plate; and upon the other surface, those which belong beneath the dial. The centre of all the wheels, as well as of the balance, should be pierced with small holes, perpendicular to the surface of the pillar-plate. In our description of the manner of copying a caliber, we shall also show the method of marking it.

Figures 1 and 2, Pl. I., represent the two surfaces of the caliber. Figure 1 shows the interior of the frame and the upper part of the small pillar-plate; Figure 2 shows the arrangement of the pieces which are placed on the large pillar-plate beneath the dial.

Place the caliber to be copied upon the plate which has been already prepared, placing the holes which are in the centre of each together, and carefully passing a copper pin through both in order to secure them from any change of position, then press the two plates together with pincers, first wrapping a scrap of paper about the pieces so that the pincers may not injure them. Care should be taken to place the blades of the pincers in such a position that they will not cover any of the holes that are to be pierced.

Having pierced the holes with a small drill, and separated the plates, trace the circles with the utmost care. For this use the burin or watchmaker's compass, holding the points exactly perpendicular to the surface to be traced.

The barrel, *a*, is placed at the side of the fusee, *b;* the spring is better so because it is larger, and the barrel being higher, it is less apt to vibrate on its axis.

The large centre-wheel, *c*, is at the centre; the small centre-wheel, *d*, and the crown-wheel, *f*, are traced afterwards. From the centre of the balance, *g*, to the centre of the crown-wheel, *f*, the straight line, *i*, is drawn, which indicates the position of the pinion of the balance-wheel. From the same centre of the balance, *g*, the straight line, *i h*, is drawn, perpendicular to the line, *i f*. This line, *i h*, represents the front of the potance, which should occupy the whole space between this line and the barrel, with a slight play for the passage of the chain. This is all that belongs to the interior of the frame.

The other pieces traced upon the caliber are—first, the bridge of the fusee, *m;* second, the rack groove, *n;* and third, the rosette, *o*.

The other surface (Fig. 2) shows the pieces which are under the dial; first, the canon-pinion that carries the minute-hand, *p;* second, the minute-wheel, *q*, with its bridge; third, the dial-wheel, *r;* fourth, the bridge, *s*, which receives the pivots of the small centre-wheel and the crown-wheel; fifth, the ratchet-wheel of the barrel, *t*, which serves to confine the mainspring, and to secure it by the click, *v;* sixth, the holes 1, 2, 3, 4, which mark the rests of the pillars.

Before describing the manipulations which should be employed in the execution of all the pieces composing this watch, it is important that we show the advantages possessed by this caliber. From Figure 3, in which Berthoud has placed all the parts on the same right line, and the pillar-plates of which are intersected by the centre of the holes, we may easily do this.

The large pillar-plate, or plate of the pillars A A, is made from thick brass. Around it is arranged a beater or false-plate, *a a*, and a groove and fillet, *b b*, so that it may rest on the edge of the case. In the centre, at the side of the beater, the large drop, *c c*, is placed, the use of which we shall presently learn. This pillar-plate should be about one line in thickness, the smaller one is somewhat thinner.

A cavity with a flat bottom is then made by means of the lathe in the centre of the large pillar-plate, to contain the entire thickness of the centre wheel, B, leaving a small space so that it may not rub against the cavity in the plate. The drop, *c c*, of which we have spoken, holds the base of the rod of the centre-wheel, to which a short rod is left, designed to carry off from the wheel and centre pinion, the oil which is placed in a reservoir made in this drop on the side of the dial.

The centre-wheel, B, thus resting in the body of the plate, facilitates the support of the fusee, C, with its wheel, and thus gives greater solidity to the chain. The barrel, D, which is placed at the side of the great wheel, also reaches to the top of the frame, and a spring is thus obtained whose spring-band is broader, and consequently, stronger and more solid, although thinner.

To obtain for the fusee, C, the advantage of the drop in the centre-wheel, namely, that of carrying off the oil from the base, M. Berthoud proposes to place a drop, *d*, at the opening of the fusee-hole in the large pillar-plate, with a cavity resembling that of the centre-wheel. To obtain a similar drain from the upper pivot, he places a strong bridge, *f*, upon the small pillar-plate which receives the pivot; this bridge is fastened with a screw.

By the aid of the bridge, *h*, which the author has placed under the dial, giving it as much elevation as the position will permit, he has facilitated an increased length of the lower rods of the small centre-wheel, E, and the crown-wheel, F, and by placing the plane of the small centre-wheel between those of the large centre and the crown wheel, he has resolved an important problem of mechanism. He thus arranges these three wheels in such a manner that the pressure which each exerts upon its respective pinion is nearly at the centre of the length of the rods between the two pivots. By this method, the friction is equally distributed between these two pivots.

Before this happy arrangement was made, the small centre-wheel was sunk in the large pillar-plate, its lower pivot being carried with scarcely any rod in a cap which crossed the cavity; and the large centre-wheel was placed upon the large pillar-plate with no grooving; this lessened the base for the fusee and barrel. The pinions of the large and small centre-wheels were rarely sheltered from the oil which their leaves contained. This was also the case with the wheel *q* (Fig. 2) which, rubbing against the large pillar-plate, often took the oil placed upon the large centre wheel and accelerated the friction of the machine.

In the new construction (Fig. 3) the pin that holds the minute-handle, *g*, being elevated on account of the drop *c*, *c*, thus causes the like elevation of the wheel, *i*; the pinion of this has a longer rod whose pivot turns in the pillar-plate, its other pivot entering the bridge, C.

By placing the rod, *m*, of the balance-wheel perpendicular to the rod of the wheel F, a double advantage is gained, as we thus obtain a shorter and more easily turned rod, and a more perfect gearing than when this rod passes by the side of the rod of the crown-wheel and ends at the edge of the small pillar-plate.

The author has also improved the two pieces in which the two pivots of the balance-verge move. The lower pivot moves, as before, in the arm of the potance, and its point rests on a plate of tempered and polished steel. A small plate is placed upon the lower foot to carry off the oil. Above the cock is placed a balance-cock of brass, which should be as thick as the case will permit, as may be seen in P, and upon this is another balance-cock of tempered and polished steel. These two balance-cocks are fastened together by the same screw, the brass balance-cock being more firmly secured to the cock by two chicks which prevent it from turning. In order to turn the oil towards the two pivots, the arm of the potance and the brass balance-cock are rounded by a screw with a round head, on the side of the steel plates, care being taken to leave a small space between this screw and the steel plate to permit the passage of the oil. In this manner the oil is drawn towards the end of the pivots without extravasation. We shall presently speak of the potance.

In the old construction, the upper pivot turned in the cock, and the verge had no plate; the oil therefore was soon dried up by spreading over the whole surface of the balance-cock. In the new arrangement, a long rod is given, as may be seen in *p*, which often preserves this pivot from breaking; care should be taken to have the aperture of the cock as small as possible, without letting the rod rub against its interior. This construction also possesses another advantage,—that of preserving the balance-wheel from injury—since, if the aperture of the cock is small enough, it holds the verge in its place, and the train cannot move if the upper pivot is broken by a fall.

We shall not speak here of the construction of wheels or pinions, nor of the barrel and escapement, as we have devoted several chapters, in another part of the book, to this important subject. We shall limit ourselves now to the description of the fusee, as invented by Ferdinand Berthoud.

Figure 4 represents the fusee-arbor in profile and perspective. This arbor is made of steel, and is forged from a single piece. The arbor is commonly soldered to the fusee with tin, but the method is defective, as these fusees are apt to break away. The following arrangement is preferable, and also possesses the advantage of permitting the fusee to be renewed without difficulty, yet preserving the arbor. After having turned the rod *a*, to its proper dimension, it is fitted closely in the hole in the centre of the fusee B (Fig. 5), which represents the top of the fusee; a cavity is then made in the upper part of the fusee, into which the body of the hook is sunk, while the hook itself enters the notch *b*. The arbor is joined to the fusee by means of a screw, so that it cannot turn separately; this screw confines the arbor to the cavity.

The click and spring-work is lodged in the base of the fusee to give it the greatest possible size; for this the base C C (Fig. 6), seen from beneath, is grooved with two indentations; in the first, *a a*, rests the click-spring and the ratchet-wheel, carried by the great wheel, D D (Fig. 7); in the second, *b b*, is closely fitted the flange, *c c*, of the cog-wheel E, seen flat and raised (Fig. 8). The teeth of the cog-wheel are placed on the first grooving, *a a* (Fig. 6). This cog-wheel, seen in profile (Fig. 8), has two pins, 1, 2, which enter the holes *b b* (Fig. 6). Thus, the cog-wheel is impelled by the fusee, and rests upon the bottom of its grooving, being held there by the great wheel. This wheel, D D, is held against the base of the fusee by a piece of steel, F (Fig. 9), which is termed a drop. This piece rests in a funnel-shaped cavity, sunk in the centre of the great wheel; it is for this that the drop, *d d*, is reserved, resting in the space in the cog-wheel E (Fig. 8). The piece *i*, *i*, *f* (Fig. 7) is the click-spring, which is riveted on the wheel with brass pins; *g* is the click.

Figures 10 and 11 show the arrangement of the different pieces of this watch in the interior of the frame. Fig. 10 shows all the pieces without the pillar-plate, which is represented reversed, that is as seen from beneath when it covers the large plate. The same letters indicate the same pieces seen in Fig. 3, but arranged in the order in which they are placed in the watch.

In Figure 10, we see in B the head of the regulating-plate with the hinge S, the crown-wheel, consequently, is placed on the diameter indicated on the dial by the figures 12–6, being placed above the figure 6.

In Figure 11, we see the potance, H, which we shall hereafter describe; the balance-wheel, G, whose inner pivot enters the pallet; the counter-potance, *n*, with the screw that fastens it to the pillar-plate, and the steel plate against which its outer pivot revolves. We also see the chain-guard, *r*, with its spring, *s*; the outline of the barrel, the chain and hook of the fusee, dotted and representing the momentum of the stop-work of the fusee.

We shall now give the number of teeth of wheels and leaves of pinions, which Berthoud has prescribed for watches.

Common Watches.

	Teeth of Wheel.	Leaves of Pinion.	Revolutions per hour.
Great wheel	54		
Large centre-wheel . .	60	12	1
Small centre-wheel . . .	48	6	10
Crown-wheel	45	6	80
Balance-wheel	13	6	600

The inclined lines which connect the figures in the preceding and following examples, indicate the pinions into which the corresponding wheels work, thus causing their revolutions.

The balance-wheel, as we see here, makes six hundred revolutions per hour, while the large centre-wheel makes but one in the same time. But as the balance-wheel has thirteen teeth, and as each tooth produces two vibrations, by multiplying six hundred by twenty-six, or twice thirteen, we obtain for a product 15,600, which is the number of vibrations which the balance beats in an hour. Experience has proved that a watch which beats from 17,300 to 17,400 vibrations goes with the most regularity, and is the most easily regulated. This rule is now practised.

Common Second-Watches.

Berthoud, in the arrangement of his caliber, intended to suit it either to common or second-watches as he declares, and as may be seen from the caliber, Fig. 1, and the disposition of the pieces, Fig. 10. We see in the caliber the diameter, *r*, *s*, which indicates the line of the hours 12 and 6; 12 at *r*, and 6 at *s*. In this construction it is only necessary to change the number of the teeth of the wheels and the leaves of the pinions thus:

	Teeth of Wheel.	Leaves of Pinion.	Revolutions per hour.
Great wheel	54		
Large centre-wheel	60	12	1
Small centre-wheel	48	8	7
Crown-wheel	48	6	60
Balance-wheel	15	5	480½

The balance-wheel has fifteen teeth, thus giving thirty vibrations to the balance in each revolution, and consequently 14,400 vibrations per hour, or four per second. By lengthening the pivot of the crown-wheel which makes sixty revolutions per hour, or one per minute, and placing a slender hand upon this pivot, this needle will mark the seconds, divided into fourths, upon a small dial traced above the figure 6. The fifty-four teeth of the great wheel, as recommended by Berthoud, work into a pinion of twelve, and necessitate six and a half turns of the spiral-spring around the fusee for the watch to run thirty hours without winding, as is the general custom. This arrangement has not been sanctioned by most clock-makers; they give sixty teeth to the great wheel and ten leaves to the pinion of the large centre-wheel. This combination, which does not change the caliber, gives but five turns round the fusee, while the watch runs thirty hours.

The description of new watches which we shall give, after describing the potance invented by Berthoud, will be sufficient to show the manipulations employed by good workmen in the execution of these ingenious machines.

The Potance.—We owe to Ferdinand Berthoud the perfection of this piece, which is important on account of its function of receiving the three principal pivots of the escapement. He gives the following description.

"The potance, C, is seen in profile in Fig. 12; *d d* is the grooving made to receive the pallet or potance D (Fig. 13). The adjusting-screw, *e*, enters into the hole tapped in the potance parallel to the course of the pallet. The part *g* of this screw enters into the notch *h* of the pallet D (Fig. 13). This, therefore, is only moved in the grooving of the potance as the adjusting-screw is turned. This movement of the potance is necessary in order properly to adjust the watch in its beat. To confine the pallet to the grooving, *d d*, of the potance, the latter is perforated at *k*, and a screw inserted whose head rests on the pallet, and the hole *b*, through which the screw passes, is lengthened to prevent it from checking the movement of the pallet. The plate E is of steel, it is fastened by a screw to the top of the potance to receive the end of the pivot of the balance-verge which revolves in the arm, *f*, of the potance. This arm is rounded off on the top with a round-headed screw to retain the oil of the pivot between the spherical part and the plate E. The chicks 1, 2 of the potance fit closely into the holes of the small pillar-plate. To prevent the oil which is put on the inner pivot of the balance-wheel from being carried past the pallet, Leroi has conceived the idea of covering this hole with the steel plate F (Fig. 13), which meets the pallet and is secured to it by the screw which fastens it. The end of the pivot of the balance-wheel revolves on this plate. To secure the simultaneous movement of the steel pallet and the nose of the potance, the latter bears the pin *n*, which enters a hole in the steel plate.

"The potance, *m*, is rounded off at the back by a round-headed screw in order to retain the oil of this pivot. We see in G (Fig. 13) the steel plate joined to the pallet. The credit of this excellent method of confining the oil to the pivots is due to Messrs. Sully and Leroi."

II.—BREGUET WATCHES.

The *Breguet* system of watches differs essentially from those we have just described, first, in the caliber, and second, because the large pillar-plate, without pillars, alone is used, the small pillar-plate being replaced by bridges. The fusee movement is not employed, and the escapement is usually a cylinder of Breguet's own invention.

The watches called *demi-Breguet* are constructed on the same caliber, the only difference being in the form of the bridge which supports the barrel. We shall first describe the *demi-Breguet* watch, and afterwards speak of the bridge which we have just mentioned.

Figure 15, Pl. 1, shows the caliber in its natural size. We see at A the barrel, which has eighty teeth; at B, the large centre-wheel, with sixty-four teeth and a pinion of ten leaves; the small centre-wheel, C, has sixty teeth, with a pinion of eight leaves; the crown-wheel, D, also has sixty teeth, and its pinion eight leaves; the cylinder-wheel, E, has fifteen teeth, with a pinion of six leaves. We see at F the dimension of the balance. It may easily be seen that this watch beats 18,000 strokes in an hour.

Figure 1, Pl. 2, shows this system on a larger scale than the caliber (Fig. 15, Pl. 1), in order to point out more clearly all the parts of the watch. The movement here is seen upon the surface of the pillar-plate, opposite the dial, because, as we have already said, there is but one pillar-plate in this kind of watch. The pillar-plate, A, has a small base around its edge by which it rests on the case, to which it is fastened by several screw-keys.

The barrel B, of which we see but a part, the rest being hidden by the bridge C C, carries eighty teeth on its rim. The bridge C C, is fastened upon the pillar-plate, A, by two strong screws, *a a*, and two chicks. We see on this bridge a steel ratchet-wheel, *b;* a click-wheel, *c*, and moving upon a screw, is constantly impelled against the teeth of the rachet-wheel by the spring, *d*, which is fastened to the bridge by a screw and chick. These two last pieces are also of steel. The three screws which we see on the ratchet-wheel around the centre, are not tapped into the bridge, as might be supposed from an inspection of the plate, but are screwed into the base of the arbor, for otherwise they could not turn; they serve to join it to the barrel-arbor, which winds the main-spring and holds it by the click and spring-work, so that it may not fall back. It is in the adjustment of the pieces which compose the barrel-arbor, the click and spring-work, and the form of the bridge, C C, that the *Breguet* watches differ from the *demi-Breguet*, of which we are now speaking; we shall hereafter describe the difference of these pieces, and compare them in order to point out this difference.

The large centre-wheel, D, is the highest of all, passing above the barrel and the balance, as may be seen in the plate; this is supported by the bridge, E, which is fastened to the pillar-plate, like all the others, by a strong screw and three chicks.

The small centre-wheel, F, supported by the bridge, G, is placed under the large centre-wheel, D, and beneath the balance.

The fourth wheel, H, is supported on this side by the bridge, I. This cylinder-wheel passes through the pillar-plate into an opening which we see in Fig. 2, at M, and is lodged in a cavity made in the barret N, which is fixed upon this surface of the pillar-plate by two good screws and two chicks.

The cylinder-wheel, which is concealed in the figure by the bridge, K, which supports it, and by the balance, has one pivot revolving in the bridge, K; the other revolves in the barret, N, which is found on the other surface of the pillar-plate, and which also receives the lower pivots of the two wheels, F and H.

The upper pivot of the balance revolves in the cock, L; the lower pivot moves in another bridge, which is placed on the other surface of the pillar-plate, and is called the *chariot*. The bridge, L, of which we have just spoken, supports the small ear, *r*, which receives beneath, in a small hole which may be seen there, the pivot of the pinning of the spiral spring. We see a sort of hand at *m;* this is the end of the regulator, which is moved to the right or left to accelerate or retard the movement of the watch. This piece is made in the following manner. Take a thin piece of steel, long enough to reach from the end of the hand, *m*, to its opposite extremity, *o*, pierce a hole in the centre of the part *n*, place it on an arbor, and trace the two circular lines seen in the figure. The centre of the circle may even be removed, care being taken to make the hole slightly conical; that is, smaller on the surface designed to rest on the cock, L, than on the outer part. The rest is filed to the shape indicated in the figure. Then place on the circle the small piece of steel, *n*, which is inversely conical to the hole in the regulator. This piece is fastened to the cock in the middle of the regulator by two screws. The regulator can now be turned with ease around the piece, *n*, grazing it slightly.

The ear, *o*, at the end of the regulator, has two small pins on the under side, very near each other. Between these two pins passes the first turn of the spiral-spring, the elasticity of which commences near this point.

The cylinder-escapement is generally used, but any other dead-beat escapement may be substituted for this; we shall enter upon the details of this escapement in the chapter devoted to the subject, only saying here that, in good watches, the four pivots, at least, of the two pieces of the escapement revolve in holes made in jewels which are adjusted to the pillar-plate, or upon the bridges.

Figure 2 represents the second surface of the pillar-plate on the side of the dial, figure 1 having shown the surface on the side of the wheels. We see in Fig. 2, at P, an opening in which the cylinder constituting the barrel can turn without any friction against the interior of the opening P; this gives facility for the largest possible spring, as the barrel may be raised almost to the dial. We also see in Fig. 2, a barret, N, which is fastened to the pillar-plate by two screws. This barret receives, at *a*, the pivot of the small centre-wheel; at *b*, that of the crown-wheel, and at *c*, that of the escapement-wheel. This barret is edged off beneath, in order to give to the brass the requisite thickness relative to the length of the pivots.

We see in the same Figure 2, a second barret, O, which is called *chariot*. This barret has, near its centre, a projecting part, R, of the thickness of the pillar-plate. This part, R, enters a notch of the same form, which is made in the pillar-plate, reaching to the level of the other surface, and is adjusted loosely enough to permit a movement of three or four degrees or more to the right or left; the reason of this we shall soon explain. This slide is first fastened with a screw, *s*.

The cock L (Fig. 1) is not fixed upon the pillar-plate by the screw, *t*, but is fastened to it by the part R, of the *chariot*, O, and by three chicks which are marked there. We see at *d*, on the same *chariot*, the place of the pivot of the cylinder. We can readily conceive that, if the two pieces are closely fitted and fastened together, the *chariot*, O, being also fastened upon the pillar-plate by the screw, *s*, the point, *d*, in which the lower pivot of the balance rests, can describe a small arc of a circle about the point *s*, and that by this means the cylinder can approach or recede from the centre, *c*, of the wheel; the escapement can thus be rectified at pleasure if in the adjustment of the two pieces composing it any error is perceived.

To guard against this inconvenience, a screw with a large head, T, is sunk into the pillar-plate; this screw supports a notch, *v*, into which a steel pin, fastened to the end of the *chariot*, enters, so that by turning the head a little to the right or left with a turn-screw, the cylinder is moved to the requisite distance from the wheel. When the escapement is fixed a datum is marked on the pillar-plate, and the screw, *t*, of the cock is clamped; the escapement is thus securely fastened.

The point most worthy our present consideration is the construction of the barrel-arbor; this differs in the *Breguet* and *demi-Breguet* watches. We are ignorant of the name of the inventor of the last, who seems to have adopted it because he found the system of the ingenious Breguet too difficult to execute. This system, however, has been generally admitted into the Parisian workshops, that of Breguet alone almost exclusively preserving the construction of this skilful artisan. We shall first describe the system of the *demi-Breguet*, as it will better enable us to understand the other.

Figure 3 gives an idea of the adjustment of the barrel-arbor to the *demi-Breguet* watches. The whole rod, from one end to the other, that is, from *a* to *b*, comprising also the circular plate *d*, is of a single piece. The barrel is contained with its cap in the elevation *c*, at the middle of which a hole, *n*, may be seen, pierced quite through; on this cylindrical part, *c*, the cylinder, *m*, is placed, whose diameter is equal to one-third of the inner diameter of the barrel; the motive spring revolves on this piece. But as these two pieces must be solidly and indissolubly joined together, these two holes are pierced at the same time; they are then fastened together by a good steel pin, which projects on the side in order to form a hook capable of holding the spring securely. As the barrel will rub upon the plate *d*, the friction of the whole diameter would be too great; it is therefore turned on an inclined plane, so that the barrel rests on the smallest base consistent with solidity.

The rondelle, *f*, is then arranged upon the barrel-arbor, *a*, *b* (Fig. 3), of the thickness of the bridge, C C (Fig. 1), and it is then adjusted above the cog-wheel, *g*, which is fastened to this round-plate by three screws, as may be seen in *b* (Fig. 1).

We see in the figures 4, 5, 6, 7, 8, and 9, the details of the Breguet bridge, and the adjustment of his barrel-arbor. Figure 4 shows the bridge as seen above, and furnished with its click-spring.

Figure 5 shows the same bridge as seen beneath, but without the spring; this is seen separately in Figure 6.

Figure 7 shows the barrel-arbor in profile, and at the side, in *q*, the front of the ratchet-wheel.

Figure 8 shows, on a quadruple scale, the adjustment of the piece of steel which increases the size of the arbor to the requisite proportions, and which supports the hook designed to hold back the spring. All the other figures are on a double scale for a common-sized caliber. The same letters designate the same pieces in all the figures.

The bridge (Fig. 4) is not of a single piece; it is composed of the so-called bridge, whose thickness in the upper part, *b*, *b* (Fig. 9), we may consider divided into three equal parts; one, *m*, forms a single piece with the bridge; the second, *b*, *b*, supports a socket, *a*, which is joined to the bridge by the screws, *b*, *b* (Fig. 4); the third is hollowed in the massive part of the bridge, and serves to contain the cog-wheel.

The socket, *a*, of which we have just spoken, is designed to receive the end of the key when the watch is wound up, so as to preserve the other parts from any accident caused by unskilfulness.

The main-spring, *d*, *c*, is edged off from *f* to *c* to about one half its thickness, so as to leave it no superfluous strength. It has an orifice or elongated opening at *f* to bevel the teeth of the cog-wheel. The upper part, *c*, is filed off to an inclined plane, so as to enter between the teeth of the cog-wheel and prevent them from falling back. This screw is fastened on the thick part of the bridge by a screw and two chicks, as in figure 6. The barrel-arbor (Fig. 7) is of steel and is in a single piece, and includes the cog-wheel, *s*, which is seen in the front and side at *q*. The part, *o*, *n*, is filed square, all the rest is round with the exception of the rods, *p* and *r*, which are squared for the remontoir. Upon the two angles opposite the same diagonal, two small notches, *o*, *n*, are made, and a steel cylinder, whose diameter is equal to one-third of the interior diameter of the barrel, is placed squarely upon this part. Figure 8, which is on a scale double that of the other figures, will explain this arrangement. Upon the prolongation of the diagonal of the square, *r*, which is at the centre, a hole is pierced on each side and at an equal distance from the two angles. When these holes have been wormed out, two flat-headed screws are sunk in them, and a notch is then made in each at right angles, large enough to permit the passage of the square. When this piece is in its place, each screw is turned a quarter round; the thick part of the screws is then turned into the notches, *o*, *n*; the screws serve as a key, and the whole is perfectly solid.

In these two systems a particular construction of the pin that holds the minute-handle is adopted. Instead of piercing the pinion, which in the old system was placed in such a manner as to rub against the lengthened rod of the axle of the large centre-wheel, the order is reversed. The pinion of the large centre-wheel is pierced through its axle, the pin of the minute-handle is replaced by a thick pinion, whose lower rod enters the hole made in the first named pinion, with friction enough to cause it to be drawn along, like the pin, and this rod bears the pivot of the large centre-wheel. In this manner, the upper rod of the pinion, which replaces the pin of the minute-hand, can be more lightly held, and the sockets both of the hour and minute-wheels sustain less friction.

We think that we have described these two systems intelligibly enough to be understood by every intelligent clockmaker.

The watchmakers of Geneva and Switzerland have generally adopted these systems, but their patrons, finding that flat watches could thus be obtained, have abused this advantage, and required watches so exceedingly flat that the artisans have found it impossible to make the springs as large as in the Breguet watches; the rods of the axles of their wheels being very small, the oil soon gets into the pinions, and the watches are spoiled. It is not uncommon to see these watches so flat that the wheels have not the requisite play, and rub against each other in such a manner as to destroy all regularity. As a general rule, we protest against flat watches, and the low price at which they are sold is in itself a proof of their inferiority.

III.—INDEPENDENT SECOND WATCHES.

As soon as clockmakers had succeeded in making clocks to mark the seconds, they sought the same advantages for watches, but here they encountered much greater obstacles. In clocks, the greatest regularity is sure to be secured by the slow vibrations, aided by a heavy pendulum ball and small arcs of oscillation; in watches, on the contrary, the slow vibrations and heavy balances necessitate large arcs, and all concur in rendering the mechanism defective.

All watchmakers know that a good and easily-regulated watch should beat from seventeen to eighteen thousand strokes per hour. The number of 14,400 strokes, as indicated by Berthoud, was adopted in this experiment, and, following his caliber, which places the pinion of the crown-wheel just above the figure 6 on the dial-plate, a small hand was placed on the pivot of this pinion, which turned round once in a minute, and marked the seconds on a small dial traced for this purpose; these were indicated by four equal divisions.

This construction did not satisfy those persons who wished to make exact observations, and, although they adopted dead-beat escapements, the small size of the dial, the nearness of the divisions, and the skipping of the needle, caused disagreements and rendered this method useless to them. They wished that the three hands should be concentric, that they should all mark on the same dial, and that the hand should mark the dead seconds. They succeeded in obtaining a greater degree of correctness by the following method, which increased the number of vibrations to 18,000 pér hour or five per second.

The escapement wheel under the dial was lengthened out, its pivot being supported by a high bridge, and a small cap bearing six pins at equal distances from each other, was fixed upon this rod. These pins, fixed perpendicularly upon the surface of the cap, performed the functions of a pinion which worked into the teeth of a cog-wheel placed upon the rod of the minute-hand pin. This cog-wheel had sixty teeth which were held back and fastened by a catch and moved upon two pivots, being impelled by a slight spring. Upon the socket of this wheel the second-hand was lightly fixed in perfect equilibrium. This mechanism can be easily understood; whenever a pin impels a tooth of the cog-wheel it also raises the catch which, as soon as the tooth has passed the angle thus formed, forces the wheel to move from one division to the other, retaining it there until another pin repeats the movement. The cylinder-wheel has fifteen teeth, thus giving thirty beats to the balance in each revolution; and as it beats five times in a second, six seconds are required for an entire revolution. It is for this reason that the cap has six teeth and presses six teeth of the cog-wheel forward in the same number of seconds.

It was soon perceived, however, that although this arrangement accomplished the purpose for which it was designed, it was still very defective on account of the force which was borrowed from the escapement-wheel to lift the click and impel the cog-wheel. An attempt was made to perform this function by the pinion of the crown-wheel, but, as this turned in the contrary direction, it was necessary to add a *roue-de-renvoi;* this increased the friction without giving any real advantage, and this system was at length abandoned.

Finally, in order to obtain this end without altering the movement of the watch, the idea of marking the dead second by an individual train, independent of the train acting upon the escapement, was conceived. This little train which we are about to describe has, for its motive-power, a spring enclosed in a particular barrel which is wound separately with the same key. It has no other function than to turn a train designed to mark the seconds by means of a hand which is concentric with the minute and hour hands, and which makes sixty uniform steps in each circuit of the dial.

We shall first give the number of wheels and pinions of the watch, and shall then explain the mechanism of the movement of the hand.

Number of teeth of wheels and leaves of pinions required in second watches.

	Teeth of Wheels.	Leaves of Pinions.	Revolutions per hour.
Wheel of the barrel	60		
Large centre-wheel	72	10 . .	1
Small centre-wheel	50	8 . .	9
Crown-wheel	48	6 . .	75
Cylinder-wheel	15	6 . .	600

The cylinder-wheel, having fifteen teeth, makes thirty beats at each revolution, and, consequently, 18,000 beats per hour or 5 beats per second.

The small train is composed of five wheels and four pinions, as follows:

	Teeth.	Pinions.	Revolutions.
First wheel upon the barrel arbor	80		
Second wheel	64	10 . .	0
Third wheel	60	8 . .	0
Fourth wheel, for beating seconds	60	8 . .	1
Fifth wheel	48	8 . .	7½
Fly		6 . .	60

All of these wheels are eccentric to the pillar-plate, except the fourth, whose pinion of 8 is pierced like a minute-hand pin and revolves freely upon the rod of the large centre-wheel which traverses the dial.

The socket of this fourth wheel carries the second-hand, and makes, consequently, one entire revolution per minute; this hand passes over the circumference of the dial in sixty equal strokes, independent of the movement which marks the hours and minutes. This is done as follows.

The fourth wheel of this additional train turns once in sixty seconds, working into a pinion of 8, which it causes to turn seven and a half times during its revolution. This pinion of 8 carries the fifth wheel of 48 which works into a pinion of 6, which acts as a fly; it causes this to turn eight times during its own revolution, and consequently this makes sixty turns while the fourth wheel makes one, which is one revolution per second.

This small train is arranged upon the pillar-plate of the movement in such a manner as to place the fly-wheel very near the pinion of the cylinder-wheel without touching it. It is necessary, however, that the leaves of this pinion should check the rotary motion of the fly-wheel or permit it to turn; this is done as follows:

The pinion of the fly-wheel bears upon its rod a small brass pallet, which is longer than its leaves, and long enough to enter easily between the leaves of the pinion of the cylinder-wheel; it then follows the motion of the cylinder-wheel as long as it is joined to it, but as soon as the leaf of the pinion permits the little pallet to disengage itself, it turns round and enters the tooth of the preceding pinion, continuing this as long as the watch goes. The movement of the pinion is suspended during five beats; that is, during one second, since the watch beats 18,000 strokes.

A small detent, which the observant presses with his finger, checks the train at will, and hinders its motion as long as may be wished.

This method, however ingenious it may be, does not yet present that degree of perfection which these machines should possess, particularly those which are designed for astronomical observations; it is, however, tolerably well adapted to the purpose. We cannot deny its extreme ingenuity, which will doubtless lead to the desired perfection.

IV.—REPEATING WATCHES.

Repeaters are those watches which strike the hours and quarters indicated by the hands, by the compression of a pusher in the inside of the case. They differ from the simple or common watches that we have described, by a second train which is solely designed to strike the hours and quarters pointed out on the dial, and by pieces of steel styled dial-work, because they are usually placed beneath the dial. These pieces, when in repose, that is, when they are not set in motion by the action of the pusher, have a fixed place. Their functions are entirely independent of those of the train which impels the balance, so that this movement marks the division of time as in the common watch. It only winds up the small train and puts it in motion when the spring in the interior of the case is compressed. But this small train will not displace any piece of the dial-work, or strike the hour, if it is not pressed down as far as possible, thus causing a slight sound. This displaces the pieces of the dial-work, they leave their rest, and, while the small train is restoring them to their first position, it comes in contact with the knobs of the hammers, and causes them to strike upon a bell or steel spring the number of single and double strokes of the hours and quarters indicated on the dial. Figure 10, Plate II., shows the arrangement of the pieces of this dial-work. We find at the present day two systems of dial-work in the watchmaking trade. We shall first describe the composition of the small or repeating train, and shall afterwards speak of the two systems.

The repeating train is composed of five wheels and five pinions. It is placed on the edge of the large pillar-plate, in the space between the crown-wheel and the barrel. The effect of this train is to regulate the interval between each stroke of the hammer.

The first wheel, also termed the large striking-wheel, bears a catch and a small spring upon which a cog-wheel works that forms a part of the arbor or axle of this wheel; this forms a click and spring-work which gives way when the axle turns in a contrary direction to that in which the wheel ought to turn to set the whole train in motion. The arbor of the great wheel serves at the same time as the barrel-arbor, to support the little spring which impels the train. This little spring, which turns spirally like that of the movement, is placed in a small barrel fixed to the small pillar-plate by two screws. The following number of wheels and pinions is requisite:

	Teeth of Wheels.	Leaves of Pinions.	Revolutions.
First or large wheel . . .	42		1
Second wheel	36	6 . .	7
Third wheel	33	6 . .	42
Fourth wheel	30	6 . .	231
Fifth wheel	25	6 . .	1155
Delay pinion or fly . .		6 . .	4812½

The axle of the large striking-wheel, independently of the ratchet-wheel, bears another cog-wheel which is designed to set the large hammer in motion by raising its knob. This cog-wheel is usually divided into twenty-four equal parts, half of which are then cut off, leaving twelve which are designed to strike twelve strokes for the twelve hours. Dividing the number $4812\frac{1}{2}$, the number of turns made by the fly-wheel during one revolution of the great-wheel, by twenty-four, we have for the quotient $200\frac{1}{2}$, which is the number of turns made by the fly-wheel at each stroke of the hammer. Two hammers of cast-steel are placed in the interior and upon the edge of the frame. Each hammer is firmly mounted upon an axle of tempered steel, terminated by two pivots; one of which revolves in the small, and the other in the large pillar-plate, where they are lengthened out, as we shall presently see. The rod of the large hammer is placed between the crown-wheel and the large striking-wheel; its body passes around the crown-wheel, and its head is as high as the train will permit, so that it may strike as heavily as possible. Figure 11 shows the large hammer with its knob.

Upon the rod of this large hammer, a steel socket is placed which bears, in the frame, a sort of tooth or knob, *m* (Fig. 12), which works into the twelve-toothed cog-wheel that causes it to strike the hours. This socket, which is called the knob, supports the pin, 1, which passes through the circular opening (Fig. 10) for a purpose which we shall presently mention. This same pin causes the large hammer to move when the knob, *m* (Fig. 11), is caught by the notches of the twelve-toothed cog-wheel of which we have spoken.

Independently of the pin, 1, of the knob, the large hammer has two other pins, 2 and 3, solidly fastened to its body by screws, which traverse the large pillar-plate and pass to the dial-work through the circular openings 2 and 3. The pin 3 (Fig. 11) is further from the axle, *q*, of the hammer, than is the pin 2; the spring, *g* (Fig. 10), acts against this pin on the side of the dial-work. This spring is strong, and, working by a long arm, thus causes the hammer to strike loud blows to distinguish the hours.

As soon as the hours and quarters are struck, the knob, *m* (Fig. 11 and 12), is reversed by the method we have indicated in the description of the dial-work. This knob is no longer caught by the teeth of the cog-wheel, and the pin 1, which it carries, is separated from the hammer. The quarters are struck by the pieces of the dial-work which come in contact with another knob placed beneath the dial.

This explained, we will now describe the dial-work, which Figure 10, Pl. 2, shows all the pieces in action. The pusher, *p*, acting upon the arm, *t*, of the rack, C, has pushed the latter forward. It has a double function in this movement: first, by its arm, *a*, it draws the chain, *c*, which passes at first over the return-pulley, B, and rolls itself round the pulley A; this pulley is adjusted to the arbor of the small striking-spring, and bears the knob, *d*, which is fastened to the axle by a pin. In this first function, the rack causes the pulley to make almost an entire backward revolution while twelve hours and three quarters are striking; secondly, by its second arm, *b*, the rack rests upon the snail, E, whose depressions determine the number of blows which should be struck to mark the hour designated by the watch.

This snail, E, is fixed by two screws to the star-wheel, D, which has twelve teeth fastened by the jumper, S, which at each revolution made by the minute-hand pin, presses forward one tooth of the snail; that is, one tooth per hour. These two pieces, the snail and star-wheel, are carried by a rod proceeding from the end of the screw, F, which is wormed into the piece of steel, G, known as the *all-or-nothing-piece.* The end of this rod, F, enters into a hole in the pillar-plate, which is large enough to give the rod space to move a little when the snail is pushed forward by the arm *b*.

The *all-or-nothing-piece*, G, is an important piece, the construction of which should be well understood in order to appreciate its effects, which combine with those of the motion of the quarters to prevent errors, and to secure the correct striking of the hours and quarters indicated by the hands.

The *all-or-nothing-piece*, G, has its centre of motion at the point T, on the rod of a screw resembling the screw F, which is wormed into the *all-or-nothing-piece*, and which enters into a little socket riveted to the pillar-plate in order to raise it to the proper height. Its other extremity rests upon the arbor, *f*, which is wormed into the pillar-plate. This arbor passes through the *all-or-nothing-piece* and enters into an oblong hole, thus giving the *all-or-nothing-piece* a slight backward movement at the moment in which it comes in contact with the arm, *b*, of the rack. As soon as the pressure ceases, the *all-or-nothing-piece* is restored to its first position by the small spring *h*, which acts on the arbor, *f*, in a notch made in it. The button, *j*, prevents the *all-or-nothing-piece* from springing up. The hole, *k*, is designed to permit the passage of the end of the fusee so as to give facility to the winding of the watch.

The end, H, of the *all-or-nothing-piece* is somewhat bent and ends in the apex of an acute angle. The arm, *m*, of the motion of the quarters rests on the corner of this angle when in repose.

The motion of the quarters, Q, is of tempered steel; the centre of its motion is *i*; it is pushed forward by the spring, I, in order to cause it to fall on the snail of the quarters, N, which is carried by the minute-hand pin, and on which it rests by its arm, *n*. It carries three teeth at each end, so as to strike a double blow at each quarter; the three teeth, J, act on the knob of the large hammer, while the three teeth L, act on the knob of the small hammer. Its arm, *o*, when the arm, *m*, rests on the end of the *all-or-nothing-piece*, pushes the pin 1 of the inner knob of the large hammer and prevents it from coming in contact with the twelve-toothed cog-wheel, placed in the interior of the frame. A pin, *l*, fixed upon the motion of the quarters, connects this piece with the knob, *d*, which it brings back to a state of rest. The knob of the large hammer, *q*, has two arms; the upper arm comes in contact with the teeth of the motion of the quarters, and the lower one, with the pin which holds each hammer, and which passes through the circular apertures made in the pillar-plate. Each of these knobs is placed upon the axle of its respective hammer, the end of which passes into the dial-work. The spring, *g*, as we have already said, moves the large hammer, and the spring *u* the small one. Another spring, not designated in the figure, has a double use; it acts upon the notch of the outer knob, *q*, of the large hammer, hindering it from springing up and moving out of place, and, at the same time, pushes forward the pin 1, of the interior knob of the large hammer so as to connect it with the twelve-toothed cog-wheel; this also applies to the spring, *u*, which acts in the same manner upon the knob, *r*, of the small hammer, with the dial-work. As but two hammers are used in striking the hours and quarters, the effect of three hammers is produced by means of the two pins, 2 and 3 (Fig. 11), which are fixed upon the large hammer at unequal distances from its axle. The interior knob causes the large hammer to go over a large space and give the loudest possible strokes; the knob, *q*, of the dial-work causes the hammer to pass over a smaller space, striking more gently, and better according with the effect of the small hammer.

If this description has been clearly understood, we can easily explain the effects of it, after which we shall describe the construction of the *surprise* of the snail of the quarters.

By pressing the pendant of the watch, the pusher, *p*, is made to act on the arm of the rack, *t;* the latter presses forward the rack C, causing it to describe the arc of a circle. During this movement, the large arm, *a*, draws the chain, *c*, and turns the pulley, A, by tightening the spring of the small train. The knob, *d*, which carries this pulley, turns backward and abandons the pin, *l*, of the motion of the quarters against which it was resting. During this movement, the arm, *b*, of the rack, reaches the snail, E, of the hours, and pushes the *all-or-nothing-piece* a little backward. Then the arm, *m*, of the motion of the quarters, being no longer sustained by the *all-or-nothing*-piece, the motion of the quarters, moved by the spring, I, quits its place, its arm, *n*, moves to rest upon one of the divisions of the snail of the quarters, N, and the arm, *o*, of the motion of the quarters resting no longer on the pin, 1, of the interior knob, this knob, pressed by the spring, has a double effect, returns with the teeth of the twelve-toothed cog-wheel, and suffers the repeater to strike.

The pusher is then drawn back, so that it no longer presses upon the rack. Then the spring of the small train puts it in motion, the hour indicated by the hour-snail sounds, and the knob, *d*, which in turning finds itself caught by the pin, *l*, winds up the motion of the quarters. This, acting upon the knobs of the hammers, causes them to strike, after which it brings it back to its original place, where it is held in rest by its arm, *m*, which rests on the all-or-nothing-piece; whilst, by its arm, *o*, it has reversed the inner knob, and brought it beyond the reach of the twelve-toothed cog-wheel. We see, in truth, that without the small recoil which is given to the repeating spring, the train would have moved off without any hammer having struck.

We have yet to explain the construction of the *surprise* of the motion of the quarters and its effect.

Figure 13, Pl. II., shows the minute-hand-pin and the snail of the quarters, seen in perspective and beneath. The snail of the quarters is composed of two pieces—the snail, N, properly called, and the surprise, S; these two pieces are of steel. The snail, N, is riveted upon the pinion of the minute-hand-pin, beneath which a socket is left to receive the surprise; this is fastened by a small *drop* of steel which is adjusted upon the projection of the socket of the minute-hand-pin in such a manner as not to obstruct the surprise. The surprise carries a large pin, O, riveted like a pinion upon this piece; the rod which projects enters into the notch, *y* (Fig. 10), with room for the necessary play. The surprise was invented in order that the watch should sound the three quarters until the hand should have marked sixty minutes, after which the striking of the quarters should cease. This effect is produced in the following manner:—

The pin, O, causes the snail to leap forward at the rate of one tooth per hour. In this movement, it forces the opposite tooth of the star-wheel to push the jumper backwards. As soon as the angle of the tooth of the star-wheel begins to pass beyond the angle of the jumper, the spring which impels the jumper forces the latter to fill up the space between the two teeth and pushes the pin, O, forward. This pin, which is not confined, yields, and the surprise presents itself in such a manner that if the knob of the watch is pressed at the moment when the hand marks sixty minutes, the motion of the quarters falls upon the surprise, and no quarter is struck.

The end, D, of the minute-hand pin (Fig. 13) is filed square, so as to hold the minute hand. We see, in this figure, that the socket of the minute-hand-pin, C, D, is cleft; this is done in all good watches, so that this socket may be able to fly back on the rod of the large centre-wheel upon which it enters with sufficient friction to turn the minute-hand easily from one side to the other, and to prevent the socket from clinging to the rod, which sometimes happens. This precaution, however, is not taken by some artisans, who substitute small longitudinal clefts, into which they introduce a little oil in winding them. This is an error, and watchmakers should avoid putting oil into these clefts, for, besides its tendency to loosen the minute-hand-pin upon the rod which supports it, this oil is communicated to the pinion, and thence to the *roue de renvoi*, and forms a coom which will finally stop the watch. These clefts have a double use; they give the pin a little spring on the rod, as we have already said, and facilitate its extrication, in case of clinging, by introducing a little oil, which, entering between the pin and the rod, loosens it. The watchmaker should carefully remove every trace of this oil as soon as the minute-hand-pin is extricated. This clinging, as we well know, drives many watchmakers to despair, but good workmen make a pomade of oil and wax, a particle of which they place upon the rod of the large centre-wheel. This pomade does not run, like the oil, and does not cause any of the evils which the oil entails.

We have already said that two systems of repeating watches are now found in commerce; we have just described the old system as perfected by the best artists. A word remains to be said in respect to the new system adapted to the flat watches known in commerce by the name of the *Lepine* caliber.

We seem to owe to Lepine the idea of this new system which, we think, is not very successful. The pieces are the same as in the repeater which we have just described. He suppresses the chain, *c*, and the return-pulley, B. He gives a new arrangement to the pieces of the dial-work, in order to draw the pulley, A, nearer the rack. He designs his rack in such a manner that it is terminated by the arc of a circle, the length of which equals the circumference of the pulley

A. These pieces are placed against each other and near enough to permit the rack, by a hard friction, to impel the pulley.

We see that the author has drawn this idea from the first repeaters, in which the rack was notched, and worked into a pinion supported by the barrel-arbor of the small train. The effect produced by the gearing was certain, but we do not approve of the attempt to obtain this by friction alone, as this construction constantly tends to destroy the effect which is sought.

We should also say a word in regard to some changes in the dial-work of the repeaters made by Breguet. This skilful clockmaker has suppressed the chain and the two pulleys upon which it was rolled in the ancient dial-works. This suppression has necessitated a change in the form of the rack, to which he has given teeth that work into a pinion placed squarely upon the rod of the barrel-arbor of the small train. He has thus obtained a little more empty space in the dial-work and has remedied one of the common accidents of repeaters—the elongation of the chain which causes them to strike wrong and often demands the loss of much time in repairs.

V.—ALARM WATCHES.

The alarm-watch is a watch which, independently of the mechanism common to all watches and which serves to show the exact division of time, has another small train which, at a fixed moment, by the aid of a double hammer striking upon a bell, produces a sound loud enough to awaken a sleeper.

The construction of alarms has changed much since the idea of applying them to watches was first advanced. The most simple, as described by Ferdinand Berthoud, were those which carried a small dial placed in the centre of the dial of the watch, and which were turned by hand; but this construction was in bad taste and was adjusted with difficulty.

Lepaute in his *Treatise upon Clockmaking*, page 115, has given a description of the construction in general use, which is much more correct and elegant than any before adopted. We will explain it.

Figure 14, Pl. II., shows the pieces which are under the dial, and which constitute this kind of alarm. We see in this same figure, in dots, the wheels of the movement, those of the alarm, and its hammer.

The cog-wheel, A, impels the hammer, F, G, with great rapidity. The train that impels the cog-wheel, A, is composed of two wheels and two pinions. The wheel C is carried by a barrel which encloses a mainspring which impels this wheel; it works into a pinion supported by the wheel B, which works into a pinion whose rod rises under the dial and bears the cog-wheel A.

The rod of the hammer, F, G, passes under the dial and supports squarely, at D, a pallet which works into the teeth of the cog-wheel; it also supports a fork which receives between its prongs a tooth carried by the piece E. This bears a second pallet which also works into the teeth of the cog-wheel, A. These two pieces form together a species of double-lever escapement.

When the cog-wheel is free, it impels the hammer alternately, which strikes upon the case or upon a bell. But when the alarm should not sound, the hammer is confined by a pin, *a*, placed perpendicularly on its rod in the extremity of the detent.

The detent, N, *a*, is movable around a horizontal axle, L, I, in such a manner that when its extremity, N, is free to descend, the spring, K, M, which constantly presses upward, causes the part, *a*, to rise; this disengages the pin and the hammer. The problem is thus reduced to finding how this part, N, has the liberty of descending at the hour at which the alarm should sound, and why it is elevated the rest of the time despite the spring, M, K, which tends to lower it. For this, it must be understood, that the dial or hour-wheel is placed under the part, N, of the detent, which is rested on this wheel. Upon the dial, and under the hour-hand, Q, S (Fig. 15), is placed the alarm-hand, P, O. This last hand is notched at *c*, and the notch is terminated in an inclined plane towards P. This hand is fixed upon the dial, with a slight friction, by a key. The socket of the hour-hand, Q, S, passes, without friction, through the hole in the alarm-hand, and the pin, Q, is placed upon this socket in such a manner as to enter into the bottom of the notch, *c*. In consequence of this, the hour-hand, in turning, ascends the inclined plane, and carries with it the dial-wheel.

When the alarm-hand, P, O, is placed upon the hour at which the alarm is to be struck, the pin, Q, which keeps the dial-wheel suspended, and consequently the arm, N, of the lever, N, *a* (Fig. 14), is moved upon the plane of the alarm-hand, but the instant that it encounters the notch, *c*, the hour-hand and the dial-wheel sink down together, the arm, N, is lowered, the arm, *a*, rises, the pin, *a*, of the hammer is disengaged, the train of the alarm revolves and the hammer strikes.

The stop-work, T, determines the number of turns to be given to the spring contained in the barrel in winding the alarm. The pallet, X, fixed upon the axle of the barrel, successively grapples the teeth, 1, 2, and 3, when the alarm is wound up, and at the last turn rests upon the large part and elevates 4.

The use of the piece, R, H, V, is to cause the prompt and precise cessation of the motion of the alarm. In truth, when the alarm begins to sound, the extremity, R, of the piece, R, H, V, being upon the part, 4, the highest part of the stop-work, its other extremity, V, is removed from the pin and does not obstruct the motion of the hammer; but at the moment in which the spring shall have finished its five revolutions, and that the pallet, X, shall be ready to rest at X, the part, R, will fall into the first notch, and the other extremity, V, which has a small half-circular opening to receive the pin, *a*, will suddenly check the hammer.

CHAPTER II.

OF CLOCKS.

We designate by the name of pendulum clocks those clocks for apartments which were formerly placed against the walls, and which now are generally set upon mantels, secretaries, consoles, etc.

We shall not speak here of the cases in which the movements of these clocks are enclosed; these do not belong to the province of the clockmaker, who only employs himself with the works.

The wheel-work of the clock is composed of two trains, one of which serves to measure the division of time, the other is for the striking-work. Sometimes a second striking-train is added to sound the quarters; so that there are two trains for the striking-work, one of which serves to sound the four quarters before the hour, while the other is especially designed to strike the hours only. We shall speak further on this subject after having described the ordinary pendulum-clocks. We shall divide this chapter into three sections, in which we shall treat—

1st, Of the pendulum-clocks known by the name of regulators.

2d, Of ordinary pendulum-clocks.

3d, Of pendulum-clocks striking hours and quarters, and repeating by the same movement.

§ I.—*Of Regulators.*

Clockmakers are in the habit of designating as regulators those clocks with a long pendulum beating seconds, and marking the hours, minutes, and seconds by three hands, usually concentric. Every clockmaker has one of these regulators in his shop, by which to regulate the watches and clocks which he makes or repairs. This kind of regulator, when constructed with a twenty-four hour dial and regulated to siderial time, is styled the astronomical clock.

Ferdinand Berthoud took much pains in the perfect execution of this machine, which goes a year without winding. The only change which we propose to effect in his method is to substitute for the Graham escapement the pin escapement of Lepaute, which was not known when Berthoud wrote his *Essai sur l'Horlogerie*, but which he afterwards described with many encomiums in his *Histoire de la Mesure du Temps par les Horloges*, vol. ii., page 30, which may also be found in the *Traité d'Horlogerie*, by Lepaute, and which we shall describe in the Chapter on Escapements.

§ II.—*Of Ordinary Pendulum Clocks.*

The ordinary mantel-clocks usually have two trains, one of which is designed for striking. These clocks generally have a pendulum, or long balance. The height of the case in which this mechanism is enclosed determines the length of the pendulum, and, consequently, the number of oscillations which the clock should beat per hour.

These clocks run with a spring, and generally go fifteen days without winding The striking-work is also moved by a spring, enclosed in a barrel, whose wheel has eighty-four teeth. This wheel works into a pinion of twelve, carried by the second wheel of seventy-two teeth; the arbor of the latter rests upon the small pillar-plate, and is parallel to the notch-wheel, or counter, which has twelve unequal notches to determine the number of blows which the hammer ought to strike in conformity with the hour indicated on the dial. The second wheel of seventy-two teeth works into a pinion of eight of the third wheel of sixty teeth, which is called the *pin*-wheel. This carries ten pins equi-distant from each other, which are designed to raise the hammer. The following wheel is called the locking-wheel; this has sixty-four teeth; it revolves once at each stroke of the hammer, and carries a single pin to arrest the striking-work. The locking-wheel, which carries a pinion of eight, works into a pinion of six, which carries the next wheel, called the delay-wheel, and having forty-eight teeth. The latter works into a pinion of six, which carries the fly.

This construction with the notch-wheel is subject to some inconveniences. It often happens that the striking-work miscounts; that is, that it strikes a different hour from the one indicated by the hands. We shall presently see how this inconvenience has been remedied.

We sometimes see repeating-clocks; these have a small train analogous to the train of the repeating-watches, with a dial-work based on the same principles. A cord, which passes round a pulley placed upon the barrel-arbor of the small repeating-train, serves to wind up the spring when the clock is to repeat.

§ III.—*Clocks Striking the Hours and Quarters, and Repeating by the same Movement.*

The invention of these clocks dates almost from the birth of clockmaking, when watches and clocks were constructed, which performed these four functions, including the division or measure of time, and were therefore called watches or clocks of four parts. One of these pieces has fallen into our hands which formerly belonged to the Bishop of Montauban in 1784; we shall speak of this in our Chapter on Escapements. As any license may be permitted in order to obtain a good construction, we shall not hesitate to change the dial-work, with the sole design of the improvement of the art.

Figure 1, Plate III., shows this dial-work. The two racks, A and B, have a common centre in C. They are adjusted in the following manner:—the rack A bears an axle on which it is riveted, and two pivots, one of which revolves in the pillar-plate, and the other in a bridge fixed upon the pillar-plate by a good screw and two chicks; this rack is very near the pillar-plate, room being given for sufficient play. It carries twelve teeth, saw-formed and shallow upon the convex surface, and bears internally upon the concave surface twelve other ratchet-teeth, more projecting than the first.

The rack B is riveted upon a brass socket, whose aperture is well adjusted to the cylindrical rod of the arbor of the rack A, which passes beyond this rack. Room enough is reserved between the two racks for a sufficient play, so that they may not rub against each other. They are both in a frame between the bridge and the pillar-plate. The rack B has but three teeth on the outside and inside, resembling those of the rack A.

The rack A bears an arm, D, fixed upon it by two screws; this arm, when the rack is free, falls upon the hour-snail, carried by the star-wheel, E, and thus regulates the number of strokes which the clock should strike.

The rack B also bears an arm, F, fixed by two screws upon this rack in the same manner. This arm falls upon the divisions of the quarter-snail, G, and determines the number of quarters to be struck.

A detent, H, which is continually pressed towards the racks, I, retains the teeth of the racks in proportion as they are raised up by the two teeth of the pinion, J, carried parallel to the movement by the prolongation of the rod of the locking-wheel; this bears two pins diametrically opposite, designed to arrest the train when the hook of the detent, entering into the last and deepest tooth of the racks, permits the piece, K, which is riveted upon the detent, after having traversed the pillar-plate and penetrated into the train, to present itself before one of the pins of the locking-wheel and to stop the action.

The pinion, J, also carries a piece in the form of an S, which serves to raise up the detent, as we shall see.

The piece L is the principal detent, which sets the whole machine in motion, when it acts by the impulse of the movement. This piece has its centre of motion at the point *a*, upon a small axle, supported by the pillar-plate and a small bridge. It is continually impelled to move forward; that is, towards G, by the effort of the spring *b*. This detent bears by a hinge, at the point M, the horizontal piece, M N O. This last piece detains the train in the following manner: The piece, L M, bears an arm at *c*, which is on an inclined plane on the side of L, and is cut horizontally in the direction of the centre, G. The minute-wheel, which passes under the quarter-snail, G, bears four pins, placed towards the four extremities of two diameters, and perpendicular to each other. Three of these pins consecutively are a little nearer the centre than is the fourth. These three pins only push the detent, H, far enough to permit the passage of the quarter-snail; the fourth permits the detent, L, to push it still farther, the two racks then fall at the same time; that of the hours falls and strikes the hours, while that of the quarters is sustained by the snail and thus strikes no quarters after the hour. We shall see in a moment the difference necessary to cause it to repeat.

The detent, L, in springing back, draws along the horizontal piece M N O. We see that at the point O this piece is narrower, and presents a sort of step. The piece L M, in springing back, by the effect of one of its four pins, causes the notch, O, to fall in front of the upper part of the detent, H, and when the pin has passed, the spring, *b*, pushes the piece L M, and, consequently, the piece N O; this forces the detent, H, to recoil, disengages the train, and lets fall the racks. The teeth, J, then lift up the racks, the piece in the form of an S, which they carry, raises the part N O, and hinders it from catching the detent, H, until all the hours and the quarters shall have finished striking; the detent, H, then advances as far as the last and deepest tooth of the rack will permit, and the pallet, K, stops the train. By drawing the detent, H, backward, by the cord, *d*, the racks are disengaged, and the train of the striking-work first sounds the hours and then the quarters.

When the hour-rack has finished its course and is elevated as much as possible, it encounters the end of the arm, *f*, which connects the knob of the quarter-hammer with the pins of the third wheel in order to make it strike double blows at each quarter. This is done in the following manner: The arm *f g h* (Fig. 2), movable upon the point *i*, behind the small pillar-plate, rests by the point, *h*, upon the end of the pivot, *m*, of the knob of the quarter-hammer; the other pivot, *l*, rests by its point upon the end of the spring, *k*, in such a manner that when the rack, A, is at the highest part of its course, as represented in Fig. 1, the arm of the lever, *h*, is pushed forward, the arm, *n*, comes in contact with the pins, and the knob, *p*, causes the hammer to move. But as soon as the rack, A, falls, the spring, *k*, repels the knob, it disengages itself from the pins, and the hour hammer strikes but one blow at each hour.

We know of nothing more simple than this construction which has been generally adopted, and which is an application of the system followed from time immemorial in the Comté clocks.

CHAPTER III.

OF LARGE OR BELFRY CLOCKS.

It is about a century since the advantage which is gained by placing all the wheels of a large clock on the same horizontal plane, instead of arranging one above another in a vertical frame, as had been previously done, was first perceived. This construction lessens the height of the frame, and renders the friction slighter, and the gearings more constant and less apt to vary from wear. We do not intend to speak at length concerning belfry clocks, but shall only describe the remontoirs which are adapted to these clocks, and which tend to increase the regularity of the working of the movement.

The remontoir in clocks [see Berthoud's *Histoire*, vol. ii. p. 40] is a very ingenious mechanism, designed to obtain a perfect equality for the power which keeps up the movement of the regulator, so that this force shall not share in the inequalities of the gearings and the frictions, or in that of the mainspring, and consequently shall maintain a constant equality in the extent of the arcs of vibration of the regulator. To accomplish this, two motive powers are employed. The first is that which turns the wheels of the train; this is wound up by the hand every day or once in eight days; the second motive power, on the contrary, is renewed every instant, or at very short intervals by the first motor, so that it is regarded to be constant and equal in action. We shall call this mechanism the *equalising re-*

montoir, in order to distinguish it from the ordinary remontoir of clocks.

The ancient artists who occupied themselves in perfecting the balance of clocks, long since perceived the necessity of preserving to this regulator arcs of an equal extent, in order to obtain for the clock all the accuracy of which it was susceptible. It is to this idea—alike happy and just—that we owe the first invention of the remontoir, or of a secondary remontoir, designed to render the force which sustains the movement of the pendulum perfectly equal and constant; so that it may not participate in, or be affected by, the unequal forces which cause the variation in the friction of the pivots of the movement, of the gearing, or in the inequality of the motive power. We owe the first idea of this mechanism to Huygens, who made use of it in the first marine pendulum clock; Leibnitz, after him, proposed the same method; Gaudron and other artists have also used it; and Thomas Mudge, the celebrated English artist, invented, in 1794, the best remontoir then known. Finally, in our own time, the celebrated Breguet has given us, under the name of the *escapement of constant force*, the best remontoir now in use.

This ingenious mechanism is now generally adopted in the construction of all large clocks. A beautiful clock, executed by M. Wagner, has attracted the attention of connoisseurs. The train of the movement had no action on the escapement-wheel; it was only occupied in winding up, once in two minutes, a small weight which acted directly upon this wheel.

A very beautiful clock, with an equalizing remontoir, may be seen at the *Palais de la Bourse* in Paris, which was executed by M. Lepaute, with great perfection, by a different method from that of M. Wagner, but performing the same functions.

Hitherto, they had only succeeded in sounding the four quarters before the hour, by employing two trains for the striking-work, one of which struck the quarters, and the other the hours. This movement detained the train of the quarters; the latter at each hour, after having struck the quarters, disengaged the detent of the train of the hours, which then struck the hour separately.

M. Raingo, sen., a clockmaker of Paris, occupied himself with the solution of this problem; he executed, in 1828, an apartment-clock which had but two trains, and which struck the hour, the quarters, and the four quarters before the hour, with precision. This clock has a circular balance, with an Arnold detached escapement. It marks the hours, the minutes, the days of the month, the days of the week, and the phases of the moon. This clock is described, with figures, in the *Bulletin de la Societé d'Encouragement de Paris*, of the month of April, 1828. We give here a fragment of the report made to this Society relative to the most important piece of this movement, which is very simple.

"The hour-snail is cut as in the ordinary clocks striking three quarters, and there is besides a sort of *surprise*, formed by a movable snail, which is joined together beneath the first, and drawn along in its general rotation. This movable snail remains unused except when necessary to strike the four quarters. The striking-work is regulated by a notched rack, in the manner of the Jura clocks; the detent, which abandons it for a time, causes it to rest upon some point of the circumference of the snail, and by entering then into a notch, the range of the descent determines the number of teeth passed, and, consequently, the number of blows of the hammer; the whole being in conformity with the mechanism generally in use. When the turn of the four quarters arrives, the time comes for the action of the surprise or movable snail; a detent displaces it and it finds itself in another position. The principal merit of the invention consists in this ingenious surprise; it will be seen that the clock will not miscount in the striking of the hours. This is the case with the Jura clocks which, in this respect, have served as a model to the author. Finally, a movable detent presents itself in such a manner as to permit but four blows to be struck in the parts of the snail where the surprise is not needed; for this is only useful at four hours after noon on account of the arrangement of the notches of this piece."

This invention is principally used in belfry-clocks which are designed to strike four quarters before the hour. The arrangement is rarely used in mantel or apartment clocks.

CHAPTER IV.

THE WORKMANSHIP OR EXECUTION IMPORTANT PARTS OF TIMEPIECES.

I.—*Of the Metals used.*

Steel and copper (commonly called brass) are the two metals exclusively employed in the manufacture of all the pieces composing watches, mantel and apartment clocks, and regulators, not even excepting chronometers. Of course we do not now refer to the cases which enclose the movements, and whose execution does not belong to watch-makers.

Steel.—The clockmaker only uses cast steel, as it is the purest and most homogeneous. This may be obtained in all the forms used, whether in flattened plates of various thicknesses, or draw-plates, either for wires of every size or for pinions of every number and dimension, according to the general use. This steel is rarely flawy, and one might almost choose it blindly.

Brass.—But such is not the case with brass; this metal is not found originally in the mines, but is a product of art; it results from the alloyage of zinc with the red copper, known as rose or refined copper, the best of which comes from Sweden. If tin is added to this alloy, a greasy metal is formed which is difficult to work; it sticks to the file, and, when the proportion of tin is large, it becomes so hard that it is almost impossible to work it—it is absolutely bell-metal.

When, in the composition of brass, the rose-copper is alloyed with seven per cent. or more of zinc, and a small quantity of lead is added, a dry alloy is obtained which is turned and filed with great facility. It is necessary, however, to be very sparing in the use of the lead, and careful in its choice as it must be very pure. From several experiments made with a view of obtaining a brass suited to clock-works, I am convinced that not more than one per cent. of lead should be used. When a larger quantity is employed, grains are formed which, though often very small, are so hard that the file takes no effect on them. It is especially necessary to avoid the introduction of molecules of iron or steel into the composition of the alloy, as they destroy the quality of the brass, and acquire so much hardness in the fusion that they will resist the best file and cut the hardest steel.

We do not doubt that the bad quality of the brass, of which the clockmakers complain so much, proceeds from the causes which we have just mentioned, and that, if some intelligent metallurgists would take the necessary pains, they would succeed in finding an alloy which would procure a perfect brass for the use of clockmakers. From numerous experiments which we have made, we have obtained an alloy composed of

85	parts of pure rose-copper.
14	parts of pure zinc.
1	part of pure lead.
100	parts.

This alloy, which we have not been able to make on a large scale, seems to us to contain just the proportions.

II.—*Of the Fusee.*

The invention of the fusee, which Pierre Leroi, and, after him, Ferdinand Berthoud, unceasingly eulogized, is a mechanism which is infinitely useful in watches in rendering the action of the spring equal to that of a motive weight. It has been generally adopted, yet it has several inconveniences which it would be exceedingly desirable to remedy.

It was thought that the dead-beat escapement of Tompion, in 1695, might obviate the necessity of the fusee, and this idea, renewed whenever a new escapement was invented, and then contradicted by experience, has been revived in our day by some celebrated watchmakers, who have suppressed the fusee in their works.

The detached escapements seem best suited to correct the inequalities in the mainspring, and to revive the hope of suppressing the fusee without affecting the accuracy of the watch. Many unsuccessful attempts with these have been made, but Berthoud has proved that no escapement can have any influence over the mainspring, and, consequently, that it cannot correct the inequalities of the motive-power from being transmitted to the balance, whose velocity is retarded or accelerated in conformity with the irregularities of the mainspring.

Let us point out the inconveniences of the fusee, and compare them with the advantages which it possesses.

1st. Without the fusee the spring would act directly upon the wheel-work; the frictions are at least doubled by the fusee. If there was no fusee, the great wheel would be carried by the barrel or its arbor, and the spring would only have to overcome the resistance opposed it by the frictions of the two pivots of the arbor, in order to transmit the movements to the large centre wheel; but when there is a fusee, the spring has first to overcome the resistance of the frictions upon the two pivots of its arbor, and then the frictions of the two pivots of the fusee-arbor. Now as these two arbors, having nearly the same diameter, oppose an equal resistance, the fusee consequently doubles the frictions, and it would be easy to demonstrate that it augments them in a much larger proportion.

2d. The friction being augmented by the use of the fusee, a much stronger spring is therefore necessary. Now every one understands that in order to strengthen a spring, its breadth remaining the same, its thickness must be increased; but this augmentation of thickness injures the spring, and makes it more easily broken, or sooner worn out.

3d. The spring breaking, it becomes necessary to replace it with another, and every good clockmaker understands that he cannot then dispense with equalizing the fusee anew, if he does not succeed in finding a spring precisely like the first, which is morally impossible. If this accident happens three or four times, it will be necessary to replace the fusee, and every workman knows the trouble which is experienced in replacing a fusee in towns far removed from the manufactories.

4th. The fusee necessitates a chain, a chain-guard with its spring, and a hook of the fusee; and the adjustment of all these pieces exacts certain precautions, which are so far beyond the skill of most workmen, that we rarely see watches in which the union of these pieces is perfectly executed—whence come the frequent breaking of the chain upon winding the watch.

5th. In short, one has to run two chances for the derangement of his watch, either the breaking of the spring or of the chain.

The only advantage which the fusee possesses in watches is that of rendering the effect of the mainspring equal through its course.

The following advantages are presented in a watch without a fusee:—

1st. Less friction in the transmission of the motive power.

2d. The spring need not possess more than half the strength ; its bands will therefore be thinner, it will be less apt to break or to wear out, it can be longer, and its effect will be surer and less unequal.

3d. In suppressing the fusee, all the pieces of the chain, the chain-guard, and the hook of the fusee are also suppressed ; we thus have a smaller motive power and a larger space in the frame by which to give the wheels the necessary play ; we can construct the watch more easily and to better account.

4th. In the repeating, striking, carillon or alarm watches, in which the want of space exacts the multiplication of the wheels of the movement of the striking-work on account of the little room which can be given to each of them, a great advantage is gained by the suppression of the fusee. The number of wheels will thus be reduced as a greater diameter can be given them ; they will work more easily, and the small spring can be longer, with a thinner band, and consequently better. The potance can preserve the form which it bears in simple watches ; it will be more easily made, and the workmen will be able to diminish the price of their works.

We may infer from the preceding facts that the invention of the fusee in watches, while correcting an essential fault, the inequality of the force of the mainspring, has introduced a number of inconveniences which its suppression would certainly remove, especially if the fusee could be replaced by some simple mechanism independent of the movement. These reflections suggested to us the idea of the construction which we shall now describe, and which we have published in the *Annales des Arts et Manufactures*, vol. xix. p. 72.

Explanation of Figure 3, Pl. III.

The barrel-arbor enters squarely into the central hole of the pinion, A, of 8 leaves; this arbor is turned with a key to wind the watch.

The pinion, A, turning to the right when the watch is wound, causes the wheel, B, B, to turn to the left. The latter bears a curve, C, fixed invariably with it in such a manner as to follow all the movements of the wheel. The points of the outline of this curve are at unequal distances from its centre of rotation, I; from the point, D, which is farthest removed from it to the point, E, which is the nearest it.

Against the sides of this curve a strong spring, G, F, acts continually, which is fastened to the point, F, by a screw. This spring, G F, bears at its extremity, G, a flange-roller, whose two sides surround the body of the curve so that it cannot quit it, and the curve rubs upon the bottom of the roller, which is flat, and rests continually upon the curve with a view of diminishing the friction.

The screw, H, which we see placed at the extremity of the fixed part, F H, of the spring serves as a catch to it, and also gives the facility of augmenting or diminishing the force of the spring, F G, as circumstances may require. The screw, H, which has a neck, may be placed in several different ways; it is either placed as in Figure 3, entering freely into the arm of the spring, and is wormed into the border; or it enters freely into the border and is wormed into the arm of the spring. In both cases the same effect is produced in fastening the screw; the arm, H, is drawn towards the border and a greater force is given to the spring; in loosening the screw a contrary effect is produced. The second arrangement is often the more convenient on account of the pieces which, being upon the pillar-plate, might destroy the effect of the turn-screw. A circular form may also be given to the screw by causing it to follow the outline of the border. As to the rest, the principle being once described, the form can easily be varied.

The two concentric dotted circles, K, K, indicate the arrangement of the barrel fixed by two screws upon the pillar-plate, and of the great movement-wheel, that is carried by the barrel-arbor which we see proceeding squarely from the centre of the pinion, A. We know that a main-spring should not be too much bent, and that it should not be able wholly to unbend itself. In the one case it would be apt to break easily or soon wear out; in the other, it would be in danger of unhooking itself from the barrel-arbor. To avoid these two inconveniences, when the fusee and the chain-guard are not used, a stop-work is commonly substituted.

Our mechanism includes all these conditions; the wheel, B, B, bears a large tooth against which a leaf of the pinion, A, props itself when the spring is bent or when it is unbent. Let us suppose that the spring can make six turns, and that but four turns of the great wheel are necessary to make the watch go for thirty hours. We should therefore give eight leaves to the pinion, A, and thirty-four teeth to the wheel, B, B, taking care to cut off but thirty-two of them; by this means a large tooth will remain which will leave to the spring a turn of the band in these two extremes.

The invention which we have just described must not be confounded with another mentioned by Ferdinand Berthoud (in his *Histoire de la Mesure du Temps par les Horloges*, vol. i., p. 77). This dates back to the fourteenth century, before the first use of the fusee, and *perhaps suggested it*. In this invention a straight spring, with the aid of a curve, opposed itself to the action of the main-spring when it was at the top of its band, and increased its action when the spring, being at the bottom, acted more feebly. Let us see the difference which results from these two constructions.

In our invention when the main-spring is at the maximum of its tension, the point, D, is beneath the roller, and the spring, F, G, is likewise at the maximum of its tension; the latter acting upon the large arm of the lever, destroys a part of the force of the main-spring. When, on the contrary, the main-spring is at the minimum of its tension the point, E, is beneath the roller, and the spring, F, G, which is also at the minimum of its tension, can no longer produce any effect upon the main-spring, which acts with all its remaining force.

Our mechanism differs essentially from the ancient method in this arrangement. In the ancient the spring, F, G, was subtractive during a certain time, after which it became additive; while in ours it only acts as subtractive.

1st. The double effect which we perceive in the spring of the ancient construction would be more difficult to execute and could not be very sure; this was probably one of the reasons which caused its abandonment. 2d. The curve should produce the same effect as the fusee which has replaced it; now the fusee does not produce this double effect which they professed to obtain by the aid of the curve. When the spring is at the maximum of its tension, it acts upon the fusee by the smallest arm of the lever, which augments in proportion as the main-spring loses its force; the curve should render the force of the main-spring equal, with the aid of the spring, F, G, by acting in an inverse direction to the fusee. The subtractive spring should oppose to the main-spring a greater resistance as the latter is tightened, and this resistance should diminish in the same proportion as that of the main spring diminishes. This is the effect produced by our curve when it is correctly made.

Some details respecting the manner of executing the curve and the *subtractive* spring, seem to us to be useful. The rod which carries the wheel, B, B, is terminated by a square, and it is by this square that the curve is carried; it is fastened there by a pin which passes through the square, and we thus obtain a facility of taking away the curve whenever necessary to cut it, and of replacing it without trouble. The curve should be of steel, its diameter, before being cut, is equal to the internal diameter of the wheel, B, B, and between this wheel and the curve a round shield of brass should be placed to separate these two pieces, so that the roller may not rub upon the wheel, B, B. The spring, F, G, should be as high as possible; it should neither rub upon the pillar-plate nor upon the wheel, B, B. At its extremity, G, it bears the brass roller, which turns loosely upon its axle and continually rests upon the curve.

The thickness and the force of the spring are determined by the force of the main-spring, but as we have observed that, in suppressing the fusee, we do not need as strong a main-spring, but can use a long spring with a thinner band, this spring, therefore, being weak, does not require a strong compensation-spring. This should insensibly diminish in thickness, so that it may be elastic through its whole length, and its movement should always be directed towards the centre, I, of the wheel, B, B. To determine the length of this spring we should describe an arc, G, I, from the point F, the centre of its movement, with F I for the radius, which will determine the length, F, G, of the spring, with sufficient precision; the centre of the roller should always be found in the arc, G, I.

All being thus arranged, we proceed to the cutting of the curve. For this, the main-spring being quite down, give it a turn upon its arbor and turn the wheel, B, B, until it presents the large tooth to the pinion, so that the latter stops the return of the pinion backward and leaves the spring bent in one turn, which is the minimum of its tension. Take away the steel plate, which should be cut in a spiral form, and bring the roller of the spring as far as the centre, I, of the wheel, B, B, by the aid of the screw, H. Replace the curve after loosening the screw F enough to give to the *subtractive* spring the liberty of passing over the curve. Let it loosely approach the centre, I, and mark the point which the roller reaches. Then wind up the main-spring, which again should have a turn of the band at the point in which the tooth of the pinion is checked by the large tooth of the wheel. Place the *subtractive* spring in such a manner that the roller may be on the edge of the curve, encircling it, and mark the point at which the roller is found. The last point corresponds to the point D, and the first to the point E. Divide the surface of the steel plate which is to form the curve into eight or ten nearly equal parts, and trace as many radii to the centre I. Then, after having well fastened the screw F, remove the matter in the direction of each radius by the aid of a round file until you find an equality of all the points of this spring by means of the arm for equalizing the fusee, which is placed on the arbor of the main-spring. This preliminary executed, pass a curve over all its points, then remove the superfluous matter, and the curve is nearly finished; then rectify it and polish the edges.

We see with what facility this curve is cut; it is isolated and can be removed without taking the frame to pieces. The place in which it should be touched can easily be seen; while to equalize a fusee, it is necessary to dismount the whole, often working at random and rarely sure of what has been done.

The late M. Breguet knew nothing of this invention until the eve of his death. He spoke of it to us and from the description which we gave him, he approved it, and promised us that he would execute it, but his death prevented the performance of his promise.

III.—*The Barrel.*

In all watches, whatever may be their construction, the barrel should be as large and as high as the caliber will permit. The best spring is that which is largest, with the thinnest band; it thus becomes longer, the motive-power is less irregular, and it is less apt to break.

Whatever system may be adopted—whether the fusee is retained or suppressed—a curb should always be given to the spring. This piece is a small steel band which is placed at the inner edge of the barrel, entering by one of its ends into the bottom of the barrel and by the other into the cover; it is placed at nearly a quarter of the circumference of the barrel, reckoning from the hook which fastens the spring to the barrel. This curb, which Figure 14, Pl. I., represents at *a*, at the side of the barrel-arbor B, whose hook is seen at *d*, causes the first band of the spring to rest against the barrel, and thus protects the eye of the spring from injury. This eye cannot be made until after having annealed the extremity of the spring, which, in this part, has lost its force and elasticity. It is very important that its action should commence when the spring preserves its good qualities.

The method which we have described in detail in the preceding paragraph can be executed in the different systems of watches which have been adopted, both in the common balance-wheel and the Breguet system. It is only necessary to make a slight change in the barrel, which should be fastened by two screws to the pillar-plate, or to a bridge like the small spring of the train of the repeater; and its arbor, as in the same train, should carry the great wheel and the click and spring-work. The other pieces are beneath the dial and do not dispense with the use of the different stop-works of which we are about to speak, and which have been happily substituted for the chain-guard.

IV.—*Stopworks of the Remontoirs.* Pl. III.

We designate, under the name of stopworks, those constructions which have been adopted in watches and clocks, to replace the chain-guards, or to regulate the number of turns which should be given the main-spring.

Independently of that which we have adopted in our mechanism for the suppression of the fusee, several other kinds of stopworks have been invented which it is important to understand.

1st. That represented in Figure 4. A round-shield, A, is placed upon the square of the fusee or barrel-arbor, and at its side is a star-wheel, B, carrying as many teeth, plus one, as the number of turns that the fusee should make. The round-plate, A, has a plate in its centre which is elevated to the thickness of the star-wheel, whose teeth are very large: these teeth are all depressed or filed in hollows in their middle, D, except the last, C, which is rounding. A steel tooth is fixed upon the round-plate at the point E, this pin works into the clefts of the star-wheel. At each turn of the round-plate, A, it passes one tooth of the star-wheel; the middle of this tooth encounters the base of the round-plate which enters into its hollow and prevents it from turning; but when the convex tooth, C, arrives, it can no longer pass, and the stopwork is formed.

2d. Another surer and more ingenious stopwork has been invented, whose construction is shown in Figure 5. A wheel, A, is placed squarely upon the fusee-arbor; this square also bears a tooth or arm, B. The wheel A has twelve teeth, this works into a wheel, C, of ten teeth which carries an arm, D. After the fusee has made five turns and the wheel C has made six, the two arms, B and C, meet and prop against each other, thus forming a stopwork without wearing the teeth of the wheels.

If we should place the wheels in a contrary direction without changing the numbers; that is, if we should place the wheel C upon the fusee, and the wheel A at the side, the fusee would make six revolutions before encountering the stopwork. The numbers may easily be varied at pleasure to obtain the stop at the desired moment.

3rd. Figure 6 indicates a kind of stopwork invented by Lepine for very flat watches. A flat-bottomed cavity, *a*, is made in the pillar-plate, or rather in the cover of the barrel, as these watches have no fusee, in the middle of which a large drop is left in order to lodge therein a sort of spring in the form of the wheel B, cleft at *b*, and which enters into this cavity like a cover of a barrel; on the opposite side, at the cleft *b*, as many teeth are made as are needed for the number of turns required for the spring. A steel wheel, A, cut in cogs, is placed upon the arbor; a steel pin, *c*, is fixed in this wheel, which works into the teeth of the spring-wheel B, upon which it passes; when this pin encounters no more teeth the stopwork is formed. This cog-wheel serves for the stopwork; the click and spring are fixed upon the pillar-plate or the bridge.

These stopworks, which are those most in use, can be varied in a thousand different ways, and may be adjusted to the fusee, or to the barrel when the fusee is suppressed.

V.—*Of Workmanship in general.*

We shall not go over all the pieces of clockwork, in order to describe the construction of each of them. As it is impossible in this art to replace by a book the practical advice which a good master can give in a sufficiently long apprenticeship, we will limit ourselves to giving some advice which will be useful at least to beginners.

Of the working of brass.—When the best brass that can be procured of the required thicknesses has been chosen, it must be remembered that in this state the metal is too soft, and that it can only obtain the necessary hardness and tenacity, by being forged when cold with a good hammer, upon a hard, smooth hand-anvil. A plate of the metal of twice the thickness required for the piece, and of a little more than half the size indicated by the caliber, is first sawed. After having scraped the piece, that is, after having filed each surface with a rough potance-file, the piece is stretched in both directions and on both surfaces by successive blows with the face of the hammer, until it shall have acquired the dimensions fixed by the caliber, care being taken to remove with the file the smallest cracks which may be perceived on the edges, as they frequently affect the whole piece and render it defective. These cracks are generally caused by the unskilfulness of the workmen. There is another defect which should be avoided: that of bruising the brass and making it rise up in puffs. This fault is occasioned by too heavy blows, carelessly or falsely struck, and cannot be remedied. Such a piece is spoiled.

We have seen some apprentices who, in forging small pieces, such as small wheels, cut their brass too large for fear of striking their fingers with the hammer. They content themselves with levelling it, leaving the piece double the required thickness; they are then obliged to remove all the superfluity, and their piece becomes soft. They are probably ignorant of the fact that the brass only becomes hardened in the surface which comes in direct contact with the hammer, and that when the piece is too thick they remove all the hard surface with the burin. The forged piece ought to be as nearly as possible of the required thickness; it should be cut as straight as possible, and when it is turned round and of the proper size, a light stroke should be made upon the two surfaces and the edges to indicate that it must be filed in order to render it perfectly straight.

Of the working of steel.—Nothing but cast-steel of the first quality should be used, and care should be taken in hardening it not to give it a greater degree of heat than a cherry-red, and to harden it in oil. Hardening it in water at this degree of heat would be apt to make it too brittle. Care should also be used in the tempering that each piece does not exceed the required color, so as to obtain the degree of hardness best suited to the uses for which it is designed.

All that we have said in this paragraph applies to both clocks and watches.

CHAPTER V.

OF GEARINGS.

By *gearings*, we mean a system of wheels and of pinions whose circumferences are covered with teeth, and which act upon each other in such a manner that the movement given to one of them is communicated to all the rest by means of the teeth of wheels which enter into the teeth of pinions, the diameters of which are in a given proportion to those of the wheels. It is very essential that the *gearings should be perfect*, to cause the machine to go with a regular movement.

"*Perfect gearings*" possess the following conditions: 1st. That the force employed by the wheel which conducts the pinion shall be as slight as possible. 2d. That the velocity with which the wheel impels the pinion shall also be, at every instant, as great as the wheel is capable of giving to it. 3d. That this force and this velocity shall be constantly the same from the point of meeting until the moment in which the tooth of the wheel abandons the leaf of the pinion and *vice versa*. 4th. That the friction of this tooth, during all its course, shall also be as slight as possible.

All clockmakers know that the curve which affects the teeth of the wheels and the pinions is called the *epicycloid*, but very few understand the nature of this curve or the manner of tracing it. This knowledge may not be so important to them in respect to the workmanship as it would otherwise be, since the teeth of the wheels of the watches and clocks and of the leaves of their pinions are too small to permit them to give them precisely the form of an epicycloid. Yet this curve, traced on a large scale, will give them the idea of the form which these teeth should have, however small they may be, and they will seek to approach it even if they are not able to exactly obtain it.

Experience has taught us that the most interesting class of clockmakers—the workmen who execute the machines designed to measure time—are the least instructed in the science which alone should serve as their guide. The most of the workmen who have consulted us on the part of which we now speak, after having read one, or, at the most, two pages of a book which we regarded as perfectly intelligible, have frankly told us that the language used by the author was above their comprehension. When they perceived the least proportion, the slightest formula, or the smallest sign, they closed the book and would no longer consult it. Yet, on taking up the author which they had thrown down, and simply reading the text to them, suppressing the formulas, they easily understood it. Adopting the hint, and availing ourselves of the works of the best authors on gearings, we hope that they will read with profit.

Of the Cycloid.—If along the straight line, C D (Fig. 7, Pl. III.), we turn the flat cylinder, A E, placing a small projecting point upon the point A of the circumference, and taking care that it does not glide off, this point will trace on the plane which bears the line, C D, a curve, A B E A; this line is equal, therefore, to the circumference of the cylinder, or of the *generant circle*, which has traced this curve, called *cycloid*, and which serves to find the form required for the teeth of a wheel or of a pinion, which works into the teeth of a straight rack.

The curve which we have just shown, is described after the same method as that which we shall explain for the epicycloid.

Of the Epicycloid.—When a flat cylinder, S (Fig. 8), or a circle, turns upon the outer circumference of another circle, C M D, with the same conditions as in the *cycloid*, the curve, C E D, which the point describes upon the plane, is called the *epicycloid.* If the same *generant circle*, A, instead of revolving over the outer, or convex circumference of the circle, moves in its inner circumference of G to H, the point describing E, which is a part of the point G, will describe another kind of epicycloid, G E H. The first of these two epicycloids is known as the *outer epicycloid*, and the second as the *inner epicycloid.* The first serves for the teeth of the wheels and pinions which are generally used, and whose teeth are placed upon the convex circumference of the wheels and the pinions; the second, which is very rarely employed, serves for the teeth which are placed upon the inner circumference of the wheels.

It would be a great mistake to suppose that the figure of the epicycloid should be employed, as a whole, to indicate the form of the teeth of the wheels. But a part of the beginning and a part of the end of the curve, according to the size of the tooth, is taken for this purpose. When this size is known it is marked upon the *primitive circle*, C M D, of the wheel, from the point C to F, for instance; the other half, E D, of the curve is then moved in such a manner that the point D falls upon the point F; these two demi-curves cross at the point H, and all beyond this point is useless, and is cut off; the rest, that is, C H F, gives the form of the tooth which projects beyond its *primitive circle.*

Before describing the method of tracing a cycloid or an epicycloid by points, let us explain the meaning of the term, *primitive circle.*

If we conceive a circle, J K (Fig. 9), which represents a wheel without teeth, and the small circle, N, a pinion without leaves, which meet at the point M, so that the wheel conducts the pinion by the simple contact of its circumference, in such a manner that the pinion may be always obliged to turn by the simple movement of the wheel, we then give the name of the *primitive circle* of the wheel to the circle, J M K, and that of the *primitive circle* of the pinion to the circle, N. It is only necessary to add the teeth to these to give them the names of wheel and pinion, as we see in Figure 9.

The cycloid or the epicycloid is traced by points in the following manner. The primitive circle, A B C, of the wheel is described (Fig. 10); above it is the circle E, whose diameter is equal to double the radius of the primitive circle of the pinion, and which touches the first circle at the point B, for instance. Twelve very small equal parts are then taken on the large circle from B to C, beginning at the point D, and insensibly diverging from a straight line. With the same opening of the compass, beginning at the point B and going towards D, as many points are marked on the small circle as had before been marked on the large one. The first radius, P B, is then traced, which should be prolonged until it meets the circumference of the generant circle, E. Through the centre of the great circle and through the six divisions (which are supposed indicated by the following figures, but are not traced on the figure to avoid confusion), 2, 4, 6, 8, 10, and 12, of the large circle, prolonged radii are traced like the radius, P B. Upon each of the prolongations of these radii, and with the same opening of the compass which served to describe the circle E, the six demi-circumferences pounced in the figure are then described. The first of these circumferences has two divisions, and a point is marked on the second; the second has four, and a second point is marked on it; the third has six, always counting from the point of contact of the two circles; the next bears eight divisions; this point is also marked, continuing thus unto the last. A curve is then passed through these six points, and a portion of an epicycloid is thus obtained, which is longer than is needed for the form of half of the tooth.

As the other half of the tooth should be precisely the same but placed symmetrically, it is only necessary to copy this portion and place it on the other side, reversing the copy as the side-figure represents it, and suppressing all that exceeds the point where the two curves meet. This is done in the following manner: When the requisite size of the tooth is found, which is easily obtained by dividing it in such a manner that it shall have at least as much fulness as depression, we will suppose it equal at F G, we rest the curve upon F, and the other symmetrical part on G, and their junction indicates the length of the tooth beyond the primitive circle. The two parts, F H, and G I, are called the flanks of the tooth, and serve to lodge the curves of the leaves of the pinion. The points of the teeth of the wheels and the pinions are rounded; the effect of the gearing is seen in Figure 9.

All that we have just said in relation to the form of the teeth of the wheels, equally applies to the leaves of the pinions, whether they carry or are carried. The sole difference consists in the pinion having more depression than fulness, and that in every case the half of the primitive radius of the piece worked, that is, of the wheel or pinion of which the form of teeth is to be found, should be taken for the radius of the generant circle.

The epicycloid gives the best form for making a good gearing; but this is not all that is needed to obtain a perfect gearing. For this it is also necessary that when the two pieces work into each other, the tooth of the one which carries the other begins to touch its tooth in a right line, which is called the *line of the centres*, that is, the line passing through both the centres of the pieces which work into each other. Pinions which have but few leaves never possess this advantage. The learned Camus, who has expatiated at length on this subject, has proved that pinions having less than eleven leaves present this difficulty, and that it is greater in proportion as they are less numerous. One is, therefore, obliged to make them weaker, and to file the pinions very thin to prevent them from scotching. We recommend this important treatise to the notice of the reader; it may be found in vol. ii. of his *Mécanique Statique*, p. 355. The treatise of Delalande, on the best form to give to the teeth of wheels and to gearings, may also be read with profit in *Traité d'Horlogerie*, p. 230, by Lepaute.

We shall conclude this chapter with a judicious observation of Camus, which confirms what we said in the beginning of it.

"1. Although the rules that have just been given for the formation of the teeth of wheels and of the leaves of pinions can only be practised when the teeth are at least five lines in width and five lines in length, reckoning from the primitive circle, they will not be useless to artists who make finer teeth than these, because having the figure of a large tooth which they wish to copy in miniature before their eyes, it will be more easily imitated.

"2. As one cannot hope to form the teeth with all the equality and precision which are necessary in order that the primitive circumferences of the wheel and the pinion shall always turn with the same velocity; as some teeth will not conduct the leaves which they should impel as far after the line of the centres as is needed, and as this may result in the propping of the leaves against the flanks of the teeth, the artists may prevent this difficulty by making the primitive diameter of the wheel a little larger than it should be, relatively to the pinion.

"3. By means of this increase of the diameter of the wheel, which should be proportionate to the defects which may be feared in the teeth, the tooth which follows the one that pushes the leaf after the line of the centres, takes the next one a little more slowly; and, when the preceding tooth has impelled the leaf after the line of the centres as far as it can uniformly do, the wheel takes a little more velocity than it communicates to the pinion. This is a fault; yet this fault is less to be feared than are the abutments to which they would otherwise be exposed.

"4. It is evident that what has just been said respecting the increase of the diameter of the wheel beyond that which is necessary uniformly to conduct the pinion, supposes that the wheel will impel the pinion, when the pinion should carry the wheel. It is clear, therefore, that, in order to shun the abutments, the primitive diameter of the pinion should be a little larger than is necessary to conduct the wheel uniformly."

However a watchmaker may have reflected on the gearing of the crown wheel with the pinion of the escapement wheel, he must agree that this gearing is bad and very defective, and that the system long since adopted in Geneva and Switzerland, of passing the axle of the escapement wheel by the side of the axle of the crown-wheel, tends to render it still more imperfect. The pinion that gears into the crown-wheel can only form a better gearing by taking a conical form, according to the rules prescribed by Camus.

CHAPTER VI.

OF ESCAPEMENTS.

Under the name of *escapement* is designated the action of the last wheel of the movement upon the balance. By this action, the balance suspends the movement of the wheel during its own vibration, after which it disengages the wheel to permit the passage of one of its teeth, which, in its progressive movement, restores to the balance the force that it had lost during its vibration, or its preceding oscillation. This invention dates far back in the history of the horological science; the name of its author is unknown.

Escapements for Watches.

Two things should be considered in every escapement—1st, the lifting of the escapement; 2d, the arc of vibration of the balance.

1st. By the lifting of the escapement, we mean the number of degrees which each tooth of the wheel causes the balance to pass over, whatever escapement may be employed, from the moment in which it begins to act upon the escapement-piece until it quits it. The arc described between these two limits is called, the lifting of the escapement.

2d. By the *arc of vibration*, we mean the total arc described by the balance when impelled by the motive force which is transmitted to it by the teeth of the wheel; whence it follows that the greater the motive power, the more forcible will be the action of the tooth which transmits it to the escapement-piece by its inclined planes, or by its pallets, impelling the balance in such a manner as to cause it to pass over larger arcs of vibration; this is reversed when the motive power is diminished. We may therefore conclude that in these two cases the vibrations cannot be *isochronal*, since this word supposes that they have the same extent and that they are of equal duration. This simple reasoning will not require the support of experience to prove the error of those watchmakers who persist in maintaining that the dead-beat escapements correct the inequality of the motive force.

I.—*Balance-Wheel Escapement.*

This escapement, which is the oldest known, is the most simple and easily executed of any, and is found in the most ordinary watches; yet, as Ferdinand Berthoud has remarked, when one wishes to make it with all the art of which it is susceptible, it becomes very difficult, and few workmen are skilful enough to succeed in it. It has a crown-wheel, with an uneven number of teeth.

The balance-wheel escapement is *recoil;* that is, when a tooth of the wheel has given the impulse to the spiral spring, the latter, after the lifting of the escapement, presents to the following tooth an inclined plane during its arc of vibration, and causes the wheel to retrograde. But this escapement is so well known that it is unnecessary to describe it.

II.—*Cylinder Escapement.* Plate III.

The cylinder escapement was invented in 1720, by

Graham, a skilful watchmaker of London; it was not known in France, however, until the year 1724. It received its name from the fact that the escapement-piece is a steel cylinder, upon which the balance is riveted.

The cylinder-wheel is of a different form from the other wheels; it is canting, like a crown-wheel, but differs from it, especially in the form of its teeth. It is hollowed like a crown-wheel, and, when its height is fixed, a flange, sufficiently projecting to form the inclined planes which the wheel carries, is preserved on its exterior, on the top of its upper surface. When the wheel is thus prepared, a number of teeth double to that which is required, is cut with a thin cutting file; these may be even or uneven, at will. The teeth are alternately suppressed, and a circular form is then given to this space by means of a cutter, so that the inclined plane remains supported by a small column (as in Figure 11, which shows it in elevation, and in Figure 12, which shows it flatwise on a larger scale).

When the wheel is cut, it gives the outer and inner diameter of the cylinder. The length of each inclined plane gives the interior diameter, which is made a little larger in order to avoid the friction. The exterior diameter is equal to a cut-off tooth, plus twice the thickness of the cutting file used in cutting the wheel, so that the cylinder is of the same thickness as the cutter.

The cylinder in the part in which the escapement is made, is not notched in proportion to its diameter, but a little less; the projection which forms the inclined plane beyond the circle of the wheel which passes through the point of the inclined plane determines the size of the notch. When the tooth *b* (Fig. 12) is in the interior of the cylinder, the inclined plane, *a c*, forms the diameter of the cylinder.

The cylinder is generally made of tempered and highly polished steel; the two edges, *m* and *n*, upon which the escapement is made, are of different forms; the edge, *n*, by which the tooth enters the cylinder, is rounded, the edge, *m*, by which it goes out, is on an inclined plane. We set at *e* (Fig. 13) another and much larger notch at the bottom of the cylinder; this notch is only designed to permit the balance to vibrate freely without letting the cylinder touch the lower part of the wheel, as this would produce irregularity in the machine by diminishing the arcs of vibration.

The cylinder being finished as we have just described, brass cylinders or stoppers are adjusted about its two ends. Fig. 14 shows the upper stopper, and Fig. 15 the lower one. A rod of tempered steel is driven into each of these stoppers, at the extremities of which pivots are formed. These stoppers are now generally made of steel, of a single piece with the rod which turns them. The upper stopper A, carries at *b* the balance which is riveted there; the part *c* is designed to receive the ferrule of the spiral spring; the part *d* enters exactly into the top of the cylinder. When all is thus prepared, both for this and for the lower stopper *f*, the projecting parts in the interior are cut off on the lathe and the two stoppers are put in place; these should be so well adjusted as to be solidly fastened by a slight blow of the hammer. Fig. 16 shows the cylinder mounted.

The cylinder should be notched in such a manner that the lifting of the escapement may be twenty degrees at each impulse. Fig. 12, designed upon a large scale, will clearly show the arrangement of the wheel and the cylinder in the different times of the escapement. The tooth B, which rested upon the convex surface of the cylinder, begins to enter the cylinder; but the point *f* cannot reach the point *a* until the cylinder shall have made a circular movement on its pivots, determined by the projection of the inclined plane of the tooth B, and consequently until the edge, *a*, shall have reached *h*. Then the tooth B passes and takes the position

C, its point resting upon the concave surface of the cylinder, where it remains until the balance, having finished its arc of vibration, brings the cylinder back to the point where the tooth D presents itself. This process is the same as the preceding one, the point *g* cannot entirely depart until the inclined plane shall have caused the cylinder to retrograde in such a manner that its edge *r* may reach *s*; the following tooth, E, then comes to rest upon the convex surface of the cylinder, and the effect which we have before described for the tooth B will be produced when the balance shall have brought back the cylinder to the point at which we see it in B. The importance is obvious of having all the parts of the inclined planes of the wheel uniform and equal. We give a description in a following chapter of new tools designed to obtain this perfection.

The difficulty that has been experienced in finding brass pure enough for the wheels of the cylinder has caused the adoption of wheels of cast and tempered steel in carefully executed watches; the cylinder is a jewel, or at least the edge on which the escapement is made. This stone is fixed by gum-lac into a steel apparatus which the workmen call *manivelle*, and which serves to connect the upper part of the cylinder with its lower part.

Figure 17 gives an idea of this ferrule. We see that it is formed of three cylindrical parts, *a*, *b*, and *c*, supported at the proper distance by the two columns *d f*. To make this a round piece of steel is taken which is pierced at both ends with a smaller hole than is required for the cylinder. When it has been turned round, in the form indicated in the figure, it is notched, leaving only the two columns *d* and *f*; half of the cylindrical part *b* is removed, and a grooving whose two extremities are seen opposite *b*, is made in the remaining half of the cylinder in order to lodge there the demicylinder of stone, called the *pallet*—this finishes the ferrule, which is then polished. The upper cylinder or stopper is adjusted in the cylindrical part *a*, and the lower stopper in the cylinder *c*, in the manner which we have described for the common steel cylinders.

Breguet changed almost entirely the form of the two essential pieces constituting the cylinder escapement—the wheel and the cylinder.

The wheel (Fig. 18) is simply a crown wheel, the crown of which is a part of a truncated cone whose larger base exceeds the smaller one in an equal quantity to that presented in an ordinary wheel by the projection forming the inclined plane. Double the number of teeth required are then cut in the wheel with a thin cutting-file, and an alternate tooth is suppressed; the front of each tooth is then filed in an inclined plane from the side where it moves forward nearly to the end of the tooth, leaving but a small space flat by which the repose and lifting are made. The back of the tooth is also filed in an inclined plane, but less than is the front of it.

Figure 19 indicates Breguet's form of *mounting*. The demi-cylinder *a* bears the grooving *d d* to receive the *tuile* or the demi-cylinder of stone. The part *c* is properly the *mounting*, with a sort of column which connects the two parts *a* and *b*. The ferrule *b* is pierced with a hole large enough to receive the axle of the cylinder, to the ends of which the pivots are formed. These pivots, which are as fine as possible, are first turned in a cylindrical form, and then depressed in the middle of their length. This construction tends to diminish the friction, since the pivot only rubs by the two extremities of its length, while the depression in the middle serves to retain the oil and lessen the friction. Breguet did not round his pivots as had been done before; his pivots are flat beneath while the edges are slightly rounded.

By this improvement he got rid of variations caused by the position of the watch. Without his improvement, if the watch was lying flat, the pivot working only upon a rounded point moved with greater freedom than if it was hanging, when it worked in the length of the holes.

Figure 20 shows the cylinder mounted with a fragment, *n*, of the balance. We see there the pallet, *m*, and the two pivots *h* and *g*. The inner pivot, *g*, is received into the bridge, *r*, which is seen in plane at *a*, and in profile at *b* (Fig. 21). This bridge is supported by the slide. This escapement, whose perfect execution demands a practised and skilful workman, has never before been fully described.

III.—*The Duplex Escapement.* Pl. III.

This is a dead-beat escapement, and is much more easily executed than the cylinder escapement. The escapement-wheel is flat.

Figure 22 presents but a fragment of it at A; its teeth are cut as in a cog or star-wheel, but are very long and are placed apart. This distance from one tooth to another is necessary in order to drive a pin into the crown-wheel perpendicular to its surface in the midst of this space. These pins are planted in a circle concentric to this wheel, so that they are always at the same distance from the axle of the balance. These pins, however, do not seem to be used at present; but a crown is reserved on the plane of the wheel as in the crown-wheel, and this crown is divided by the wheel-cutter in the same manner as the teeth of the wheel, so that they may be equi-distant. We have examined a construction of this kind in an English watch which renders the wheel lighter, and which will serve as the model to our figure.

The axle of the balance carries a roller, B, which is usually a jewel, having a small notch, *a*, designed to receive the points of the long star-teeth, C D E. A large arm, G, is carried above this roller by the same axle of the balance, and reaches as far as the pins, H I J, formed by the crown-wheel which forms one with the star-wheel. This escapement works in the following manner. It must first be understood that the wheel moves in the direction indicated by the arrow *b*. The figure shows the tooth, D, working in the notch, *a*, of the roller, B; at the same time the arm, G, is lifted up by the pin, I, which pushes it backwards and communicates the vibration to the balance, armed with its spiral-spring; the tooth, D, immediately leaves the notch, *a*, and the tooth, C, comes to rest upon the roller, B, at the point *k;* the balance completes its vibration and the spiral-spring brings it back to the point where the small notch, *a*, presents itself before this tooth when it enters it. At the same time the lift, G, presents itself before the pin, H, which pushes the balance in acting upon the lift, G, as in the first case. The lifting here is sixty degrees. We see that this escapement is dead-beat, that the repose is made on the roller, B, on the side of *k*, and that the balance receives but one impulse in two vibrations.

We also see that this escapement which, at first sight, seems very easily executed, presents difficulties which can only be surmounted by a skilful artisan. It is, however, less difficult of execution than the cylinder escapement of Breguet.

IV.—*Escapements of M. Pons de Paul.*

M. Pons, a skilful clockmaker, who is at the head of the clockmaking manufactory of St. Nicholas d'Aliermont, has described his different escapements in the *Bulletin de la*

Societé d'Encouragement, vol. xxvii. p. 421, which descriptions and figures we shall literally transcribe.

1st.—*Hook Escapement.*

"Figure 1, Pl. IV., represents the escapement-wheel in plane; this wheel carries ninety-two pins. Figure 2 shows the place of the escapement piece;* we see this piece in perspective in Figure 3. In Figure 4 it is mounted upon the axle of the balance, Y, which carries the spiral-spring V. The letters *a* and *b* (Fig. 1) indicate the successive positions of the escapement at the time of its connexion with the pins of the wheel.

"*Effect.*—The piece, *a* (Fig. 1), represents the escapement in its state of rest, a pin of the wheel is in contact interiorly with the piece *a;* the balance turning from right to left, this piece will turn around the pin; the balance returning from left to right, the pin will glide along the lift, *o*, and will make it pass over an arc of thirty-five degrees. As soon as it escapes, a third pin comes to place itself on *c;* in this position a pin will be between the one which escapes and the one that comes in contact as we see in *b;* the balance returning from right to left, the pin will glide along the curve, *c*, giving an arc equal to the first. At the moment in which this last pin escapes, the one placed in the interior of the escapement-piece comes in contact with this piece as in *a*, to recommence the effect which we have just described.

"We must remark that the lift of this escapement can always be alike, because knowing the extent and the lifting, *c*, we can incline or elevate the lift, *o*, at pleasure to cause it to pass over an equal arc.

* This piece is of the hardest tempered steel, and is fixed upon a support-socket forcibly adjusted upon the axle of the balance.

"This escapement is well adapted to watches in which slow vibrations are required."

2d.—*Spiral Escapement.*

"Figure 5 represents the escapement-wheel in plane; this wheel carries twelve pins. Figure 6 is a roller with a notch, whose edges are rounded to facilitate the disengagement of the pins of the wheel. Figure 7 shows the plane of the escapement-piece; we see this piece and the roller in perspective in figure 8. In the Figure 4 these two pieces are mounted upon the axle of the balance Y, upon which is fixed the spiral-spring V. The letters, *a b c d* (Fig. 5), indicate the successive positions which the escapement-piece takes at the time of its connexion with the pins.

"*Effect.*—The piece, *b*, represents the escapement in its state of rest; the pin is placed in the notch of the roller, and the spiral spring of the balance has no tension. The balance turning from left to right, the pin leaves the notch of the roller and places itself on the lift, *o*, as indicated in the piece, *c*. The action of the wheel continuing, the pin glides along, *o*, and comes in the position of the piece, *d;* in this movement the lift will have passed over an arc of ninety degrees. At the moment when the pin escapes, the following one places itself upon the lift, *f*, and the balance returning from right to left, the pin glides along this lift until it escapes and comes upon the roller in the position, *a*.

"In this movement the lift will have passed over the same arc of ninety degrees in a contrary direction; and the balance returning from left to right, the pin will return to the position, *b*, in order to recommence the movement.

3d.—*Gearing Escapement.*

"Figure 9 represents the escapement-wheels in plane;

the wheel, *a*, carries eight pins, and the wheel, *b*, sixteen teeth. Figure 6 shows the plane of the piece which is connected with the pins of the wheel, *a*, and on which the repose is made. Figure 10 represents that of the piece bearing the two impulse-pallets that work into the teeth of the wheel, *b*. These pieces are seen in perspective in Figures 11 and 12. In Figure 13 these pieces are mounted upon the axle of the balance, Y, upon which the spiral-spring, V, is fixed. The letters *c*, *d*, *e*, *f*, *g* (Fig. 9) indicate the successive positions which the escapement takes at the time of the connexion of the pins and the teeth, with the pieces which compose it.

"*Effect.*—The position, *c*, shows the escapement in its state of repose; the pin is placed in the notch of the repose-piece and the spiral-spring has no tension. The balance turning from left to right, the pin leaves the notch, mounts upon the small curve opposite, and escapes as soon as the first of the two pallets comes in contact with one of the teeth of the wheel, *b*, as is represented in *d*. The second pallet presents itself beneath the following wheel at the moment in which the two first are upon the line of the centres, as in the position, *e*. The wheel continuing its movement, they come as in *f*, and, finally, as in *g*. In this movement, the escapement-piece will have passed over an arc of seventy-five degrees. At the moment in which the second pallet escapes, one of the pins of the wheel, *a*, places itself upon the large curve of the piece of repose, as in *a*, and the balance returning from right to left, this pin glides along this curve, enters into the notch, and mounts upon the small curve opposite by the impulse which it has received; it then takes again the position, *c*, to recommence the same movement. In gliding along the large curve of the piece of repose, the lift passes over an arc equal to the first.

4th.—*Inclined-plane Escapement.*

"Figure 13 (*bis*) represents the escapement-wheels in plane; the wheel, *a*, carries twelve pins, the wheel, *b*, twelve impulse-pallets on an inclined plane. Figure 14 shows the plane of the piece that connects with the teeth of the wheel, *a*, and upon which the dead-beat is made. Figure 15 that of the impulse-pallet on an inclined plane, and which corresponds with those of the teeth of the wheel, *b*. We see this in perspective in Figure 16. Figure 13 shows these pieces mounted upon the axle of the balance, Y, upon which is fixed the spiral-spring, V. The letters, *h*, *i*, *k*, *l*, indicate the successive positions of the escapement.

"*Effect.*—The position, *h*, represents the escapement in its state of repose; the pin of the wheel, *a*, rests upon the circumference of the repose-piece, and the spiral-spring has no tension. The balance turns from right to left, the pin glides along the part, going spirally towards the centre of motion; it leaves the notch and mounts upon the small curve opposite by the impulse that it has received, which gives a slight recoil to the wheel. In this movement, the lift will have passed over an arc of fifty degrees. The balance returning from left to right, the pin escapes as soon as the upper extremity of one of the teeth of the wheel, *b*, comes in contact with the impulse-pallet, as is indicated in the position, *i*; the two planes are thrown successively in contact and come upon the line of the centres, as in *k*, and, finally, in the position, *l*. In this movement, the lift will have passed over an arc equal to that of the first. At the moment in which the contact of the arc ceases, the pin of the wheel, *a*, places itself upon the repose-piece, as in *l*, and resumes the position, *h*, in order to recommence the movement."

We see that the first two of these four escapements bear some analogy to the Duplex, but they more nearly resemble the simple hook-escapement, which has been abandoned on account of its difficulty of execution. We fear that they present the same objection, although they seem very ingeniously conceived.

V.—*Detached Escapements.*

In the dead-beat escapements of which we have just spoken, the movement of the wheel is suspended during the vibration of the balance, but this suspension is caused by the wheel itself, which, during the whole time of vibration, rests one of its teeth upon a cylindrical part, carried by the axle of the balance. It is evident that the force with which the wheel is impelled produces a friction upon the axle of the balance which, however slight it may be, is an obstacle to the free movement of the spiral-spring. The dead-beat escapement requires oil, and thus induces variable resistances, which are very pernicious.

Berthoud seems to have had the first idea of detached escapements in 1754. He gives the following explanation in his *Histoire*, etc., vol. ii. p. 23 :—

"The defects which I have remarked in the ordinary dead-beat escapement have caused me to seek the means of remedying these evils. For this purpose I have combined the escapement in such a manner that the spiral-spring can freely accomplish its vibration as soon as the wheel has given its impulse, and that during this time the effort of action of the train is not suspended, as in the dead-beat escapements, by the spiral-spring itself, but by a detent which the balance disengages in an indivisible time; so that the regulator does not thus meet with any resistance or friction except that of disengaging the detent, which suspends the effect of the wheel, while the balance oscillates freely.

In this escapement the balance makes two vibrations, while but a single tooth of the wheel escapes at a time; that is, the balance goes and returns, and on its return at the second vibration, the wheel, in escaping, restores to the regulator in one vibration the force it had lost in two. Thus the action of the wheel remains suspended by a detent during the whole of one vibration, and the greater part of the second, so that the balance oscillates freely during this period.

We shall not attempt to describe all the detached escapements which have been invented, as this would far exceed our proposed limits, but shall confine ourselves to a description of one which is now successfully used, both for watches and clocks, and also for chronometers.

VI.—*Arnold detached Escapement.*

Plate IV., Fig. 17, presents all the details of this escapement. The cylindrical piece, A, is notched at *g*, as is shown in the figure. This piece, A, is carried fixedly by the axle of the balance. This axle also carries a tooth or finger, *a*; these two pieces, which are invariably fastened to the axle of the balance, move with it. Upon the pillar-plate of the movement the spring, *b*, *c*, is fastened by a screw and two chicks; this bears three arms, *d*, *f*, *k*. The first, *d*, serves to suspend the movement of the escapement-wheel, B, and to permit but one tooth of the wheel to pass successively when forced by the spiral-spring.

The second arm, *f*, which is fixed like the first upon the spring, *b*, *c*, serves to determine the length of the small spring, *i*, *h*, which is fastened in this arm, in the same manner as is the spiral-spring in its screw. This small spring reaches nearly to the axle of the balance, so that the little finger, *a*, cannot turn without causing it to vibrate. The third arm, *k*, receives into a small notch the little spring, *i*, *h*, whose use we shall explain.

When the balance turns in the direction pointed by the arrow, it draws along the cylindrical piece, A, and the little finger, *a*. The latter causes the small spring, *i*, to bend; this yields easily on account of its great flexibility, and permits the passage of the finger, *a*. All this is effected without any movement of the escapement-wheel, B, whereby to cause the cylindrical piece, A, to reach any tooth. But when the balance returns backward, after this first vibration, the finger, *a*, seizes the top of the spring, *i*, and causes it to rest upon the arm, *k*, which then becomes the centre of motion of the spring, *b*, *c*. This arm, *k*, is placed as near as possible to the cylindrical piece, A; the small spring, *i*, then becomes strong enough to cause the spring *b c* to yield, which, in rising, draws along the arm, *d*, and disengages the tooth of the escapement wheel, B. This spring returns to its first position, and the arm, *d*, arrests the following tooth. During this movement, the tooth, *m*, comes to rest upon the arm *d*, and the tooth *n*, which advances at the same time, encounters the lift *g*, and restores the force to the spiral-spring, which it has lost in the two vibrations.

Breguet adopted this construction for chronometers beating but five vibrations in two seconds. This escapement makes an audible sound, so that it is easy to count the vibrations; these are slow but possess great regularity.

VII.—*Detached Escapement of L. Seb. Le Norman.*

This was invented in 1784, and operated well. It was executed in a small clock belonging to the Bishop of Montauban, instead of an anchor escapement.

Figure 18, Pl. IV., shows the wheel in place. This wheel has two crowns; that is, it has a crown like that of an ordinary crown-wheel upon each of its surfaces. The wheel is about half-a-line in thickness, and the thickness of each of its crowns does not exceed half-a-line. These crowns form the inclined planes which each tooth of the wheel bears alternately upon one of its surfaces. The wheel always has an even number of teeth, as each tooth forms the lift, sometimes on one surface and sometimes on the other.

This wheel is easily cut upon the tool for cutting the balance-wheels, and is finished on the same tool, including the inclined planes. It is first divided into equal parts by an ordinary cutting-file of half a line in thickness; then one tooth is alternately taken from each side by a flat cutter, whose thickness should equal the length of one tooth, and finally the width of the remaining tooth is cut with the inclined cutters by the diagonal of the rectangle, which each of them presents in face. The teeth then appear as shown in Figure 19, the wheel being in profile.

The escapement-piece (Fig. 20) here is nearly of the natural size; it is fixed in *a* (Fig. 18) in such a manner that it can only turn with this axle which is placed vertically and in a plane parallel to the plane of the wheel. A fork, *b*, is fixed with a socket upon the same axle; this should be opposite a tooth or finger, *c*, fixed in the same manner upon the axle of the balance *d*. The balance, *f*, is placed horizontally above the frame, and in a plane perpendicular to the plane of the pillar-plates. Above it is placed the spiral-spring, S. Figure 21 shows the form of the fork, *b*, fixed upon the axle of the escapement-piece (Fig. 18); and Figure 22 shows the tooth, *c*, carried by the axle of the balance, *d*, and which works into the fork, *b*.

It is evident that when the spiral-spring brings back the tooth, *c*, between the teeth of the fork, *b*, the balance will force the escapement-piece, *a*, to make a rotary movement; it then presents its notch to the inclined plane of the tooth which, in escaping, restores to the balance the force which it had lost during the preceding vibration, through the medium of the pin and the tooth, causing it to describe a lifting of forty degrees. The following tooth then comes to rest on the escapement-piece, *a*, until the balance disengages this piece on its return and lets a second tooth escape, which also causes a lifting of forty degrees, and so on. The essential point in this easily executed escapement consists in placing the upper surface of the escapement-piece, *a*, in the plane of the horizontal diameter of the wheel. This escapement-piece should be somewhat thinner than the cutting-file used in cutting the wheel.

We have suppressed in this figure the bridges which support the escapement-piece and the balance, in order to render the design less complicated.

VIII.—*Escapements for Pendulum and Belfry-Clocks.*

Independently of the escapement which we have just described, and which is suited to those apartment-clocks in which a pendulum is not desired, this escapement procures the advantage of directly beating the dead-seconds, whatever may be the height required for the case which encloses the movement. A great number of escapements applicable to this kind of clocks exist, but we shall confine ourselves to the description of those which are acknowledged to be the best, and which are most in use, such as, 1st, the anchor-escapement, which is used in nearly all the small apartment or mantel-clocks; 2d, the Graham-escapement, used in many regulators, and in belfry-clocks; 3d, the pin-escapement of Lepaute, which is unquestionably an excellent one, and which is now much in use for regulators and belfry-clocks.

§ IX.—*Anchor Escapement for Belfry-Clocks.*

This escapement was invented by an English clockmaker, whose name is not positively known; some attribute it to Thomas Mudge, and others to Clement. It is called "anchor escapement," because the two branches that compose it bear some resemblance to the flukes of an anchor. It is represented in Fig. 23, Pl. IV. We are obliged to enter into some details in respect to this escapement, as well as to the one improved by Graham, in order to point out two errors respecting the nature and the uses of these escapements which have been propagated within a few years.

The first of these errors consists in the assertion that this escapement is *recoiling* in mantel-clocks. It was given by the inventor as a dead-beat escapement, and Fig. 23, Pl. IV., which represents it, proves this incontestibly, as the curves *d c*, and *m n*, upon which the two dead-beats are made, are arcs of circles which have their centre at *a*.

We shall presently see that Berthoud has expressly declared this, in giving rules by which to make them *recoiling* in small clocks, with the view of rendering the vibrations isochronal. In 1763 he pointed out a method of rendering the anchor escapement, invented in 1681 by Clement, a London clockmaker, a *recoil*. This had been therefore exclusively a dead-beat escapement for eighty-three years, before any one had succeeded in giving it the best form for *recoil* in order to make it isochronal. Since the discovery of Berthoud, we have seen many of these recoil escapements, although very few are isochronal, because most workmen neither know how nor care to practise the rules which he prescribed. The construction of this escapement as dead-beat, has not, however, been abandoned, and it is incorrect to assert that this escapement is recoiling by nature when it was only made so by art.

The second error consists in maintaining that this escapement, and even that of Graham, permits two teeth to pass at each oscillation. This assertion is too absurd to merit a serious refutation.

We will only say to those who affirm this, that if they guide the pendulum of a clock with their hand, and count the number of strokes which the wheel when impelled by the motive power beats at each vibration, they will count but one. Now each tooth gives a stroke in passing.

Berthoud gives the following rules for making the anchor escapement recoiling:—

"The distance from the centre, *a*, of the escapement-anchor to the centre, A (Fig. 23), of the wheel, depends on the arc over which the pendulum is to pass. If it is to describe a large one, ten degrees for instance, the centre, *a*, must be placed near the wheel. Care must be taken in all cases that the opening of the compass which serves to trace the repose shall be such that in drawing from the point, *n*, a line passing to the centre, *a*, of the anchor, and letting fall from the extremity, *n*, a line passing to the centre of the wheel, the line shall be perpendicular to *n*, *a*.

"Julien Leroi, and Saurin, in 1720, and Enderlin in 1721, employed themselves in researches by which to determine the curvature which should be given to the faces of the anchor to render the oscillations of the pendulum isochronal. Berthoud succeeded in ascertaining the true form required for the anchor, and resolved the problem given by preceding clock-makers in a satisfactory manner.

"The isochronal escapement which we propose to describe is not a dead-beat, neither is it as much recoiling as is the anchor of Enderlin; but its recoil is mean between the dead-beat of the first and the recoil of the second."

This escapement for rendering the oscillations isochronal, is shown in Pl. IV., Fig. 24; we have represented it on a large scale, that the peculiarities of its construction may be more easily distinguished and understood, after which it will be easy to trace it in miniature by the prescribed rules.

To trace the escapement-anchor, we take a well-tempered and polished thin plate of brass, eight centimetres square, which is called the escapement-caliber, and pierce a hole towards one of the edges of the plate, at a sufficient distance to be able to trace there the circumference of the wheel. We adjust the small rod of the pinion of the bottom of the wheel into this hole, in such a manner that the whole wheel is laid upon the plate, and then trace a circle, of the exact size of the wheel, with a watchmaker's compass.

With the same compass, we take upon the pillar-plate the distance from the centre of the escapement-wheel to the hole of the pivot of the anchor-rod; we carry this distance on the brass plate, and trace from the centre, B, of the wheel, the portion of the circle *b*, *c;* we pierce a small hole of the size of the pivot of the anchor-rod at *a;* this hole represents the centre of the anchor. From this centre we draw the line *a*, *b*, which may be a tangent of the circumference, *b*, *c*, of the wheel; if through the line of touch, *b*, we draw the radius B, *b*, it will be perpendicular to *b*, *a*, as is demonstrated in geometry; and, according to the principles of mechanics, the action of the teeth of the wheels should be at the point *b*, on the anchor; thus, *a*, *b*, is the length which must be given to the arm of the anchor, in order that the wheel may act upon it in the manner best suited to the movement.

We place the wheel upon the brass plate; we then place one point of the compass upon the hole of the anchor, and with the opening of the compass, *a*, *b*, we make the other point agree with that of a tooth, *b*, of the wheel taken in front. For this, we turn the wheel as required, then holding it stationary while we carry the point of the compass to the other side to see if it appears at the back of the point of a tooth, *c*;* if this is not effected, we change the opening of the compass until it passes by the teeth nearest the points of contact, *c*, *b*, and we find the portions of a circle, *b*, *t*, *c*, *p*, which represent the two faces of the flukes of the anchor.

To find the two other faces, the opening of the compass must be changed, so that the teeth having passed over half their interval, they pass through a second part of a circle; but as this can either be done by opening the compass further, or by closing it half the interval of a tooth, the opening should be chosen which will make the length of the lines to differ least from the points of contact, from which they should diverge as little as possible. We then find the two other faces of the anchor, *d*, *s*, *e*, *q*, which we place within in order to diminish the space which the anchor passes over, and consequently, its friction. We will thus have the four faces of the two arms placed in such a manner as to permit the teeth to escape alternately, in proportion as these flukes penetrate and depart from the wheel by the movement of the pendulum.

To regulate the length of the flukes of the anchor, we divide the extent of the lifting required for the escapement, which we fix at five degrees on each side or thereabouts.

To mark this lifting of the escapement exactly, we must have a semicircle graduated in degrees, the centre of which must accord with the hole of the anchor-pivot, which is pierced in the escapement-caliber; we prolong the line *a*, *b*,

* The part of the circle, *c*, *p*, should pass behind the tooth, *c*, so that the angle, *c*, of the fluke, *c*, *e*, may not prop against it as the tooth, *b*, draws away the arm, *b*, *t*, and as the latter inserts itself between the teeth of the wheel.

as far as *f*, the edge of the graduated semicircle, and turn the instrument until one of its divisions corresponds with the line *b*, *f*, marking within a point, *g*, five degrees distant from the other. Through this point we draw a line passing through the centre of the anchor, and mark, at *d*, the quantity to be given the fluke, so that the wheel turning in an inclined plane, the anchor will describe five degrees. To find this inclined plane, we trace the lines *d*, *b*, which should pass through the points *d*, and *b*, in which the right lines, *a*, *f*, *a*, *g*, which measure the angles, *g*, *a*, *f*, cut the portions of the circle *d*, *s*, *b*, *t*; we then have the fluke, *d*, *b*, traced.

We proceed in the same manner to obtain the other fluke of the anchor; we obtain the angle, *i*, *a*, *h*, of five degrees, which determines the direction of the inclined plane, *c*, *e*. By this method, the total lifting of the escapement will be ten degrees.

The escapement thus traced will be dead-beat, as it is formed by the arcs of a circle concentric to *a*; but as such an escapement will not correct the inequalities of the motive power, the curves, *b*, *l*, *e*, *k*, should be traced upon the anchor; this will cause the wheel to retrograde as the flukes become connected with the teeth by the increase of the motive power.

To trace the curves in such a manner as to give the recoil suited to render the oscillations isochronal, the following dimensions should be employed: take with a compass the interval *b*, *m*, which separates the arcs of the circle *b*, *t*, *d*, *s*; carry it three times over the arc of the circle, starting from the angle *b*, of the inclined plane, and mark the point 4 of the third division with the same opening of the compass. From this point with the radius *a*, *b*, describe a small arc of a circle towards *n*; and from the point *b*, with the same opening of the compass, describe a small arc towards *n*, which cuts the first at the point *n*.

This point, *n*, will be the centre from which, with the same radius, *a*, *b*, to describe the arc *l*, 4, *b*, which will give the desired curve.

To trace the other curve in the interior of the fluke *c*, *e*, take the same thickness, *e*, *u*, of this fluke; start from the angle *e*, of the inclined plane, and carry it three times upon the portion of a circle, *e*, *q*, of the third division; then mark the point 4, with the same opening of the compass upon the direction of a line, 3, *a*, as has been done on the other side. We find the point *o*, in the same manner as we found the point *n*, by taking an opening of the compass *e*, *a*, and tracing with this opening two small arcs, from the point *e*, and from the point 4, which intersecting at *o*, give the centre of the arc *e*, *k*, 4, traced by the radius *e*, *a;* this determines the curve required for this second fluke.

We thus obtain the figure which should be given to the escapement-anchor exactly traced, and to procure isochronal vibrations it is only necessary to execute it by these directions.

§ X.—*Anchor-escapement as improved by Graham for Regulators and Belfry-clocks.*

Figure 25, Plate IV., shows this escapement. It will only be necessary to say a few words of this after the details of construction of the anchor for mantel-clocks, given in the first part of the preceding paragraph. The escapement-wheel is at A, the escapement-anchor, B, has its centre of motion at *a*, at a distance of three times the radius of the wheel A. The dead-beat is made upon an arc of a circle, C, D, E, which passes through the centre of the wheel A. Each tooth of the wheel, therefore, reposes alternately upon the outer arc, D, E, on one side, and upon the inner arc, C, on the other; these two arcs belonging to the same circumference of circle. A tooth passes at each oscillation of the pendulum.

To find the inclination of the planes, we determine the number of degrees which the pendulum is required to describe, and form an angle, *f*, *a*, *g*, on one side, and another, *h*, *a*, *b*, on the other, each of half the degrees which have been fixed on. In this construction, as we have indicated for the anchor of the mantel clocks, the sides of these angles will give the inclination of the planes, C, 1, for one of the flukes, D, 2, for the other.

XI.—*Pin Escapement of Lepaute, for Regulators and Belfry-clocks.*

Figure 26, Pl. IV., shows this escapement, whose first piece is an arbor, F, placed horizontally and terminated by two pivots, one of which rolls in the pillar-plate of the pillars, and the other in a cock fixed outside of the other plate. The fork of the pendulum is riveted upon the arbor, between the cock and the pillar-plate.

This arbor bears two recurvated arms, G, A, *c*, and H, B, *d*, which are fixed on it with a hard friction in such a manner that they can be opened more or less, and caused to make the angle necessary for the effects which may be desired.

The parts, R, I, L, S, of the arms, are arcs of a circle whose centre is in the plane of the wheel and upon the axle, F, but they are terminated by the inclined planes I *c* and L *d*. The arm, G, A, *c*, passes behind the wheel, while the arm, H, B, *d*, is upon the front part of the wheel. The wheel bears pins upon its two faces which are perpendicular to its plane. We have left those in white which are in front of the wheel; the black pins, placed alternately with the others, are on the back part of the same wheel.

The wheel descending by the force of the weight from *u* to x, as indicated by the arrow, the pins of the front part encounter the inclined plane, L, *d*, and impel it towards B. By this movement, the arm, G, A *c*, which is on the other face of the wheel, is advanced beneath the following pin; the pin, Y, having then escaped at the point *d*, and the arm continuing to turn by the force of impulse communicated to the pendulum, the following pin, *u*, is found upon the circular concave part, R, I, which is the arc of repose. The arms being brought back from the side of A by the descending oscillation of the pendulum, the pin which rubbed upon the arc, R, I, directly encounters the plane, I, *c*, upon which it acts like the first, but in a contrary direction, pushing the arms of C A until the following tooth comes upon the arc L S, to descend thence upon the plane, L *d*, and so on.

As each pin of the wheel answers to one oscillation of the pendulum, there should be sixty pins upon the wheel in the regulators, thirty of which are placed upon one of the faces of the wheel, and the other thirty in the intervals of the first, but upon the other side of the wheel. These pins, on both sides, are not placed precisely upon one circumference, or equidistant from the centre of the wheel; but the pins which are to act upon the plane, I, *c*, act by their inner side, which is nearer the centre of the wheel, and the pins which push forward the plane L *d*, act by their outer side, which is further from the centre. These are arranged so that the inner sides of the pins, *m*, *n*, and the outer sides of the pins, *x*, *y*, are precisely upon the same circle; for this the pins of one of the faces of the wheel must be placed on a circle whose radius is less by the diameter of the pin than the radius of the circle upon which the pins of the other face are planted. By this means, the impulse upon the two planes is made at exactly the same distance from the centre of the wheel, and by an arm which is always equal.

If the two pins were sound, the one which would come to the extremity, *c* or *d*, of the plane, would escape as soon as its centre should be opposite the angle, *d*, or *o*, and before the entire thickness of the pin would have passed between *d*, or *c*. Now, as the whole thickness of the arm, I, *c*, or *d*, L, should pass between the two pins, and as it can only pass there when the entire pin shall be beneath *c* or *d*, it therefore follows, that this pin will descend to the value of its radius after having escaped, and consequently the pin that is above will fall in the same proportion; but this fall should always be avoided, both on account of the jerking and wear which it produces in the pieces, and the loss of force which is uselessly employed in the shock.

By cutting off half the thickness of the pin, it will be able to pass beneath the arm as soon as it has escaped, and the following pin will come upon the arc of repose without any fall.

Although the pins may be reduced to semi-cylinders, it is still their convexity or their lower surface which rubs upon the arcs of repose. Now there can be no slighter friction of surfaces than that of a convex upon a plane surface; and the oil and dust which accumulate beneath the surface of a tooth, and which contribute to the wearing out of every other escapement, cannot collect under so thin a pin. These pins act upon the inclined planes by their convexity, *x*, *m*, *y*, *n*, and do not escape until the angle of the pin has reached the lower angle of the inclined plane. This escapement, therefore, unites all the advantages which have been sought in these pieces without any defects.

The dead-beats are perfectly equal and at the same distance from the centre; the friction upon the arcs of repose is very slight; the two arcs of repose are both concave, and are passed over with the same velocity, the same force, and in the same direction. The arms by which the wheel acts are alike, as well as the planes upon which they act; the impulse commences at the same distance from the centre, ends at the same distance upon both, and is made with an equal force and in the same manner.

We will add an improvement to the construction which we have just given in the words of the author. It consists in placing a brass plate upon one of the arms, G, A, *c*, which can take a small circular movement. This plate is wormed in a direction perpendicular to the line F I. Upon another arm and opposite is placed another plate in which the head of a screw is inserted, which only permits it to take a circular movement around its axle. The helices of this screw are wormed into the plate which is placed upon the other arm, so as to perform the functions of an adjusting screw. The result is, that by turning the head of this screw to the right or left with a key, the two inclined planes are drawn together or separated in order to adjust the escapement with precision. Artisans will readily understand this construction.

CHAPTER VII.

THE COMPENSATION, OR METHODS USED TO CORRECT THE EFFECTS OF THE TEMPERATURE IN MACHINES DESIGNED TO MEASURE TIME.

"THE fact that heat expands all metals, and that cold contracts them, is universally acknowledged and proved by experience," and "as it happens," adds Berthoud, "that we do not experience the same degree of heat for two consecutive moments, we may therefore say that all the particles of the body which we formerly considered to be in a state of rest are, on the contrary, in perpetual motion, and that this body is consequently larger in summer than in winter, and in the day than in night.

"We also know that the longer the pendulum is the slower will be its vibrations, and that the shorter it is the more will they be quickened.

"Now, as the heat lengthens the rod, we see that in summer the pendulum-clock will lose, and in the winter will gain time by this action. These causes would prevent the regular movement of the machine, and in order to attain perfection for it we must understand the amount of expansion and contraction of the different metals by cold and heat, and find a method of correcting these defects."

The reasoning which Berthoud applies here to clocks is also applicable to all regulators; as in watches the spiral-spring as well as the balance is subject to the same laws of expansion and contraction. The method used to correct these defects is known by the name of *compensation*.

From the innumerable methods which have been invented for obtaining the compensation we shall choose those which seem to us to be the surest and best, referring curious readers to the works of Thiout Sen., Lepaute, Berthoud, and others, for descriptions of the remainder. We shall first point out the methods used to obtain the compensation in watches, after which we shall speak of the same methods as applied to the pendulum.

The principal piece employed in all compensations is a bi-metallic rod, or one composed of two metals, whose expansion and contraction by heat and cold are in different proportions. For this brass and steel are generally used, and numerous experiments have proved the expansion of the brass to that of the steel to be in proportion of 121 to 74.

It therefore follows that if we suppose a bi-metallic rod, formed of a rod of brass, and a rod of steel of the same length, width, and thickness, to be fastened together by riveting, or, which is better, by soldering; and if we also suppose these two rods thus united to be solidly fastened by one extremity upon the pillar-plate, while the other is left free, the heat acting upon them will lengthen the rod of brass beyond the rod of steel, and will force the latter to bend down on the side on which it is placed. The cold, on the contrary, will contract the brass more than the steel, whose extremity will describe an arc in a direction contrary to the first.

Skilful clockmakers have profited by this well-known property in metals, and have applied it in different methods, both in watches and in clocks, for obtaining the corrections or compensations which they sought.

I.—*Compensation in Watches with Circular Regulators.*

If the irregularity of watches proceeded only from the expansion or contraction of the material of which the balance and the spiral-spring are formed, there is no doubt that the use of a bi-metallic band, properly applied to the escapement, would correct the fault which we seek to remedy, but, unhappily, this is not the case.

Better to explain what we have to say, we shall divide the numerous watches which are manufactured into three distinct classes. In the first of these we shall place those known as chronometers, of which we shall not specially treat.

In the second class are comprised those watches which, though less costly and less accurate than the first, have a much more regular movement than those of the third class, commonly called the balance-wheel watches.

We will limit ourselves to the description given by M. Destigny, of Rouen, of the principal methods used to obtain the perfection of the watches of which we speak. These improvements consist in reducing the frictions, and rendering them as nearly equal as possible by causing the pivots to revolve in holes made in jewels, in furnishing the rubbing parts of the escapement with jewels, in making this escapement in such a manner that it may be able to correct the inconvenience of a variable motive power, and in making an application of a well-tempered spiral-spring, whose oscillations may be isochronal in all conditions.

Isochronism, or the equal duration of the oscillations of the balance, is the basis of exact time-keeping, but there are so many causes which concur in affecting this isochronism, that those who seek to obtain it will attempt it in vain if they do not join a knowledge of mathematics and physics to that of the laws of motion.

"Independently of the action of the temperature upon the spiral-spring, which by expanding or contracting renders it weaker or stronger, and thus diminishes or increases its action on the balance by retarding or accelerating the vibrations, consequently causing the watch to gain or lose time; it also influences the balance in the same manner, augmenting or diminishing its diameter, and thus producing a second cause of irregularity.

"The cold acting upon the oil in the pivots and causing it to lose its fluidity, augments the resistance of motion in the proportion of the amount of the frictions, which occasions a delay in the movement. This effect can be infinitely varied, as it results from the difference of the frictions, which are increased or diminished in proportion to the size of the pivots, the diameter and weight of the balance, and the extent of the space which it passes over. We see that the cold, in exercising its influence upon the different parts of the watch at the same time, produces two contrary effects, as it were, a natural compensation. If these opposing effects were in the same proportion, an exact compensation would be established which would render the employment of another compensation useless, or rather injurious. If, on the contrary, the delay arising from the increase of the frictions was greater than the advance caused by the contraction of the spiral-spring, the cold would retard the watch, and in this case the compensation would be still more objectionable as it would increase the variation. The same reasoning may be applied inversely to the heat."

This theory explains why a change of temperature causes some watches to gain and others to lose, and it also explains why a common watch executed by an indifferent workman may run regularly for a little while, while another watch which is really well executed, but which has no compensation, gains or loses with the heat or cold.

The compensation represented in Figure 27, Pl. IV., was invented by Breguet. This is a bi-metallic band, *c*, of steel and brass soldered together, the steel being outside. This band is turned back upon itself, following the circumference of the balance. It is fastened with a screw upon the rack, *b*, a part of which is seen here. The inner branch is free, and carries the arm at its extremity, which presents itself before a pin which is riveted upon the same rack. The spiral-spring, *d*, vibrates between this arm and the pin. We see that there is no facility given here for elongating or shortening the bi-metallic band, and that if it compensates it is chiefly the effect of chance.

Compensation of M. Destigny.

M. Destigny, after having studiously reflected upon the inconveniences arising from this construction, remedied them by placing a second rack upon the first, but in such a manner as to be drawn along by it. Upon this second rack he fixed an angular arm, hinged at the top of the angle, and with the aid of a small spring he forced the two sides of this angle to keep constantly apart. The movable side is incessantly impelled against the arm of the Breguet compensation, and bears another arm similar to the first at its extremity. This arm presents itself before the pin of the spiral-spring, which vibrates between the two.

It is evident that as the compensation no longer acts directly upon the spiral-spring, but upon the additional arm, the desired compensation may be easily obtained by advancing or drawing back the arm. We shall not describe this mechanism at length, as simpler methods have since been invented.

Compensation of M. Perron.

In the year 1821, M. Perron, jr., a watchmaker of Be sançon, addressed an explanatory memoir of his invention to the Society of Encouragement, which may also be found in the *Annales de l'Industrie*, vol. iv.

M. Perron employs a bi-metallic band like that of Breguet, but not turned back upon itself,—it is extended and turned in a semicircle (Fig. 1, Pl. V.) This is fixed by the neck-screw, *a*, to the large end of the rack. This screw enters into a circular grooving which permits the elongation or shortening of the bi-metallic band, *b*. This band bears a curb, *d*, at its free extremity, which moves along the band in order to regulate the compensation. This compensation is formed of a steel band of three-eightieths of a line in thickness, upon which a brass band of five-eightieths of a line is soldered, so that its total thickness is about eight-eightieths of a line. To obtain the exact compensation of the effects of the temperature, the compensator must be made longer than is necessary, so that the correction may be too great; that is, that the watch may gain time by heat and lose it by cold.

The watch is set in motion at 27 or 28 degrees of the thermometer of *Reaumur;* in this state the spiral-spring should have very little play between the pin of the rack and the extremity of the angle of the curb's play. The temperature is then lessened and the watch is regulated by 12 or 15 degrees; after which it is exposed to the heat of 27 or 28 degrees, and finally to the cold of the freezing point. If the watch loses by cold and gains by heat, the curb should be removed from the extremity of the compensator, and the band bent down so that the curve may be opposite the pin of the rack, in order to obtain the exact correction of the effects of the temperature; if this should be reversed, that is, if the watch should gain by cold and lose by heat, the effect of the compensation should be increased by lessening its thickness,—but this seldom happens. The length of the compensator should be a little more than half that of the circumference of the balance.

Compensation of M. Robert, jr.

In 1829, M. Robert, a watchmaker of Blois, invented another compensation, also based on the bi-metallic band of Breguet, but far more easily executed than that of M. Perron.

He rests a bi-metallic arc, *b*, upon the rack, *a* (Fig. 2, Pl. V.), to which he gives a nearly circular form. One of the ends is fastened to the circumference of the circle at *c*, and the other is free, according to the usual method; but the screw which maintains the piece permits it to turn with a slight friction upon its centre as upon a pivot, so that any point of the convexity of the bi-metallic arc can be opposed to the curb-pin. The further this point is from the extremity in which the screw is placed, the more marked is the effect of the expansion; the larger the space which separates the compensative arc, and the greater the liberty given to the spiral-spring in its vibrations, the more effect will the compensative arc produce. It only remains, therefore, to subject the piece to the trial of two extreme temperatures, and to turn the bi-metallic arc upon the screw, which serves as its pivot, until a constant movement has been obtained for the watch in these two conditions. A few easy trials will soon effect this.

M. Duchemin, of Paris, has perfected this invention, which is remarkably ingenious and simple, by placing a curb, like that invented by M. Perron, towards the free end of the bi-metallic arc. The spiral-spring is thus held fast as between two pins, and, in unrolling itself, is not obliged to lie upon the bi-metallic arc.

II.—*Compensation in Pendulum Clocks.*

The effect of the temperature on metals—expanding them by heat and contracting them by cold—is always the same whatever form may be given them, for these effects take place in every direction. When the experiments of learned philosophers had confirmed this truth, and had proved that different metals expanded in different proportions, skilful clockmakers felt convinced that it was very important to find a sure method for remedying the effects of the temperature on the pendulum, in order to render its length invariable.

When, by careful experiments, the proportion of expansion between brass and steel had been found to be in the ratio of 121 to 74, it was sought to combine rods of steel with rods of brass in an inverse proportion; that is, to give to the bands or rods of steel a length as 121, and to those of brass a length as 74. They proposed to take these lengths from the centre of motion to the centre of oscillation. The centre of motion of the pendulum is always easily found, but the centre of oscillation presents many difficulties, as we shall see in a succeeding chapter. They did not consider that the proportions between the brass and the steel, which we have just given, are not constant—that these proportions change according to the nature of the brass or the steel, and the degree of hardness that it has acquired by hammering.

The same causes which produce variations in the compensation of the regulators of watches, and which M. Destigny has so well explained, also affect the pendulum, or regulator of clocks. We could, therefore, only succeed in exactly compensating the effects of the temperature upon this pendulum by chance, as we have proved concerning the balance, or the regulator of watches.

In mantel-clocks M. Destigny employs a bi-metallic band, composed of a band of brass and a band of steel, of equal dimensions, which are soldered together and fixed upon the pillar-plate by a foot which is placed upon the bottom of the bi-metallic band, the steel occupying the upper part. This arrangement may be seen in Figures 28 and 29, Pl. IV., in which D is the bi-metallic band, fixed to the pillar-plate by the screw C; the other extremity of this band passes into a species of cap into which the suspension-spring also passes. The screw that is fixed to the centre of the head, G, serves to raise or lower the pendulum-ball, and hence to regulate the movement of the clock. We remark in this: 1st, that the bi-metallic band is fixed, as the author states in his description; 2d, that the bi-metallic band supports the weight of the pendulum and pendulum-ball, suspended at the end of a spring-band, which he has judiciously substituted for the silk frequently used in these pendulums; 3rd, that a cock, B, is fixed upon the pillar-plate by a screw and chicks, bearing two cheeks between which the suspension spring passes freely and without play.

We are sorry that the author of this construction has not gained from it all the advantages of which we believe it to be susceptible. We have conceived the following slight improvements:—1st, Suspend the pendulum by two very slight springs, supported by their two ends, between two brass bands, at the distance of two and a half or three lines apart. 2d, If the pillar-plate is square, place the bi-metallic band near the upper edge of the pillar-plate (Fig. 30), and give it a straight form; if the pillar-plate is round, as it is generally made, and as Figure 28 represents, give to the band the circular form of the pillar-plate; but do not fix it immovably by its foot, C, with the aid of a notch, in an arc of a circle which has its centre in the centre of the pillar-plate, but allow the opportunity of advancing or receding to this band, in order to establish the nearest compensation. This property of advancing, or of receding, can be obtained by an adjusting screw; this piece is fixed by the screw, L (Fig. 30). 3rd, Suppress the cock, B, and replace it by a piece, M, which bears two cheek-pieces, between which the two suspension-springs pass freely and without play. This piece, M, slides freely and without play on the pillar-plate, and can have no movement, except in a vertical direction. Four strong pins, parallel to each other, are fixed in the upper part of this piece, which receive the free end of the bi-metallic band freely and without play. 4th, The little frame of the suspension-springs is carried by the end of the screw, N (Fig. 31), in such a manner that, by turning the head of this screw, the pendulum may be lengthened or shortened, and the clock regulated at will.

By this construction—1st, the bi-metallic band is independent of the pendulum, it no longer supports it; and this weight, however slight it may be, can affect the regularity of the compensation; 2d, by giving the facility of lengthening or shortening the bi-metallic band, we can obtain the greatest regularity in the compensation.

We give a sufficient length to our bi-metallic band to enable it to compensate according to the length of the pendulum. Each metal is half a line in thickness, and the band is two lines in width; consequently by separating the two suspension-springs to the distance of three lines, it passes easily between the two, and its sole function consists in elevating or lowering the point of suspension by moving the piece, M, which, if properly made, will offer no resistance.

This construction is equally applicable to the regulators whose pendulums beat the seconds with a spring-suspension, and is free from the inconveniences of the former inventions.

But when the clock has a suspension of the pendulum, which is judiciously adopted in good astronomical clocks, the same method cannot be employed; the ingenuity of the artists, however, has overcome this difficulty.

A well adapted and ingenious construction was invented by M. Charles Zademach, a clockmaker of Leipsic.

The same letters indicate the same objects in the three Figures, 3, 4, and 5, Pl. V.

Two steel bands, A A (Fig. 4), are screwed upon two pieces of brass of the same thickness which we see at *i* (Fig. 4), and at *y* (Fig. 5), and hold them parallel to each other. These two figures are supposed here to make but one, and are joined by the ends at A, A, in order to form the entire length of the pendulum, which they show in profile.

At the lower extremity of the brass band, B, the double screw, *u*, *u*, is fixed (Fig. 3); this band is supported in its position between the two others by the segments of circle, *h*, *h*, (Fig. 4 and 5), which hinder it from approaching nearer to one than the other, and by two friction-rollers, *d*, *d*, (Figs. 3, 4, 5), which traverse it, and which are themselves traversed by an axle or screw, *g*, *g*; the apertures made in this band for the passage of the rollers are, as we see in *f*, *f*, (Fig. 3), large enough and long enough to prevent these rollers from becoming obstacles to the movements of extension and contraction which the changes of temperature occasion in the band. We see at *x* (Fig. 5), how its upper extremity is bound to the brass piece, *y*.

The compensation is effected by the means of the two levers, C, C; their axle or point of support, *t*, *t*, is fixed upon two steel bands, and while the excess of the extension or contraction of the brass band over the others is shown upon the two arms of its levers by the screw-nuts, D, D, the other raises or lowers the cross-bar, *b*, *b*, and with it the cylindrical cross-bar, *a*, to which the crossing, E, E, is suspended, which supports the pendulum ball, K; so that the latter mounts or descends according to the degree of expansion or contraction taken by the steel bands. The letters, *c*, *c*, (Fig. 3 and 4), indicate the grooving in which the cylindrical cross-bar, *a*, moves.

The design of the two screw-nuts, D, D, of the double screw, *u*, *u*, is to regulate the course of the extremity, *v*, *v*, of the levers, by placing them at a greater or less distance from their point of support, *t*. It is evident that the nearer the point on which the screw-nut rests is to the axle of the lever, the greater will be the course, *v*, when the band, B, is expanded.

The pendulum-ball, K, of which we see but a part, is fixed upon the crossing, E, E, which terminates the pendulum we have just described. The separation of the two branches of this crossing is determined by the separation and thickness of the steel bands, A, A, and by the ease with which the crossing can glide along these two bands when, by the excess of expansion of the brass band over the latter, the cylindrical cross-bar, *a*, which supports the crossing, is raised. The two screws, *t*, *l*, placed at the upper end of the branches, E, E, (Fig. 4), support them in their position without affecting the movement which the crossing should obey.

Effects of this Pendulum.

If we suppose this instrument set in a place whose temperature is suddenly raised, the three bands, A, A, and B—the two first of which are of steel and the last one of brass—will expand unequally and in the proportion that we have already indicated—that of 121 to 74. The band, B, which we may call the compensator, propped at the top by an invincible obstacle, *y* (Fig. 5), and at the bottom by the two levers, C, C (Fig. 3), will exercise its expansive force upon the points of contact of these two levers and the screw-nuts, D, D, will sink in a quantity equal to the excess of the extension of the band, and will determine the elevation of the cross-bar, *b*, *b*, which rests upon the extremities, *v*, *v*, of the levers.

In order to obtain the exact compensation in this movement, the cross-bar, *b*, *b*, and consequently the cylindrical cross-bar, *a*, to which the crossing of the pendulum-ball is suspended, must wind up in a proportion equal to that of the expansion of the steel bands of the pendulum; this is easily done by combining the arms of the lever in such a manner that, *v*, *t*, or the larger arm, may be as small as the space passed over by the extremity, *v*, is to that passed over by the point of the lever, C, upon which rests the screw-nut, D; that is, that *v t* shall be to *t c*, as 121 is to 74, or as 60·5 : 37, or in the proportion of the expansion of the two metals. This consideration is useless, as we shall see, and will be rejected on account of the difficulties which this theory represents. The two arms of the lever should be made alike, and, by some experiments with the pyrometer, the screw-nuts, D, D, will directly fix the exact point of difference of these two levers for the exact compensation. If one wishes to convince himself of this, after having made the arms of the levers equal in length, let him divide the arm, C, C, into sixty and a half equal parts, and he will be convinced, after having found the exact compensation, that the screw-nuts, D, D, will be fixed near the 37th division.

If the metallic pieces always expanded in a quantity proportional to their dimensions, it would be possible to assign in advance the degree of extension which their surfaces would take, and to determine precisely, in a case like the latter for instance, the point of the levers to which the motive power of the compensation should be applied; but as we have already said, two similar pieces of the same metal rarely expand equally; it is therefore necessary to find for this new pendulum a method of correcting the difference between the true and the calculated expansion.

We use the expressions of the true and the calculated expansion to designate the actual expansion which a piece takes, and that which it should take in accordance with a general rule, determining the degree of expansion proper to each substance. For instance, a piece of brass of a certain size might expand itself three lines and a half, when, according to observations for determining its extension, its expansion ought not to exceed three lines; its true expansion would therefore be three lines and a half, and its calculated expansion three lines.

M. Zademach, who has also observed this, has chosen the most simple and natural method by adopting screw-nuts to transmit the expansive force of the band, B, to the levers; for by the aid of these screw-nuts we can, as we have already remarked, easily find the point of the small arm of the lever to which the compensator should be applied in order to produce, at the opposite extremity, an effect equalling the degree of expansion of the steel bands. It is only necessary to bring the screw-nuts near the point, *t*, *t*, or the points, Z, Z, to correct the inequality produced in the movement of the pendulum by a false compensation.

Other Methods of Compensation.

In 1829, M. Henri Robert, a pupil of Breguet, and a practical clockmaker, presented to the Society of Encouragement two new methods for effecting the compensation of pendulum-clocks.

1*st Method.*—M. Robert having remarked that platinum expands but slightly, while zinc has a great dilatation, in the proportion of 294 to 85, executed a half-second pendulum of these two metals in the following manner:—

He formed his pendulum-rod of a platinum-tube of 13¾ inches in length, including the suspension, and of a pendulum-ball of 5¾ inches in diameter, terminating it towards the carrier screw-nut by an end-piece, of one inch, all of zinc, and cast together.

The report which was made of this invention, by M. Hericart de Thury, may be found in the *Bulletin de la Societé d'Encouragement*, vol. xxviii., p. 50. "M. Robert," says the learned reporter, "has obtained the conditions which he sought,—1st, by utilizing the dilatation of the pendulum-ball, usually counted as nothing, and consequently neglected;—2d, by having a very short rod, in order that the centre of oscillation may coincide as nearly as possible with the centre of gravity of the pendulum-ball;—3d, by making this rod of a slightly expansible metal, while the pendulum-ball possesses the contrary property in the highest degree;—4th, that its compensation, although made of platinum, is but little more costly, and that its price, in clocks of precision, will not be sufficiently increased to hinder its use from becoming general."

2*d Method.*—Fir-wood has long been known to possess the property of preserving an almost equal length in all changes of temperature. Several clockmakers, particularly M. Wagner, presented in the exposition of 1827, a large clock, whose pendulum, beating seconds, had a rod of fir. This wood is also known to have a propensity to twist, in accordance with the hygrometrical influences of the atmosphere. M. Robert succeeded in forming his new compensation in such a manner as to profit by the almost inextensible property of the fir-wood, by sheltering it from the influences of the atmosphere, and thus opposing its torsion.

The rod of the pendulum is formed,—1st, of a prismatic case of brass with a rectangular base;—2d, of a pendulum-ball of the same metal, pierced in its diameter with a mortise, into which the prismatic case glides easily but without play;—3d, of a rule of fir-wood terminated at each end by a little case which surrounds it; the case fixed at the upper end bears a collar which rests on the extremity of the tube, and the suspension-hook is fixed above this collar. The lower case bears a wormed rod at its extremity, which receives a screw-nut, and the counter-nut for supporting the pendulum-ball firmly.

It is evident in this construction, that the wooden rule, which is inextensible, will keep the pendulum-ball at a fixed height; it is therefore the expansion of the radius of this pendulum-ball which compensates the expansion of the suspension-hook of the prismatic case, and of the other parts. This may be made of any size, only observing that in its construction the wooden rule should be made as long as the apparatus will permit, that the rule should enter the prismatic case freely, without touching the sides of it, and that it is only fixed there by the thickness of the band forming the outline of the small cases which terminate the ends of the rule. These two cases should fit exactly into the ends of the prismatic case.

This pendulum is very simple, but the calculation is not sufficient to determine the lengths of the different metals employed in the compensation, which can be obtained only by experiments; this the author has formally confessed.

We fully approve of the fir rule of M. Robert, inclosed in a prismatic case of brass, in which it is sheltered from the hygrometrical influences of the atmosphere, and, consequently, can experience no alteration; for if the fir wood is inextensible by the temperature, it is affected by humidity. The Viscount du Molard has proved by exact experiments, that the silver fir is elongated to one eight hundred and ninetieth of its original length, taken at the zero of the hygrometer of Saussure.

The lower mechanism which supports the pendulum-ball in the invention of M. Zademach can be successfully applied to the construction of M. Robert; and an easy method is thus obtained for compensating the dilatation in pendulums with exactitude.

Mercurial Compensation.

In order to obviate the difficulties attendant upon the frequent trials necessary to obtain an exact compensation of the zinc and platina; the method of adjusting a steel or glass tube filled with quicksilver to a steel-rod, and thus obtaining a speedier compensation, has been successfully adopted. For this purpose a tube eight inches long is attached to the rod—the exact quantity of quicksilver which it must contain can only be ascertained by actual experiments; this, however, is very easy, it being only necessary to pour the quicksilver from or into the tube. In this the expansion of the ball alone forms the compensation.

Compensations of MM. Leroi and Arnold—Chronometer Balance.

Before the application of the pendulum as the regulator of clocks, the balance had been used for this purpose, but this was immediately abandoned after the invention of the pendulum; yet as all exterior motion is opposed to the isochronism of the pendulum, the balance was still the only regulator which could be successfully applied to portable clocks. The addition of the spiral-spring to this regulator has produced a revolution in the measure of time and has permitted it to approach the exactness of the pendulum. The first invention relative to the application of the spring to the balance with the view to obtaining by its elasticity the power which renders the action of this kind of regulator similar to that obtained by means of the gravity of the pendulum, is attributed by the English to Dr. Hook, yet he seems to have made but a limited application of it; Huyghens, extending this idea, substituted for the simple spring the hair-spring, which is much more advantageous to the isochronism of the balance.

The alterations to which the lengths of the pendulums as well as the movements of watches are exposed by the variations of temperature have already been mentioned, but the balance-machines are still more exposed to irregularity, not only because the balance dilates or contracts, according to the raising or lowering of the temperature, but because the spiral-spring itself experiences the same changes. In proportion as the balance contracts, and as its diameter becomes smaller, it is no longer transported in its vibrations in the same manner but oscillates with greater rapidity; besides in proportion as the spring attached to the balance is contracted at the same time by the cold, it acts with a greater power, and these two effects unite in quickening the vibrations. Mr. Harrison has invented a method for correcting these inequalities, which consists in shortening or elongating the spiral-spring when the heat or cold may give it greater or less force. M. Leroi has invented another method, which has been modified by Arnold. It consists in producing a dilatation in the balance itself, instead of a contraction which would be the effect of the cold; by this means the spring, in its greatest state of rigidity, acquires a compensative effect in its functions. This invention of Pierre Leroi is represented in Fig. 32, Pl. IV., in which a chronometer balance is designed. A circular piece of steel is turned and hollowed out in a cup in such a manner as to form a circular grooving of sufficient depth; into this grooving some brass of the best quality is placed together with a little borax in order to prevent the oxydation of the metal; the whole is put in a crucible which is heated sufficiently to effect the fusion of the brass; this last metal being in fusion, will adhere strongly to the brass without the necessity of using solder. The piece thus prepared and cooled is replaced on the lathe, and all the superfluous brass and steel are removed in such a manner as to obtain a regular circle whose exterior is of brass and interior of steel; the thickness of the brass should be nearly double that of the steel. This done, the interior of the plate is hollowed out by means of the file and drill, leaving two or three equal and symmetrically placed radii; in this state the exterior circle is cut in two or three places, even cutting off a portion as in Figure 32, and a small movable weight is adjusted to the extremity of each sector; these masses should be equal in weight and susceptible of being moved and checked on the sectors at the distance from the radii which the essays made in different temperatures may prove to be best suited to the compensation.

It is easy to demonstrate the manner in which this balance works in the changes of temperature. For instance, when the heat which generally tends to retard a watch by its action on the movement, the spiral-spring, and the radii of the balance, acts on this last, the sectors will contract and will consequently draw the masses near the centre to advance the watch; this will effect the compensation, if we are certain of finding the distance at which this compensation takes place, by the displacement of the masses.

We have said before that the sectors are composed of brass and steel; both are dilated, it is true, by the effect of the heat, but in an unequal manner, the brass more than the steel. The inner steel of these sectors being firmly bound to the outer brass, will counteract its greater dilatation, and the effect of the curvature which will result from it will be to draw the masses nearer the centre of oscillation. This will be reversed by the effect of cold.

Fig. 33, Pl. IV., shows a modification of the same principle adopted by Arnold. The compensative weights are cylindrical and are adjusted by screws to the ends of the sectors. These sectors are established on the extremity of the two radii which carry an interior circle; this circle is furnished with three masses with friction which serve to poise the balance.

The necessity of these different masses will be understood, when it is considered that the pivots of the balance sustain an unequal friction in the different positions of the chronometer, and that it is necessary that, the compensation being obtained, the balance may be still in equilibrium in every position.

All these arrangements require experiments, which skill alone can abridge. The frictions should be the same, whether the balance rests on one of its pivots or on the cylindrical faces of both. The balance itself preserves a nearly permanent form, while the spiral-spring, in the vibrations, is more or less relaxed, and its distances from the centre are variable. It cannot be expected that a balance deprived of its spiral-spring, which is in this case in perfect equilibrium, shall still be so and furnish at the same time equal vibrations when it is in its place and in every position. Besides these difficulties, there is an epoch of vibration in which the force of the spring and the inertia of the balance are not simply in opposition in respect to each other, but are combined with the motive-power during the action of the escapement. The remedy of all these difficulties, which has been successfully applied in the construction of marine chronometers, is to maintain them in such a position that the axle of this piece shall be constantly vertical;* by this method this piece is not affected by the differences of gravity. As to the pocket chronometers, the skill of the artists has conceived numerous ingenious methods which we cannot describe in our narrow limits. The general principle most in use, is to consider the balance independent in its adjustment like a pendulum which would be placed above and beneath its centre of suspension, acting by the gravity in the same time in which it is incited to repose by the elasticity. In such circumstances, the vibrations will be more rapid when the fixed point of the equilibrium is below; they will be slower in a contrary position of the machine. This indicates for a remedy the diminution either of the extent of the radius or of the burden of this side, which is the lowest when the velocity is too great. Thus, for instance, if one of the screws placed at the extremity of the radii of the first of the balances described above, finds itself below when the velocity is too great, it must be slightly turned so as to draw its weight nearer the axle, in the same time that the opposite screw will be loosened, and its weight carried a little outside. The defects of equilibrium can thus be remedied without any other derangement. If an imperfection is perceived in the vibrations of the balance when it is tested in a vertical position, having its lowest point at rest, in a line making a right angle with that which passes through the middle of the radii, a similar change should be effected in the masses of expansion, either by a slight deflection of the circular sectors, or by altering the mass;

* The chronometer will consequently be in a horizontal plane. To keep it in this position despite the movements of the vessel, it is suspended on gimbals. This consists in supporting the case on two pivots placed above its centre of gravity, which pivots are themselves suspended on a brass ring, which is free to oscillate on the horizontal plane. The pivots of the case and those of the ring are thus perpendicular in their direction.

or, which is still better, by means of small screws fixed into the regulating masses themselves, which are thrown back from or drawn towards the centre of the balance in the same manner as are those placed at the extremity of the radii. By these methods, and by corresponding ones, the balance can be arranged in such a manner as to furnish equal vibrations in every position in which its plane is not parallel to the horizon; but these essays require much pains and care before exact results can be obtained.

It often happens that chronometers tested in extreme temperatures, and regulated in these limits, are irregular in intermediate temperatures; their balances then disagreeing with the movements, these are replaced by others; and the balances which disagree with such movements are often found to go well with the others.

Sometimes it also happens that the balances compensate too much, but this is easily provided for by advancing the compensating masses of the sectors of the radii, and by taking care that this advancement does not change the equilibrium of this piece. As there are two kinds of movable masses, it is easy to obtain these conditions, which are essential to the regularity of the functions of the balance.

A very curious observation was made in New Holland, by General Brisbane, the governor of this establishment; he perceived that perfectly regulated chronometers, when they were set towards the east in a certain position in respect to the horizon, experienced some variations when changed from this position: the following explanation of this phenomenon has been given.

Before attaining their definitive form, the balances of the marine chronometers, composed, as we have already said, of steel and of brass, sustain a repeated friction from the burin and the file. This operation procures a factitious magnetizing to the balance, as may easily be perceived by submitting it to a contact with iron filings. These particles attach themselves to the radii and to the limb, and it therefore seems that the balance is magnetized, and it is probable that it is polarized.

If, in this state, a balance was disengaged from its spiral-spring, admitting it to be sufficiently free on its pivots and in a horizontal position, it would discover the east on account of the magnetic line of the place, in a manner closely resembling the needles of the compass; but there would be, in consequence, other positions or poles of the same sort, also set towards the east, which would be repelled, while, in the contrary case, they would be attracted. Thus the position of the chronometer may be such with regard to the magnetic meridian of the globe, that the balance experiences difficulties or facility in being brought back to its position, and these causes may be combined together, be avoided, be added or even poised.*

On land it is easy to give to these instruments a fixed position in one locality; but in a vessel, which so often changes its position with regard to the horizon, it is quite a different thing. Each ship, in respect to the quantity of iron, of cannon and steam engines which it contains, is a

* Ships themselves contain so great a quantity of bars of hammered iron, cannons, and iron projectiles, that they may be considered as a magnetic mass possessing two poles and a particular magnetic meridian. Here, then, are three circumstances which may be combined to act by their sum or difference on the movement of the balance of marine chronometers.

Steam-ships are those most exposed to these variations by reason of the masses of iron which they contain and which is continually in motion. But not by transporting a chronometer to any part of the globe, and observing the differences when it is brought back to the point of departure, can we perceive them all. Steam-ships, not being subjected to the variations of route which may result from contrary winds, follow a direct line in their course, both in going and returning; it is therefore probable that the errors will be compensated in a great measure by the two inverse positions of the ship, relatively to the magnetic meridian of the globe.

polarized body; its magnetic meridian combines with that of the globe in a manner which differs in each ship, according to the locality, and it will not be strange if variations are found in each of them. These anomalous causes may have but a slight influence on chronometers, but as they may be added to others, it would be well to seek methods by which to provide for them. Other metals than steel may be employed in the construction of the balances of marine chronometers, platinum for instance, whose dilatation in proportion to the brass is still less than that of the steel.

The thickening of the oils which are used to lubricate the pivots of the trains, is not one of the least causes of variation, especially when great changes of temperature are experienced. These changes affect the liberty of the movement in proportion to the frequency of the renewal of the oils, and to the accumulation of particles in the pivot-holes; this is also true of the dust, which it is very difficult to hinder from penetrating into the interior of the frames, however hermetically they may be closed.

CHAPTER VIII.

THE REGULATOR.

The circular balance is generally used as a regulator in portable clocks, or in those whose place is often changed. Steel was first employed in the construction of this, but was afterwards rejected, as it was thought that its attractibility to the magnet might affect the regularity of the clock. Brass, and sometimes gold, have been used for substitutes; brass is generally employed.

In all of the stationary clocks, the pendulum serves as a regulator. Here, the kind of metal employed is of less consequence, and the regularity of the movement depends, in a great measure, on the exact length given to the regulator.

In both cases, clock-makers must follow the invariable rules indicated by physics, and developed by the learned artists who have written upon this subject. We shall divide this chapter into two sections, in which we shall point out that which it is indispensable to know.

I.—THE REGULATOR IN PORTABLE CLOCKS.

Berthoud was the first who carefully studied and clearly described the solution of the different problems necessary to attain perfection in this important part of horology.

The first watches that were constructed had small steel balances, very slight, and without a hair-spring; their movement was, consequently, very irregular. In 1695 the celebrated Huyghens invented the spiral or hair-spring, which he applied to the balance, thus causing it to produce vibrations independent of the escapement; the diameter of the balance was then increased, and its vibrations were perceived to be quicker and of less extent in proportion as the spiral-spring was stronger, and on the contrary, to be slower and more extended as the spring was weaker. It was therefore evident that a great degree of accuracy might easily be obtained by the combination of these three elements—the diameter and weight of the balance, and the strength of the spiral-spring, in order to obtain the greatest regularity.

The principle was acknowledged, but its application was not easy; science had not then progressed far enough to give the solution of so important a problem; and they experimented for a long time before they gained their object. Sully and Julien Leroi, the most skilful clockmakers of the beginning and end of the eighteenth century, had already opened the way, but to the indefatigable and learned Berthoud was reserved the task of bearing the light of science to an essential part of the art. It is not sufficient in the industrial arts to possess theoretical science in a high degree, but practice must also be joined to it; that is, one must be an artist to make a correct application of science. We have irrefragable proofs of this truth every day. Berthoud joined practice to theory; it is not strange therefore that he threw a brilliant light upon questions which, until then, had been unresolved.

In comparing the effects of the pendulum, of which we shall presently speak, with the balance moved by the spiral-spring, he reasoned in this simple manner:—"If a balance is made, to which a given impulse procures isochronal oscillations, and preserves its movement during a very long time, the frictions and the resistance of the air are reputed to be reduced to the smallest possible quantity, so that this balance will be the best regulator applicable to a watch. We will therefore consider how we may obtain this.

"It has been demonstrated that the forces which bodies in motion employ to overcome obstructions are in the composite ratio of their masses, and of the square of their velocities.

"Now, as the force produced in a body is equal to the action which causes it, it follows that the force which has been used to give a motion to a body, is as the product of the mass of this body, by the square of the velocity that it has acquired. If we compare two bodies of different dimensions, designating the parts of the large body by capital letters, and the corresponding parts of the small body by italics; we will indicate the first body or the first balance by A; its mass by M; its velocity by V; and its force by F; and in the same manner we will designate by a, the second body or the second balance; by m, its mass; by v, its velocity; and by f, its force;—we shall have this proportion:—$f : F :: v^2 m : V^2 M$. But as the product of the extremes is equal to the product of the means in every geometrical proportion, we shall have the following equation:—$f V^2 M = F v^2 m$, which is applicable to all cases.

"1st. If the two forces are equal; that is, if we suppose that $f = F$, we can suppress them in both members of the preceding equation, as the two members are thus divided by the same number which does not change the quotients. Thus we shall have $V^2 M = v^2 m$, which signifies that when the forces of two balances are equal, the masses, multiplied by the squares of their velocities, are also equal. We can draw a geometrical proportion from this last equation by considering the first member as the product of the extremes, and the second member as the product of the means; we shall then have $V^2 : v^2 :: m : M$; that is, when the forces of the two balances in motion are equal, the masses are in the inverse ratio of the square of the velocities; or if the masses are in the inverse ratio of the square of the velocities, the forces of the balances are equal. For instance, if the velocity of $A=1$, and that of $a=2$, the square of the velocity of $A=1$, and the square of the velocity of $a=4$; if the mass of the balance $A=4$, and that of $a=1$, by placing these numbers in the place of the letters of the last equation $V^2 M = v^2 m$, which expresses the value of the forces of each of the two balances, we shall have $1+4= 4+1$; consequently both forces are equal since $4=4$. This clearly proves what we have advanced.

"2d. If the masses of the two balances are equal, that is, if they have the same weight so that $m=M$, the fundamental equation $f V^2 M = F v^2 m$, becomes $f V^2 = F v^2$, by dividing the two members by the equal quantities $m=M$, from which we draw this proportion $f : F :: v^2 : V^2$; which signifies that if two balances have equal masses and are moved with unequal velocities, their forces are in proportion to the squares of their velocities. We will again substitute the numbers for the letters in the preceding proportion, to render it more intelligible to those unaccustomed to this form of calculation. Let us suppose that the velocity of the balance A, expressed by $V=1$, its square, or $V^2=1$; that the velocity of the balance a, expressed by $v=4$, its square, or $v^2=16$; and the preceding proportion will be thus transformed,—$f : F :: 16 : 1$, which signifies that the force requisite to sustain the movement of the balance a, is to that requisite to sustain the movement of the balance A, as 16 to 1; that is, these forces are as the squares of their velocities.

"3d. If the velocities of these two balances are equal; that is, if $v = V$, the primitive proportion will become $f : F :: m : M$, and consequently the forces will be in the proportion of the masses; the actions required to sustain the movement will, therefore, be as the masses, or as the weight of the balances.

"4th. In general, if the velocities and the masses of the two balances are unequal, their forces will be to each other as the composite relation of the product of the masses by the squares of the velocities; this is expressed by the primitive and fundamental problem $f : F :: v^2 + m : V^2 + M$."

From these principles, Berthoud resolved all problems relative to the balances, and determined their weights, their diameters according to the number of vibrations, the force requisite to make them pass over certain arcs, etc.

"By knowing the mass of a balance, its velocity and the force which sets it in motion, in a well-executed and tried watch, we can easily deduct all the conditions required for the balance of another watch, when it should have a different mass, more or less velocity, more or less motive force, etc.

"To compare the velocities of the two balances, we must multiply the number of vibrations during a given time by the diameter of each balance; the products will express the velocities when they describe similar arcs, but when this is not the case, it is necessary to make a product of the three following quantities for each balance; 1st, of the number of vibrations in the same time; 2d, of the diameter or radius of the balance; 3d, of the arc passed over by the balance. Some examples will show the application of this."

Berthoud observes that these calculations relate to the cylinder escapement, but we add that they are applicable to all dead-beat or detached escapements, and generally, to all escapements which require the spiral spring. As to the balance-wheel watches, these calculations are useless; for all workmen know that it is easy to proportion the weight of the balance to the motive-power, whatever may be its diameter, the arcs it passes over, etc. It is only necessary to cause the watch to go without the spiral spring in such a manner that the minute-hand will pass over from 25 to 27 minutes an hour, thus losing from 33 to 35 minutes an hour. Yet Berthoud observes that the amount of this loss should vary; 1st, according to the frictions of the pivots; 2d, according to the size of the balances; this loss, therefore, cannot be precisely stated, as it varies in every watch, so that in those pieces in which great accuracy is wished, it will be well to determine by the same calculation the weight of the balance from the force of the motive-power.

"To succeed exactly," says Berthoud, "in proportioning the weight of the balances of watches which go with the spiral-spring, to the motive-power, I commenced by constructing an instrument by means of which I could with the greatest precision determine the force which the mainspring communicates to the train. By placing this instrument upon the square of the fusee in the same manner as a lever for equalizing fusees, the force of the spring may be estimated by the degree of the branch where the weight is stopped in order to equilibrate with the spring; by comparing the force of the motive-power with that of a watch, we determine the weight of balances," etc. A description of this instrument will be given in the chapter on tools.

"To find the dimensions of a watch which we wish to make, we use, as a term of comparison, a good watch, arranged as well as possible, and constructed in such a manner as to reduce the frictions to the smallest quantity; so that the motive power may have the requisite relation to the regulator, that the watch may go with the greatest possible accuracy. This done, we measure the diameter of the balance, and its weight; count the number of vibrations which it makes per hour, and the extent of its vibrations; compute the force of the main-spring by means of the instrument of which we have just spoken; and finally reckon the time which the fusee, or the barrel-arbor when there is no fusee, takes to make a revolution.

"I prefer the use of a carefully executed watch to determine the dimensions of another, differently constructed, for two reasons; 1st, because the calculation is more easy for the workmen, and 2d, because the dimensions are more exact than could be procured by calculation alone; as the effects of the frictions are not sufficiently understood, the motive-power of a watch being given as well as the diameter of the balance, to be able exactly to ascertain its weight and the arcs which it should pass over; while by comparing it with a watch already made, these requisites are found at once, and the necessary dimensions can be obtained with more precision.

Problem First.

"The dimensions of a comparison-watch, A, being given, to find the weight or mass of the balance of another watch, *a*, the diameter of its balance and the number of its vibrations being known."

As calculation by decimals is more easily executed than by fractions, we have changed the solutions of Berthoud to decimal fractions.

"In the solution of this problem, we suppose that in the watch *a*, the extent of the arcs of the motive power is of the same size as those of the comparison-watch A, and we demand that there shall be the same relation of the motive-power of the watch *a*, with its regulator, as there is between the motive-power of the watch A and its regulator.

We give the following dimensions of the comparison-watch A, which is a cylinder-escapement like that which is to be made. We have placed below, in the same line, all the data of the watch *a*, placing the letters corresponding to the general formula before each article in order to facilitate the operation.

Comparison-Watch, A.

M.	Weight or mass of the balance, ...	grains,	6·25
V. {	Diameter of the balance, ...	lines,	8·50
	Vibrations per second, ...		5·
	Extent of the arcs of vibration, ...	degrees,	2 40
	Fusee in 5 hours, ...	revolution,	1·
F.	Mainspring producing an equilibrium at $4\frac{1}{4}$ inches from the centre of the fusee at, . . .	drams,	5·75

Watch to be Executed, *a*.

m.	Weight or mass of the balance, ...	grains,	x.
v. {	Diameter of the balance, ...	lines,	10·25
	Vibrations per second, ...		2·
	Extent of the arcs of vibration, ...	degrees,	2 40
	Fusee in 5 hours, ...	revolution,	1·
f.	Mainspring causing an equilibrium at $4\frac{1}{4}$ inches from the centre of the fusee at, . . .	drams,	5·15

As the forces of the spring are supposed to be equal, we have the second proportion to resolve—$V^2 : v^2 :: m : M$, but m being the unknown quantity which we seek, this proportion becomes $V^2 : v^2 :: x : M$, which gives us the equation $x = \frac{V^2 \times M}{v^2}$.

To obtain the velocity of the balance A, in figures, 8·50, which expresses the diameter of the balance, must be multiplied by the 5 vibrations which it makes per second;—this gives 42·50. By multiplying this number by itself, in order to raise it to a square, we have 1806·25, for the value of V^2.

In the same manner, to obtain the value of v^2, 10·25 must be multiplied by 2 vibrations per second, which gives 20·50, the square of which is $420·50 = v^2$. By substituting the numbers which we have just found for the letters in the preceding equation we have $x = \frac{1806·25 \times 6·25}{420·50}$; an equation which is resolved by the simple rules of arithmetic. The quotient will give the weight of the balance in grains.

Problem Second.

If the forces of the springs are not equal, this datum must be entered into the calculation, and the fundamental equation or proportion which we have furnished executed thus, $f : F :: v^2 m : V^2 M$; in which we see that the forces which we had neglected, supposing them equal, become elements of the calculation, which is conducted in the same manner as in the preceding problem.

Problem Third.

In the two preceding problems, we have supposed that the two fusees, or barrel-arbors when there is no fusee, each make one revolution in 5 hours; but if the watch to be constructed should make more or less revolutions than the comparison-watch, it becomes necessary, in order to be able to compare the motive powers, to reduce them to unity; that is, to the force which will be necessary to move the slowest fusee. Thus, supposing the watch, *a*, to be an eight-day watch, whose fusee revolves in 40 hours, while the watch, A, performs this in 5 hours, we make this proportion:—If 5 hours require 5·75 drams of force, how much force does 40 hours require, and, consequently, $5 : 5·75 :: 40 : x$. In executing it, we find that the spring of the watch, *a*, should have a force of 46 drams, placed $4\frac{1}{4}$ inches from the centre of the fusee, and this new element will be added to the proportion, which will no longer present any difficulty.

General Observation.

Those of our readers who are accustomed to calculations will perceive that the general proportion, or each of the proportions which the author has deducted from it, may be easily used to find one of the unknown elements, the others being given. Let us suppose the same data which we gave in ascertaining the value of *m*, and that we wish to find the diameter to be given the balance of the watch, *a*.

We will avail ourselves of the second proportion $V^2 : v^2 :: m : M$. Our unknown quantity is found in the term v^2, as it is the diameter of the balance, connected by means of multiplication with the number expressing the vibrations which it makes per second, and the product then raised to a square; it is therefore necessary to invert our process for finding the value of v^2. We then have the equation v^2 or $x^2 = \frac{1806{\cdot}25 \times 6{\cdot}25}{18{\cdot}20}$.

In executing it we find $x^2 = 620{\cdot}28$, but this number is the square of x; it is therefore necessary to extract the square root, which gives 24·90. This last number is the product of a multiplication, one factor of which is the required diameter of the balance, while the other factor is 2 per second. By dividing 24·90 by 2, we have 12·45 lines for the diameter of the balance, which differs a little from the 10·33 which Berthoud supposed.

This author afterwards perceived this difference, and executed another comparison-watch, A, with still greater care, whose elements it is only necessary to give, as they do not change the principles, nor the forms of calculation which have already been shown.

Comparison-Watch, A.

M.	Mass or weight of the balance, ...	grains,	19·75
V.	Diameter of the balance, ...	lines,	10·50
	Vibrations per second, ...		2·
	Extent of the arcs of vibration, ...	degrees,	2·40
	Fusee in $4\frac{1}{2}$ hours, ...	revolution,	1·
F.	Mainspring causing an equilibrium at $4\frac{1}{4}$ inches from the centre of the fusee at, . . .	drams,	3.

By substituting these data for those in the preceding calculations, much more accurate results may be obtained.

Clockmakers have generally adopted for the dimension of the balance the same dimension of the diameter of the barrel. This seems to have been the practice of Breguet, and is nearly the same with that adopted by Berthoud from the calculation.

II.—THE PENDULUM.

The pendulum is the most important piece of the clock-work, as we have already said; it is the true instrument of the measure of time, dividing the time by its oscillations, and regulating the velocity of the wheels by the escapement to which it is joined. By a double effect of the escapement, these same wheels transmit to the pendulum the force of the motive-power, and sustain its oscillatory movement, which the frictions and the resistance of the air tend to destroy.

It is essential to neglect nothing connected with the study of the pendulum. Before arriving at the practice, one should therefore impress himself with the following principles which are adopted in physics.

Theory of the Pendulum.

The pendulum is used in the study of the gravity when its force is to be exactly determined. We know that, at Paris, the velocity which is communicated to a falling body is 32 feet at the end of a second, while in the first second the body only passes over 16 feet in its fall. To measure this force of gravity in a specific manner—the body falling too quickly—we must have recourse to the pendulum. The pendulum is of great importance in this respect, as it serves to mark the ratio of the force of gravity in different places, as we shall presently see.

Another application of the pendulum consists in the balances of clocks. In this connexion it is very essential to study it in this work.

We distinguish two kinds of pendulums,—the *simple pendulum* and the *composite pendulum.*

The simple, or rather the ideal pendulum, consists of a heavy point, suspended by an inextensible thread without weight, and moving without friction around a fixed point. This pendulum cannot be realized, but we can calculate what its laws of motion would be if it existed.

The composite pendulum is a body susceptible of being moved around a horizontal axis. The forms and dimensions of this are variable. Before investigating the laws of the pendular movement, we will examine the nature of the movement of a simple pendulum.

Let us suppose a pendulum, A, B. We know that it will be in equilibrium when the thread by which the material point is suspended shall be vertical; the action of the weight upon the movable part will then be destroyed by the resistance of the fixed point to which it is suspended, but if we draw aside the pendulum to an inclined position, and then abandon it, it will not remain there, but will descend to regain its original position, with swinging movements termed oscillations; these oscillations in a simple pendulum would have equal duration and amplitude.

The weight that acts on the material point is a vertical force, which may be separated into two parts,—one, acting with the prolongation of the thread, is destroyed by the resistance of the fixed point, the other, acting in a perpendicular direction, has all its force, and attracts the movable part. This decomposition of the weight may be made at each point of the arc described by the movable part, and the nearer this movable line approaches the vertical, the more will the effective component diminish. It is evident that the weight will move as far as its original position with an accelerated movement, neither uniform nor uniformly varied, for the effective component which causes it to act, although continually diminishing, yet transmits to it an accelerating force which adds at each instant to the first impulses, and thus augments its velocity.

On regaining its primitive position, the pendulum will ascend on the other side by reason of its acquired velocity, although the gravity which attracted the movable line is entirely destroyed. The gravity will then act again upon it, but as a force abating its velocity. It will ascend on the other side to the same height that it quitted, then redescend, executing another oscillation precisely like the first. It therefore follows, that during the ascending movement of the pendulum, the weight will take away all the increase of the velocity transmitted to it in its descent.

If we suppose the pendulum to be exempt from all friction, the oscillations will constantly have the same amplitude and the same duration, and will be indefinitely continued. But in performing the experiment with a composite pendulum, we are certain that it will stop; partly on account of the resistance of the air, and partly because of the friction of the upper part of the pendulum. The following are the laws of the pendular movement of which we have just spoken, that is of the simple pendulum:—

First Law.—The oscillations are isochronal. By this we understand that they are executed in the same time, and that their duration is independent of their amplitude, so long as this amplitude does not exceed certain limits.

Second Law.—The duration of the oscillations in the same place for pendulums of different lengths, varies in proportion to the square roots of the length of these pendulums. Thus, a pendulum which is four times the length of another, requires twice as much time for making an oscillation, or makes but one while the other makes two; a pendulum nine times the length of another requires three times as much time for its oscillation, or makes but one while the other makes three.

Third Law.—The duration of the oscillation is in the inverse ratio of the square root of the weight; that is, if the weight has 4, 9, 16 . . . times more intensity, the pendulum will beat 2, 3, 4 . . . times faster.

These three laws are implicitly included in the formula $t=\pi\sqrt{\frac{l}{g}}$ in which t is the time of an oscillation; π the relation 3·14159 of the circumference to the diameter; l, the length of the pendulum; and g, the intensity of the weight; t is expressed in seconds, and l in inches.

Composite Pendulum.—What we have said applies to a simple pendulum, oscillating in a vacuum, which cannot be realized, but if we suppose this pendulum to oscillate in the air, the resistance of the air will gradually diminish the amplitude, and finally stop the pendulum. The composite pendulums used in the arts and sciences are generally formed of a prismatic, or cylindrical rod, to which a heavy metal ball is suspended, and which rests by a steel suspension upon two polished planes of steel or agate.

When a composite pendulum is set in motion, the connexion existing between all the parts of the apparatus necessarily requires that all the molecules—whatever may be their distance from the axis of suspension—shall execute their oscillations in the same time. Now if the molecule A, which is the nearest the axis of suspension, were free, it would oscillate more quickly than the molecule B, which is the most distant. But by reason of the connexion of the system, the velocity of A will be abated, while that of B will be accelerated, and there will necessarily be another point, C, between these two extreme points, whose motion will neither be accelerated nor retarded. This point, and all those at the same distance from the axis of rotation, will oscillate as though they were free. This is called the *centre of oscillation.*

We therefore conclude that a composite pendulum executes its oscillations in the same time as a simple pendulum, whose length is the distance from the centre of suspension to the centre of oscillation.

But yet there is a difference: a simple pendulum having no resistance to overcome, moves indefinitely without any variation of the amplitude or duration of its oscillations; whilst in a composite pendulum, the friction of the axis of suspension against the supports with the resistance of the air which it is obliged to displace, gradually diminishes its velocity, and brings it sooner or later to a state of rest. But, happily, despite the diminution which the amplitude of the oscillations of the composite pendulum continually experiences, their duration remains the same when these oscillations are small. This is evident, as the resistance of the air and the friction lengthens the descending semi-oscillation in a quantity equal to the diminution of the ascending semi-oscillation by the same causes. The duration of the whole oscillation remains the same, and the laws contained in the formula $t=\pi\sqrt{\frac{l}{g}}$ are appliable to the composite pendulum, provided that we understand by l, the length of this pendulum, the length of the simple pendulum to be synchronous with it.

Applications.

1st. *Measure of the force of gravity.*—"We deduct from the above formula," says M. Pinaud, in his programme of a course of physics, "the following value:—$g=\frac{\pi^2 l}{t^2}$."
To calculate g, it is only necessary to know the length of the pendulum and the time of an oscillation. These measures have been obtained with great precision by Borda, of Paris. He first obtained the length, l, by measuring with a micrometrical apparatus the distance from the axis of suspension to the centre of oscillation. To obtain the duration, t, of an oscillation, it is necessary to count the number of oscillations made by the pendulum in a given time, and to divide this time, expressed in seconds, by the number of oscillations. But as this counting would be very laborious, and liable to many errors, Borda eludes these inconveniences by the *method of coincidences*. He places the pendulum near a well-regulated clock, the balance of which beats faster or slower, and at a given instant sets both in motion. From the first oscillation they cease to go together, and at the end of a certain time they again coincide at the point of departure. The number of pendular oscillations

during this interval of the two coincidences must then be counted; this number will be constant. It will henceforth suffice to count the number of coincidences in order to deduct the total number of oscillations effected in a time marked by the clock, and consequently the duration of each of them. This method is susceptible of extreme precision.

We thus find that $g = 32$ feet. We thence conclude that at Paris a heavy body, falling in a vacuum, passes over 16 feet in the first second of its fall. The number g being known, if in the formula $g = \pi \frac{2\,l}{t^2}$ we suppose $t = 1$, we can calculate the length of a pendulum beating seconds in the latitude of Paris; we find $l =$ 39·12+inches.

2d. *Variation of the Force of Gravity with the Latitude.*—The force of gravity from the surface of the earth varies with the latitude, increasing from the equator to the poles. This may be verified by transporting the same pendulum to various parts of the globe, and measuring in each place the time of the pendulum oscillation, or the number of oscillations made in a given time. In truth, if the intensity of weight augments, the duration of the oscillation diminishes, according to the third law. Now the fact has been well established by numerous observations, that the *same pendulum* oscillates more slowly at the equator than in the polar regions, and that the oscillation becomes slower as it approaches the equinoctial line.

What are the causes of this diminution of the force of gravity in going from the poles to the equator? There are two:—1st, the flattening of the terrestrial globe; 2d, the centrifugal force.

The earth rises at the equator and flattens at the poles. According to astronomical calculations, the radius of the equator exceeds the radius of the poles about fifteen miles.

One of the principles of mechanics is that the attraction of a spherical or spheroidal mass upon a point placed at its surface, is the same as though the whole attracting mass were concentrated in its centre. The points which are at the equator, being farther removed from the centre of terrestrial attraction than are those at the poles, should therefore be less strongly attracted, since the weight decreases as the square of the distance augments. The force of gravity is only constant in reality when very near the surface of the globe; when the distance is comparable to the terrestrial radius, the gravity diminishes as the square of the distance increases. This decrease may be sensibly perceived at the summit of high mountains.

In the second place, the earth turns upon its axis once a day; its centrifugal force is increased in each parallel circle in proportion to the greater radius of the parallel, and as the equator is the greatest of all, the centrifugal force is there at its maximum. Besides, the centrifugal force at the equator is directly opposed to the action of gravity, as it acts in conformity with the prolongation of the terrestrial radius or of the vertical. In the other parallels, the direction of the centrifugal force, which acts according to the prolongation of the radii of these circles, is inclined to the vertical in proportion as the circle approaches the poles. But a part of these forces—the vertical component—then resists the gravity, and it diminishes as the inclination increases.

At the poles, the centrifugal force has no effect. It has been calculated that if the earth turned seventeen times faster at the equator, the centrifugal force would equal the gravity, and bodies would lose their weight.

The pendulum is not only of service in demonstrating that the force of gravity decreases in going from the poles to the equator, but also in determining the law of this diminution, and consequently, the flattening of the globe and its figure.

The laws of the pendular movement are very important, as they find an application in numerous physical phenomena.

The isochronism of the oscillations of the pendulum forms the most exact and valuable means for the measure of time, and we shall now regard it in this light.

III.—THE PENDULUM OR REGULATOR OF STATIONARY CLOCKS.

Galileo first conceived the idea of measuring time by the oscillations of the pendulum, but we owe to Huyghens the application of this pendulum to clocks in order to obtain the regularity of these movements. He projected the means of making it serve as a moderator to the trains of machines designed to measure time; we will give a brief abstract of his laws for the pendulum.

"It has been demonstrated, 1st, that pendulums describing arcs of any kind, perform their vibrations in times which are to each other as the square roots of the lengths of the pendulums.

"2d. That the lengths of the pendulums are to each other as the square of the time of vibration in each. The longer the pendulum, the more time remains for its vibrations; so that if the lengths of two pendulums are to each other as 4 to 1, the times of vibrations will be to each other as 2, the square root of 4, and 1, the square root of 1 of these lengths. It therefore follows that while the pendulum 4 makes one vibration, the pendulum 1 will make two. It is evident then, that if these pendulums beat during the same time, the numbers of the vibrations will be to each other as 1 is to 2; that is conversely as the square roots of the lengths."

For the convenience of artisans, tables have been formed in accordance with these principles, indicating the length to be given a pendulum to beat in an hour a given number of vibrations, determined by the wheel work, or to show the number of vibrations which should be beaten, the length of the pendulum being given.

To form these tables, it is first necessary to determine the length of a pendulum beating seconds; that is, making 3,600 vibrations per hour. The celebrated Huyghens fixed this at 3 feet, 8 lines, and 50 hundredths of a line by rule. The academicians of Mairan and Bouguer have found, from repeated experiments, that the length of a simple pendulum beating seconds, at Paris, should be 3 feet, 8 lines, and 57 hundredths of a line by rule; that is 7 hundredths longer than that of Huyghens; an important, though apparently very slight difference.

At the time of the establishment of the metrical system in France, the commission of geometricians who were charged with this work, verified the preceding calculations, and discovered an error therein. The accuracy of the instruments, and the improvements which had been introduced since these calculations were made, gave them facilities for rectifying the operations, and they fixed the length of the simple pendulum at 3 feet, 8 lines, and 559 thousandths of a line, which gives an excess of 59 thousandths over Huyghens, and of 11 thousandths over the academicians; a slight difference, yet important to science.

It may be well to state here that the length of pendulums beating seconds is not the same; 1st, in all countries; being longer at the poles and shorter at the equator, this variation in each degree of latitude is caused by the centrifugal force which impels the terrestrial globe in its diurnal rotation: 2d, in all places elevated above the sea; as the weight varies in places removed from the centre of the globe where attraction is exercised.

We will conclude this chapter by the description of an ingenious method invented by Berthoud for regulating the length of a pendulum by the movement of the clock when a slight motion of the screw-nut which supports the pendulum or ball has made it too long or too short. He fixes at the bottom of the ball, by two screws, a piece of brass (Fig. 6, Pl. V.), whose upper part, A, encircles the thickness of the ball; the rod, L, is cylindrical, and is pierced through with a cylindrical hole, into which the end of the pendulum passes freely and without play. This is turned cylindrically, and is terminated by a screw, upon which the screw-nut, M, and the counter-nut, N, move. A cylindrical plate of brass, O, slides easily, and without play, upon the cylinder, L, and is fixed at the proper point by the adjusting-screw, P. By raising or lowering this cylindrical round-plate, the centre of oscillation of the pendulum is imperceptibly changed, and the divisions marked on this cylinder direct the regulation. The screw-nut, M, is only used when the extremity of the cylinder has been reached without obtaining the desired regularity.

This is now effected by a small weight, placed on the rod midway between the point of suspension and the pendulum-ball, and held in its place by friction; this weight is adjusted by trial.

CHAPTER IX.

METHOD OF CALCULATING THE NUMBER OF TEETH WHICH THE WHEELS AND PINIONS OF A MACHINE SHOULD HAVE IN ORDER THAT SEVERAL MAY MAKE A GIVEN NUMBER OF REVOLUTIONS IN THE SAME TIME.

The authors who have written on horology, and the learned mathematicians who have written on mechanics, have all given rules, more or less simple and easily executed, for determining the number of teeth of wheels and leaves of pinions which the different parts of the same machine should have in order that the whole train may cause the last of these wheels to make a given number of revolutions during one or several turns of the first. We do not intend to describe here all the methods which have been proposed, for we do not write for those scientific artists who are familiar with all the intricacies of calculation.

We know of no process more simple than that indicated by Camus in his *Eléments de Mécanique Statique*, Book XI., and shall therefore take him as a guide in our treatment of this subject. We shall now occupy ourselves with the solution of some problems which an artisan may have occasion to resolve in ordinary horology.

Fundamental Principle.

Whether a wheel carries a pinion or a pinion a wheel, the number of revolutions of the wheel, multiplied by the number of its teeth, is equal to the number of revolutions made in the same time by the pinion, multiplied by the number of its leaves; so that the number of synchronal turns of the wheel and the pinion are conversely proportional to the number of their teeth.

Let us suppose the number of teeth of the wheel, A, and of the pinion, F, to be represented by the capital letters A, F, and the number of their synchronal turns by the italics a, f.

"We wish to demonstrate that $a \times A = f \times F$, and, consequently, that $a : f :: F : A$.

"*First*, The number of the teeth of the wheel being represented by A, the wheel will work into the pinion at each revolution a number of teeth represented by A. Thus, while the wheel shall make a number of revolutions expressed by a, it will work into the pinion a number of teeth represented by $a \times A$.

"*Second*, As F represents the number of leaves of the pinion, this will work a number of leaves expressed by F into the wheel at each revolution. Thus, while the pinion shall make a number of turns expressed by f, it will work into the wheel a number of leaves expressed by $f \times F$.

"But while the wheel and the pinion are making their simultaneous revolutions, as many teeth of the wheel will work into the pinion as leaves of the pinion will work into the wheel. Thus we shall have $a \times A = f \times F$; and regarding the two terms of the first member of this equation as the product of the extremes, and the two terms of the second member as the product of the means of a geometrical proportion, we shall have $a : f :: F : A$, as we advanced.

We may conclude from this demonstration that if we have a train composed of as many wheels as may be necessary, with a like number of pinions working successively into each other, the same principle will be applicable to every part of the train. Let us suppose four wheels, designated by the capital letters A, B, C, D, with four pinions designated by the capitals F, G, H, I; representing the synchronal revolutions of the wheel A, and of the pinions F, G, H, I, by the italics a, f, g, h, i; we shall have according to the preceding proposition for each wheel working into its corresponding pinion, the four following proportions:—

1st. $a : f :: \mathrm{F} : \mathrm{A}$;
2d. $f : g :: \mathrm{G} : \mathrm{B}$;
3d. $g : h :: \mathrm{H} : \mathrm{C}$;
4th. $h : i :: \mathrm{I} : \mathrm{D}$.

By multiplying these four proportions in order; that is, the antecedents of each proportion together, and also the consequents, according to arithmetical rules, and suppressing in the antecedents and the consequents of each proportion those terms which are common to both, the terms of the first member will be reduced to two, a, and i, and we shall have the following composite proportion:—

$a : i :: \mathrm{F} \times \mathrm{G} \times \mathrm{H} \times \mathrm{I} : \mathrm{A} \times \mathrm{B} \times \mathrm{C} \times \mathrm{D}$, whence we deduce the equation, $a \times \mathrm{A} \times \mathrm{B} \times \mathrm{C} \times \mathrm{D} = i \times \mathrm{F} \times \mathrm{G} \times \mathrm{H} \times \mathrm{I}$, and, consequently, $i = \frac{a \times \mathrm{A} \times \mathrm{B} \times \mathrm{C} \times \mathrm{D}}{\mathrm{F} \times \mathrm{G} \times \mathrm{H} \times \mathrm{I}}$. The number of revolutions, i, of the last pinion, I, will therefore be equal to the number of revolutions, a, of the first wheel, A, multiplied by the product of the number of the teeth of all the wheels, and divided by the product of the number of leaves of all the pinions; so that if we make $a=1$; that is, if we consider that the wheel A makes but one turn, the result of this equation will give the number of turns, i, which the pinion, I, will make while the wheel, A, is performing its revolution.

"It also follows from this example, that if the train which is to be executed should have one or two wheels, and as many pinions more or less than the four supposed in our example, it will only be necessary to add or subtract the required number from the four proportions, so as to have but one for each wheel and each pinion."

This general rule is applicable to the calculations of all trains which ordinary watch-making may require, as we shall prove in the following examples.

PROBLEM FIRST.

To find the number of teeth and leaves required for the wheels and pinions of a clock or watch beating seconds; that is 3,600 *vibrations per hour.*

Custom has fixed the number of the wheels and pinions in watches to be four, thus styled—1st, the large centre-wheel which makes one revolution per hour; 2d, the small centre-wheel; 3d, the crown-wheel; 4th, the escapement-wheel. We will designate these wheels by the capital letters A, B, C, D; the wheel A works into the pinion G, which carries the wheel B; this second wheel works into the pinion H, which carries the wheel C; this third wheel works into the pinion I, riveted with the wheel D; this fourth wheel, D, does not work into any pinion, but is checked in its movement at each tooth by the escapement-piece, whose construction and effects must be considered.

Three kinds of escapements are now in use in clocks and watches—1st, the recoil-escapement, also known by the name of *balance-wheel* escapement; 2d, the dead-beat escapements, which are very numerous; 3d, the detached escapements. In the first two classes, each tooth of the escapement-wheel produces two vibrations when the wheel is simple; that is, when the teeth of the wheel are cut upon its circumference as in a cog-wheel; but each tooth produces but one vibration when these teeth are placed alternately upon the two surfaces of the same wheel, as in the pin-escapement of Lepaute, and the detached-escapement of Le Normand.

The detached escapements, such as the Arnold-escapement, and the escapement of constant force, permit but one tooth to pass during two vibrations. It is therefore important, in the solution of this and the following problems, to know the nature of the escapement to be used, as this is an element which should enter into the calculation. We are therefore compelled to give two solutions, each of which applies to one of these cases.

First case; that is, when each tooth produces two vibrations. According to the general principle, the first member of the equation which we seek will be $\frac{A \times B \times C \times D}{G \times H \times I}$, but as each tooth of the wheel D, produces two vibrations, we should multiply D by 2, when this first member becomes $\frac{A \times B \times C \times 2D}{G \times H \times I}$; but, by a condition of the problem, the clock should beat 3600 vibrations; this member should therefore become the second member of our equation, and we shall have $\frac{A \times B \times C \times 2D}{G \times H \times I}$ 3600. By dividing the second member by 2 to clear D of its co-efficient, and transposing the divisor $G \times H \times I$ into the second member, by means of multiplication, we shall have $A \times B \times C \times D = \frac{3600}{2} \times G \times H \times I$, and executing the division we shall have $A \times B \times C \times D = 1800 \times G \times H \times I$. As we are at liberty to give to each pinion the number which we wish, we will choose 10 for each of them, in order to secure the best gearings; this transforms our equation thus:—

$$A \times B \times C \times D = 1800 \times 10 \times 10 \times 10.$$

The only point now in question is the decomposition of these numbers into their separate factors, by dividing them by 2 as far as possible, then by 3, and finally by 5, as these are the smallest numbers which can divide them. By dividing 1800 by 2, I obtain for a quotient 900, which I divide again by 2 and obtain 450, which I also divide by 2, obtaining 225, which is no longer divisible by 2; this divided by 3 gives 25, which is only divisible by 5; the quotient 5 divided by 5 gives 1, which indicates that the operation is exact: each of the three pinions also gives me 2 and 5, all of which divisions I write on the same line—2, 2, 2, 3, 3, 5, 5, 2, 5, 2, 5, 2, 5,—which are the factors to be used.

When the escapement is a balance-wheel, we are limited in the number of teeth, which should be uneven, and by its size. This limit extends from 11 to 17. But not having any number which can form one of these four products in the factors found, we take 3 and 5, which give 15, for the number of teeth of the escapement-wheel, D. It then only remains to divide the other factors into three parts, the products of which will give the number of teeth required for the wheels A, B, and C.

These we divide in the following manner:

1st. $2\times2\times3\times5=60$ for the wheel A;
2d. $2\times5\times5=50$ for the wheel B;
3d. $2\times2\times2\times5=40$ for the wheel C.

Our train therefore is thus composed:

	Teeth.	Pinions.	Revolutions.
A . . .	60		2
B . . .	50	10	6
C . . .	40	10	30
D . . .	15	10	120

But, as each tooth of the wheel, D, gives two vibrations, by multiplying 120 revolutions by 30, which is twice the number of the wheel D, we have 3600 vibrations for a product, which is the number required.

Second Case.—When the escapement-wheel permits but one tooth to pass in two vibrations. The wheel, D, should have no co-efficient in the first member of the primitive equation, and consequently the first term of the second member of the equation should have no divisor. It will therefore stand thus:—$A \times B \times C \times D = 3600 \times 10 \times 10 \times 10$, and operating as in the first case, we shall obtain 2 for a factor besides those which we have already noticed. Still leaving the escapement-wheel with 15 teeth, and giving 10 leaves to each pinion, we shall have for the numbers of the teeth of the wheels, $A=80$; $B=60$; $C=50$; $D=15$. In executing the above operation, we will find that the wheel D makes 240 revolutions during one revolution of the wheel A; and by multiplying 240 by 15, the number of vibrations which the wheel D causes the regulator to make by each of its revolutions, we shall find as before 3600 vibrations per hour for our product.

Essential Note.—When half the teeth of the escapement-wheel are on one surface and half on the other, as in the pin-escapement of Lepaute, the calculation can be performed in two ways. 1st, If we only count the teeth upon one surface, we execute it, as in the first case, by giving the co-efficient 2 to the wheel D. 2d, If we add the numbers of teeth on both surfaces, or multiply the number on one surface by 2, we perform the operation, as in the second case, without giving any co-efficient to the wheel D.

This is a general and unexceptionable rule, whatever number of vibrations the clock may be required to beat. The number of vibrations now in use for watches is 14,400 for four vibrations per second, or 18,000 for five vibrations per second. It is only necessary therefore to substitute for 3,600, one of the two numbers we have just given, or any other that may be wished, and to change the given number of the pinions to that which may be adopted.

The same calculation and the same process should be followed in order to find the teeth of the wheels and pinions which should precede the great centre-wheel, when the clock is required to run longer than thirty hours, as eight days, a month, a year, etc. We multiply the proposed number of days by twenty-four, the number of hours in each day, and form an equation. Let us suppose that we wish it to run eight days; this will give 192 hours, or 192 turns which the minute-wheel, A, should make during one revolution of the wheel P; we shall thus form this equation: $P \times Q$, etc. $= 192 \times 16 \times 12$, etc., provided that in this case we wish to have two wheels and two pinions.

It remains for us to give some ideas on the application of this rule to clocks whose regulator is a pendulum. But two cases present themselves, and the solution of two problems will suffice to explain this double question; these are reduced to a simple formula, in order to bring them back to the general rule.

PROBLEM SECOND.

To find the number of the teeth of the wheels and the leaves of the pinions of a clock whose vibrations are determined by the height of the space in which the mechanism is inclosed.

The whole question is reduced to finding the length of the pendulum, because when this length is once known, the number of vibrations which the clock beats per hour may be easily found by the processes which we have before described. Thus, the height of the frame exactly measured being 9 lines from the point of suspension, we ascertain that it will beat 7,700 vibrations per hour, which suffices to include this problem in the solution of Problem First.

PROBLEM THIRD.

To find the number of teeth of wheels and leaves of pinions of the striking-work of an ordinary clock.

An ordinary clock demands a few special considerations. It is composed of five wheels and pinions; the first wheel being fixed on the barrel which contains the spring. The second wheel carries the notch-wheel, and should make one revolution in twelve hours. As it should strike at every half-hour, the clock will consequently strike ninety times in twelve hours. It should therefore carry ninety pins in order to produce the same number of strokes, but as these pins would otherwise be too near each other, they are carried by the third wheel, which is called the pin-wheel. This wheel carries ten pins, and should consequently make nine turns while the second makes but one.

The following wheel, which is the fourth of the train, is called the locking or ballast-wheel, this carries a single pin, and makes one revolution at each stroke of the hammer. It is also called the check-wheel, because it stops the train when the strokes of the hammer, which are determined by the notches of the notch-wheel, are finished. The next wheel, and the pinion of the fly which terminates this train, have no other function than that of slackening the course of the train in order that the strokes of the hammer may not be too fast to be counted.

The numbers generally adopted are as follows:—for the barrel-wheel, 84 teeth; second wheel, 72 teeth, pinions, 12; third wheel, 50 teeth, pinions, 12, 10 pins; fourth wheel, 54 teeth, pinions, 6, 1 pin; fifth wheel, 48 teeth, pinions, 6; pinion of the fly, 6 leaves.

It is evident that by calculating from these numbers the number of revolutions which the pinion of the fly should make during one turn of the first wheel, we will find that it revolves 30,240 times, and that it makes 72 turns at each stroke of the hammer, or during one revolution of the locking-wheel. The velocity of the last pinion may be increased or diminished by making the wings of the fly narrower or broader.

As the first wheel of 84 teeth makes one revolution in three days and a half, according to the given numbers; it will be sufficient to have a spring making five turns to cause the clock to go for seventeen and a half days without winding.

CHAPTER X.

CURIOUS AND USEFUL INVENTIONS.

WE do not propose to describe here all the inventions which have been made in horology, the most of which have figured in the various Exhibitions of Art, but shall only cite a few which are especially remarkable.

Watch of Rock-Crystal.

A watch was placed in the Exhibition of 1827 by M. Rebiller, the wheels and bridges of which, and the caps of the case were of rock-crystal, a transparent substance of a hardness but little inferior to that of the precious stones.

The artist presented this piece to the *Societé d'Encouragement;* and we transcribe the description of it made by M. Francoeur to the *Conseil d'Administration.*

"When we consider the difficulty of working rock-crystal and precious stones, and think of the extreme delicacy of the parts of a watch so small that it can be worn on a lady's neck, we can hardly conceive how M. Rebiller could have succeeded in executing a work of this kind. It is difficult to imagine the method by which he cut a thread for screws into so hard a substance as rock-crystal. This watch is a work of infinite patience and skill, as well as an ornament of remarkable elegance.

"The difficulty of execution gives this watch so high a price that it cannot be regarded as an article of commerce, but it is a marvel of patience and art, worthy the attention of connoisseurs. It possesses no inventive merit, but much skill has been required to succeed in cutting a screw in crystal, in inserting the jewels into a material so difficult to work, and in making the wheels and the balance of crystal, and the escapement-piece with the bridge which supports it of sapphire. M. Rebiller assures us that this piece will go with almost as great regularity as a chronometer; this he attributes to the fact that the balance is of crystal, that it is moved by a spiral-spring of gold, and that these substances are very slightly affected by the temperature. We have not verified this assertion, as it would have been necessary to submit the watch to tests, and we feared by some accident to spoil so beautiful a work."

We are told that M. Rebiller has added a chain, key, and seal, made from a single piece of rock-crystal, to this watch.

Repeaters without the Small Train.

The essays at the manufacture of repeaters without a small train date back many years. In 1778 a movement whose dial-work produced this effect was invented by a skilful artisan of Geneva; this was acknowledged by watchmakers to be the first repeating-watch without the small train. In 1807, M. Berolla, a watchmaker of Besançon, took a patent for invention for a repeater without the small train.

In 1817, N. Vincenti executed a repeater the dial-work of which differed from any before known.

In 1820, M. Laresche, a Parisian clockmaker, took out a patent for the invention of the dial-work of a repeating-watch without the small train; these inventions we shall describe.

1st. *Repeater without the small train, executed at Geneva in 1778.*

The large pillar-plate is grooved with a circular cavity beneath the dial, and eccentric to the pillar-plate, by a width of about two lines, and a depth of half a line. The whole diameter of this cavity is the seventeenth of the diameter of the pillar-plate, and this circle is in contact with the circle of the pillar-plate on the side where the figure 12 is marked on the dial. A ring of steel is lodged in this grooving; this is fixed upon the pillar-plate by three steel keys, which prevent it from springing up. Fifteen ordinary teeth are made on the edge of this ring, and in the outer part on the side of the pendant. On the left side, towards the figures 7–9, are twelve cogwheel teeth.

The rest of the dial-work is very simple; a snail of the quarters with its surprise placed as usual on the minute-hand pin; an hour-snail with its star-wheel; a catch with its spring; a motion of the quarters having but three teeth at the extremity of one of its arms, with its spring as usual; and a single hammer. A steel rod carries a pinion of 12 at its inner extremity, and a large knob of the same metal as the case at its outer extremity, to which the ring which holds the chain by which the watch is suspended is fastened by a transverse screw; this serves to put the dial-work in action.

When the hour is to be repeated, the knob is turned to the left; the pinion of 12 works into the rack and forces the arm which it carries to advance towards the figure 9; this advances until it encounters the hour-snail. In this movement, two effects are produced—1st, a pin placed upon the movable steel ring removes it from the motion of the quarters, which, becoming free, goes to rest by its second arm on the quarter-snail, towards which it is incessantly urged by the spring that impels it; 2d, it passes as many of the teeth of the rack before the knob of the hammer as there are hours indicated by the snail. Then, by turning the knob in the opposite direction, the movable ring is brought back to its original place, and the hours strike; after a short interval, the quarters strike in the same manner. This must be turned slowly, in order that the strokes may be distinctly counted.

We would suggest the practicability of adding two improvements to this construction; viz., of putting in an *all-or-nothing-piece*, and of causing it to strike double quarters. This will be easily understood by watchmakers; the hour-snail must be slightly displaced in order to put in place the *all-or-nothing-piece;* a motion of the quarters must be made in the usual manner, and a second hammer added.

2d. *Repeater without the small train, by M. Berolla.*

"The exterior of the watch resembles other watches, except in a knob placed above the pendant, which must be turned to the left to make it strike; this strikes the hours marked on the dial in proportion as it is turned. In the interior, the movement is precisely like that of an ordinary watch without the repeating-train, except that there is a single hammer placed in the frame which strikes against a bell-spring.

"The dial-work is composed of a rack for the hours and another for the quarters; these cause the movement of the hammer. That of the hours connects with an endless screw, which is adjusted to the knob which we have mentioned, and which, by a mechanical movement, causes the rack of the quarters to move at the same time. There is also a star-wheel for the hours with its snail, as well as a motion of the quarters, but these pieces do not differ from those of ordinary repeaters."

3d. *Repeater of M. Vincenti.*

The movement has two trains moved by the same spring; there is therefore but one barrel to which the chain that conducts the fusee is attached. The barrel-arbor carries a steelplate, cut in cogs, upon which a great-wheel with the click and spring is mounted, so that the spring aids the chain by its extension, and the click and spring work by its centre; this wheel is constructed on the barrel-arbor in the same manner as the first wheel of the small train of a repeater. The rest of the small train is formed of wheels larger than those of ordinary repeaters.

The case does not differ essentially from others.

A longitudinal cleft is made between the figures 12 and 3, and parallel to the edge of the rim, into which a small projecting button enters. When the repeater is to be struck, the knob is pushed with the nail towards the figure 3. Two effects are simultaneously produced—1st, the arm of the piece which serves as a rack comes to rest on the hour-snail, and fixes the number of strokes for the hours; the *all-or-nothing-piece* recoils, the motion of the quarters, becoming free, falls upon the quarter-snail, and the train acts; 2d, at the same time in which this takes place, the spring is wound up far enough by the same knob to cause the hours and the quarters to strike. The *all-or-nothing-piece*, and the other pieces of the dial-work, differ from those of ordinary repeaters.

4th. *Repeater with outtrain, by M. Laresche.*—M. Laresche, a Parisian clockmaker, took a patent for invention, for five years, in 1820, for a new dial-work of a repeater without the train. This mechanism seems to us to be too complicated, and we do not regard its effect as certain, which is probably the reason that the author has not renewed his patent. We have never seen any of his watches in commerce, and shall not, therefore, give the description; it may be found in Volume xiii. of *Breve's d'invention expirés*, p. 43.

Chronometrical Index.

This machine, which formed part of the exhibitions of

1819 and 1823, was invented by us more than forty years since. We communicated it to the late M. Peschot, who changed the name which we had given it, and which perfectly expressed its functions—*chronometrical index*—to that of *chronometer*, which only signifies the general measure of time, being applicable to all clocks, and which is now applied to an especial time-keeper.

We explained the principle on which our construction is based in a memoir which may be found in Vol. xv., p. 248, of our *Annales de l'Industrie nationale et etrangère;* but did not enter into the details of its execution, as our only design was to render an account of a suit against an infringer, and to prove that the construction which he had adopted, although differing essentially from our own, was based on the same principle. The tribunal decreed that the principle belonged to us, and condemned the counterfeiter.

Although we can use a movement of any watch, yet we shall succeed much better by constructing a movement expressly for this, as it is important to have the exterior surfaces of both pillar-plates entirely free.

Those who saw, in 1820, '21 and '22, the arrows which marked the hour upon the two opposite mirrors of the Opera lobby, know that the movement of the watch that produced this effect was concealed in a case placed between the opposite feathers at the point of the arrow. Our movement is not fixed to this case; it is only carried there by its centre, around which it can turn freely; finishing its revolution in twelve hours, or in one hour, at will, as we shall presently show.

As it is necessary to displace the arrow in order to wind the watch, the square of the remontoir must be placed on the side of the small pillar-plate as in the English watches; many obstacles oppose the placing of it upon the large pillar-plate, the greatest of which is that of encountering the square which presents itself at the hole of the dial, as this square turns around the centre of the watch along with the whole of the movement, while the dial does not move. The train possesses the advantage of running eight days without winding. It is well to adjust a dead-beat escapement to this; our escapement, that of Seb. Le Normand, was invented for this movement. A verge escapement can be given it, but it will then be necessary to add a fusee on our construction for replacing the fusee which we have described. Let us suppose that there is no fusee; when the caliber is traced, a diameter is traced passing through the middle of the hole of the barrel. The axle of the escapement-piece should fall in this line. The balance turns horizontally above the frame and perpendicularly to the surface of the pillar-plates. We shall show the advantage of this arrangement.

In our system, although our movement turns around the axle of the great centre-wheel, it never changes its respective position in relation to the diameter traced on the caliber; so that this diameter constantly maintains a vertical position, while the barrel, which serves as a weight to put the lever in motion, is always at the bottom towards the figure 6; and the balance is always at the top towards 12. At each vibration of the balance, the movement inclines to turn, but at the same time the centre of gravity of the balance, which should tend to depart from the vertical direction, forces the lever to turn a little, in order to bring it back to this vertical position; by this means it is prevented from moving from its place, and is only transported in a circumference of a circle whose centre is the axle which supports the lever. But all the parts preserve the same position in respect to the vertical diameter of which we have spoken, which is continually carried on the same plane in the orb which it passes through, thus resembling the movement of the earth's axis. The watch in the chronometrical lever is always stationary like the movement of a mantel clock; this contributes much to its regularity.

The frame of the train should be enclosed by four brass bands of five lines in width; these form a frame in the midst of which the movement is suspended, which can turn freely upon the two pivots of the large centre-wheel, as we shall explain. This frame is fastened to the arrow.

The circumference of one of the pillar-plates, it matters little which, should be cut in cogs like a wheel of the click and spring-work of a watch, and a click with its spring must be placed in each of the pillars of the frame just mentioned to form a click and spring-work in this part. This precaution is important, as, without it, when the spring is wound, the movement turns and its regularity is disturbed; making it necessary to reset it, and risking the breaking of several pieces. If we take care in adjusting the two click and spring works, to prevent them from stopping both at the same time, we shall obtain the effect of double teeth to the wheel. The teeth of the cog-wheel should be turned in a contrary direction to those of the remontoir, as their effect is opposite. The click and spring-work should yield while the watch goes, and stop while it is wound.

The frame of the movement should be suspended by the fixed frame; the axle of the great centre-wheel carries a pivot at each end which should turn freely in the two opposite cross-bars of this frame. But, before describing this part of the mechanism, we will explain what we mean by the large and small pillar-plate, since, in this construction, their diameter and thickness are the same. This distinction is necessary on account of the pieces which are on the cross-bars of the frame, and which are different, in order to impart to them distinct and separate movements.

We shall call the plate on which the pillars are riveted the large pillar-plate, as in ordinary watchmaking; upon the surface of this we place the dial and hands; the other we designate as the small pillar-plate.

A small hole is pierced in the midst of the length of the cross-bar, on the side of the large pillar-plate; upon this hole and beneath the same cross-bar a bridge, fastened by two screws and two chicks, is placed; a hole, exactly corresponding with that of the band of the frame, is then marked with the pitching-tool. This hole should carry one of the pivots of the centre-wheel. A corresponding hole is made with the same tool in the cross-bar of the opposite piece. In this hole, or in a piece which replaces it, the other pivot of the large centre-wheel revolves, which, carrying no minute-hand pin, etc., does not need a long rod beyond the pillar-plate.

The barrel has 96 teeth, working into a pinion of 12, carried by the second wheel, called the *time-wheel*, which has 80 teeth, and works into a pinion of 10 which carries the large centre-wheel. The barrel making one turn in 64 hours, the second finishes its revolution in 8 hours, while the third revolves in one hour. The spring with three and a half turns will make the watch go during 224 hours; that is, more than nine days.

The numbers for the other wheels following the large centre-wheel, as well as those for the leaves of the pinions, can be found from the rules which we have given in Chapter Ninth. When the number of vibrations which it should beat during an hour has been fixed—we will suppose that it should beat 14,400 vibrations per hour—and our escapement has been adjusted to it, by giving six leaves to each of the three pinions, and twenty teeth to the escapement-wheel, which is one vibration for each tooth, we shall find the number of the teeth of this train as follows:—

	Teeth.	Pinions.	Revolutions.
Large centre-wheel . . .	60		1
Small centre-wheel . . .	54	6	10
Crown-wheel	48	6	90
Escapement-wheel . . .	20	6	720

In order that the end of the arrow may make its revolution in twelve hours, the rod of the second wheel of 80 teeth passes through the small pillar-plate and is filed square outside of this plate. A pinion of 12 teeth is solidly adjusted upon this square, which works into a wheel of 18, placed in the hole bored in the middle of the frame-band, on the side of the small pillar-plate, and inside of it; that is, on the side of this pillar-plate, a pinion of 16 and a wheel of 24 teeth, or a pinion of 26 and a wheel of 30 teeth may be used instead of these, or any other numbers bearing the same proportion to each other. In all cases, the wheel should be riveted on the cross-bar, and the leaves of the pinions should be inside, and thick enough always to work into the wheel.

It is evident that since the arbor of the time-wheel revolves once in 8 hours, it will make one and one-third turns before its pinion of 12, of 16, or of 20, shall have passed through 12 hours, and consequently that the arrow will complete its revolution in twelve hours.

When it is required to turn the arrow in one hour, the construction of the train of the movement is not changed, but the alteration is effected by the different arrangement and numbers of the wheel and pinion of which we have just spoken. We know that the time-wheel finishes its revolution in 8 hours; a wheel of 80 teeth is placed squarely on the axle of this wheel, and a pinion of 10 is riveted at the middle of the cross-bar; by this means the train will turn 8 times while the time-wheel turns once.

In both cases, a hole is pierced in the centre of the pinion or of the wheel, which should be riveted on the cross-bar;

this hole receives the pivot of the large centre-wheel in order that the movement may be solidly suspended.

When the arrow is required to finish its revolution in twelve hours, no other constructions need be made on the side of the large pillar-plate; in this case, the arrow marks the hours on a large glass, and the divisions are large enough to permit small divisions to be marked for the minutes, from 5 to 5, or from 10 to 10.

But when the revolution should be terminated in one hour, a dial should be added, upon which a hand marks the hours and minutes if wished. We place this dial on the cross-bar which supports the movement; this dial must also be adjusted in such a manner as always to present the figures 12 and 6 in a vertical position. We have invented a method which is not more complicated than the dial-work of an ordinary watch, and which produces this triple effect.

We place a wheel of 48 teeth upon the large pillar-plate of the dial, which we fix upon this pillar-plate by three screws, and which we elevate two lines by a round plate placed beneath, and not extending as far as the teeth. We remove the centre of this wheel, and of the round plate, so that the rod of the large centre-wheel may not be injured. Upon the cross-bar of the frame we place a pinion of 12, or any other suitable number, whose pivots are carried by two bridges, one of which is placed above, and the other beneath the cross-bar. This pinion works into the wheel of 48, fixed upon the pillar-plate. The bridge should be near the pillar-plate, but should not touch it, as this would stop the movement; this is the reason of the elevation of the wheel. The pinion is only placed there to transmit the movement from the bottom to the top of the cross-bar, and should be long enough to work at the same time into the three wheels of which we shalls peak. At the middle of the cross-bar, and at the top of the hole which has been pierced in it, we fix with a screw a rod of tempered steel, which should be exactly perpendicular to the pillar-plates, and in the prolongation of the line passing through the two holes of the large centre-wheel. Upon this rod we place three concentric wheels, each mounted upon a socket, with space enough between them for a slight play. These are of the same diameter as the one fixed on the pillar-plate. The first has 48 teeth; the second 52; and the third 48. The first carries the minute-hand by a socket, the second bears the silver or plated brass dial, and the third bears the hour-hand. If we give but 48 teeth to the wheel which carries the dial, this dial will be an hour in advance at each revolution. This effect is analogous to the satellite wheels of M. Pescqueur.

An explanation yet remains to be given, to facilitate the execution, and to render regular the movement of the lever. One of the two branches is shorter than the other; the movement is placed on the shorter branch; the other should produce an equilibrium. This equilibrium is easily obtained by placing the arrow on the two points, 3 and 9, and afterwards on 12 and 6; but this is not sufficient; a small weight must be placed under the point of the arrow and in the direction of its length, supported by an adjusting screw, so that it can be moved with a key, in order to place it nearer to or farther from the point of suspension, at will. This weight serves to rectify the equilibrium. We perceived the indispensable necessity of this, after finishing the construction of which we have just spoken.

We marked the minutes on a large dial of one foot in diameter, and, after having placed the minute-hand upon the small dial, we perceived a difference of twelve minutes' loss in one half of the revolution of the large dial; which loss was exactly counteracted in the second half of the revolution; this made us conclude that the equilibrium was not exact. We then decided to add the supplementary weight, by which we succeeded in regulating the movement perfectly, so that the minute hands exactly accorded; after which we removed the little hand of the small dial.

When the chronometrical lever is to be used against a glass which serves as a dial, the glass need not be pierced; a round plate of wood is turned, in whose centre a small rod of tempered and polished steel is adjusted, which must be strong enough to support the weight of the lever without bending, but as fine as possible in order to avoid friction. Before this rod is tempered its outer end should be screwed to place on it a brass screw-nut, in order to prevent any shock from detaching this lever from its place. This screw-nut is removed to detach the lever when the watch is wound. Three or four round pieces of blotting paper are then cut of the same size as the wooden round-plate; one of these is then glued on the glass with powdered quick-lime diluted with skimmed milk, and is left to dry; a second and a third paper is then glued with isinglass, and, when the whole is dry, the round plate is glued on it with common glue. This is left to dry, after which the lever is adjusted on it.

This lever is a very convenient instrument for obtaining a country-clock. A traveller can enclose it in a box and take it with him; it will go during the journey, and, when it is ended, he can place it at the centre of a dial arranged for it. When he leaves, he can carry it in the same manner, and can place it in his house, where it will continue to mark the hour without any irregularity.

New Mechanism of a Repeater invented by M. Lerot.

The mechanism of M. Lerot is remarkable for its simplicity and certainty. The numerous pieces of a repeating watch are reduced in it to four, the mechanism of which is very ingenious. By adopting this system, these watches can be sold at a low price, and the pieces are not exposed to the accidents and errors which result when they are much complicated.

A large steel wheel, whose diameter is a little less than that of the dial, and concentric, bears twelve teeth or arms upon its circumference, constructed like those of cog-wheels; these arms fall successively on the handle of the striking hammer, when they pass in their turn and come in contact with it. This wheel, which is wholly independent of the movement of the watch, turns by a little crank which is placed in the pendant, and whose axle, guided in the direction of one of the radii of the dial, carries a pinion; this pinion works into the crown-teeth with which the lower surface of the contour of the rim of the large steel wheel is furnished.

When the hour is to be struck, this crank is turned until it encounters a stopwork; this movement also turns the steel wheel, whose arms leave the hammer inactive; the crank is then turned in the contrary direction. At each turn made in the latter direction, it passes a tooth of the steel wheel, and the hammer strikes a blow. The number of blows thus struck agrees with the time marked by the hand, as a stop-work is encountered which prevents the further rotation of the crank.

The effect is certain, as the stop-work is a ratchet-piece, fixed in the minute-wheel-work upon the hour-wheel, so that it is impossible for the hammer to strike more blows than are indicated by the hand. The quarters are easily reckoned by the course which the crank takes after having struck the last blow; this course is represented by the arc described until the crank shall have reached its stop-work.

Two inconveniences attend this mechanism: The first consists in the use of the little crank which always projects from the pendant of the watch; the second is the impossibility of estimating the quarters in the interval which elapses between the hours of twelve and one, on account of the arrangement of the stop-work, and of the arm which props against it.

But these defects are easily remedied; the crank can be replaced by a milled head turned by the fingers, and the stopwork may be broken into a wheel-click to permit it to lie flat when the knob is turned in one direction, and to rise up when it is turned in a contrary manner.

Description of a Second-Watch, indicating the precise instant of observations, by M. Jacob.

The mechanism by whose aid the second-hand, after having been stopped and again set in motion, places itself suddenly on the diameter where it would have been if it had not ceased to move, is fixed on the second-wheel.

The second-wheel is riveted on a pierced pinion, a part of which is elongated. A second wheel, very slight, and carrying an axle long enough to pass through the second-wheel, is loosely adjusted into the pinion of this wheel; a ferrule, fixed by a screw on the part of the axle of the second wheel which extends beyond the pinion, holds the second-wheel in a frame on this axle, so that the two wheels can turn independently of each other.

A small arm is placed upon the second-wheel. A rack, placed as a satellite on the second wheel, carries a pin which is long enough to rest on this arm; a spring presses a click upon another pin which may be considered as the prolongation of the first, and permits the rack to move about half-way round its centre. This rack works into a pinion turning freely between the two wheels, so that when the spring causes the rack to turn, the latter turns the pinion until a rack-detent, which carries the pinion, rests on the arm of a very slight spring, placed on the second-wheel; the resistance of this point of support preventing the pinion from turning, the rack then turns until its pin meets the arm of the second-wheel, the two wheels being thus united and placed in frame on the axle of the second wheel, the hand carried by this axle marks the second and its fractions.

If the second wheel be checked at the instant of an observation by a mechanism which we shall presently describe, the second-hand will be fixed on the precise instant of observation; the second-wheel continuing to move and drawing along a pinion, this pinion will cause the rack to turn, which will push back the click; and thus, when the second wheel is freed, the spring will turn this second wheel until the pin of the rack meets the arm of the second-wheel, and the second-hand will retake the identical second or fraction of a second, which will be marked by the second-wheel which has not ceased to move. As each revolution of the second-hand is indicated by that of the minutes, the second-hand marks the fraction of the minute that has elapsed; thus, when the second-wheel shall have made a revolution while the other wheel is stopped, the mechanism will find itself in the position in which it was before the hand was stopped, and ready to mark the fractions of the subsequent minute.

At the end of each revolution of the second-wheel, a pin which is placed on the other wheel lightly touches a spring, and disengages a pinion; and the spring which presses the rack forces this pinion to make a turn, after which it comes again to rest on the spring, and the rack finds itself at its point of departure.

To remove all uncertainty in the use of this watch, M. Jacob placed a small second-dial by the side of the dial of observation, the hand of which does not stop; the two hands, having been set in motion at the same second, should always continue together; this addition simply consists in working with a third wheel into a pinion of the same number as that of the second-wheel, carrying a hand upon the prolongation of its axle.

Description of the Mechanism used for stopping or setting in motion the second-hand.

The cog-wheel, bearing twenty-four teeth, is formed of two arcs of twelve teeth, placed above each other. This cog-wheel, which turns loosely on a plate-screw, is held back by a jumper-spring. The arc which is nearest the pillar-plate is free to fall on an arm of a piece which moves loosely on a plate-screw, while the upper arc always passes without touching it. When the knob of the watch is pressed, a spring, bearing a click at its extremity, falls on the tooth of the cog-wheel, and makes it leap forward at the instant in which the tooth ceases to retain the arm, the following tooth passing above. The piece of which we have spoken, being pushed by the spring, touches the wheel which carries the second-hand and stops it. When the knob is no longer pressed, the spring returns to its first position, and the click is ready to force the following tooth to leap forward, and, by acting again on the knob, the cog-wheel lifts up the piece and frees the hand.

Apparatus designed to give the duration of any phenomenon, expressed in Minutes, Seconds, and Fractions of a Second. By M. Henri Robert.

This chronometrical instrument is worthy of attention; it is a small apparatus composed of a circular balance, a cylinder-escapement, a wheel, a barrel, and a detent; the whole is mounted on a pillar-plate on which two dials are engraved; one indicating the minutes and the other the seconds and their fractions.

The spring contained in the barrel is designed to set the whole system in motion in a short time; it must be of small extent, and its force need not be great, as it is not prolonged by a succession of gearings, but acts directly by the medium of a single wheel, on the escapement.

The simplicity of the execution of this mechanism enables the inventor to offer it at a low price; this is an essential point, as the true merit of M. Robert consists less in having invented a new instrument than in having rendered the use of chronometrical apparatus possible for many observations for which the instruments already known are not used, because their high price renders them inaccessible to many.

The second-apparatus of which we speak is arranged in such a manner that when the spring is extended, and the hands placed on the hour, it is ready to be set in motion to inscribe the duration of an experiment upon the dial; when this experiment is finished the movement is instantly suspended to preserve the note of the total duration of the observation.

This arrangement of habitual rest—the action being momentary, and dependent on the will of the observer—has several advantages; it dispenses with the necessity of remembering the position of the hands at the beginning and end of experiments, which it is difficult to do with precision when the eye should fix itself on the dial and observe the phenomenon at the same time.

We do not think it is necessary to enter into further details with respect to the construction and uses of this chronometer; the most essential point is to notice its utility and its real merit. We shall only say that it recommends itself by its ingenious construction and its moderate price; and that the accuracy of its movement is guaranteed by the skill and scientific knowledge of the inventor.

Description of the Second-Watch of M. Robert.

This watch is designed to mark seconds and fractions of a second; its hand is instantaneously moved and stopped by the finger of the observer. The train is so calculated that this hand finishes its revolution in two minutes. The dial is divided into one hundred-and-twenty parts of a second each; the pusher which acts upon the mainspring, and causes the train to move or stop at will, penetrates into the interior of the case, and rests against the head of another spring, *a*, which is strong enough to raise up the pusher, together with a bolt which is forced by a small spring to constantly rest upon the head of a spring. The rack has an end-piece which is in contact with this spring. This rack is propelled by the mainspring, with which it communicates by means of a mesh moving between two screws, one of which is carried by the rack, and the other by the spring.

Effect.—When the pusher is pushed to the bottom, the rack is reversed; the mainspring is stopped; the balance is checked in its movement by the bolt, which approaches it. The hooked end of this bolt comes in contact with one of the two pins carried by the balance, and the watch is at rest.

As soon as the finger frees the pusher, the spring lifts it up together with the bolt, and the train moves; but if the pusher is again pressed slightly, the bolt extricates itself from the spring, which falls, and stops the balance.

Thus the pusher exercises a triple function; when pushed to the bottom it impels the mainspring; when slightly pressed, it stops the balance; and when left to itself, it permits the piece to go.

M. Robert uses a very simple escapement, invented by M. Dachemin. This is a cylinder escapement, but the difficulty of the ordinary wheel is avoided, it being simply a flat wheel, whose teeth are cut in an inclined plane. When the tooth falls upon the outer surface of the cylinder, it is exactly the same as in the common escapement; but there is not, as in the latter, an interior dead-beat; the cylinder acts against the flange of the tooth and causes the train to retrograde. This escapement being alternately dead-beat and recoiling, the inventor has given it the name of *mixed escapement.*

Another construction possesses the peculiarity of only going while the observer presses a lateral button. In this the pusher simply acts as a key, serving to impel the spring of the first-mover through the medium of the rack. This first-mover is similar to that of the train of a repeater.

The train is arranged in such a manner that the hand which is at the centre of the dial completes its revolution in one minute, while that of the small hand of the eccentric dial lasts six minutes. When the lateral button is pressed, the mainspring is acted upon by a small bolt, and a small spring which serves to raise it.

When the button is free, the spring of the first-mover which keeps it elevated permits another pin to impede the movement of the balance by its hooked end, against which one of the two pins of the balance props itself; but when the button is pressed, the spring acts upon this ratch, and removes it from the balance, and the watch goes until the finger abandons the button, when it stops instantly. Thus this piece goes when the button is pressed by the observer, and stops as soon as he frees it.

Detent for Alarm-Watches by M. Robert.

In this detent, the three pieces of the ordinary detent are replaced by a single arm. The instant of the alarm is fixed by the fall of the hooked end of this arm into a notch made in a disc; this disc belongs to the alarm-wheel, and turns with it upon the hour-wheel, completing its revolution in twelve hours. The notch is made in such a manner that the striking-work acts at the instant in which the hand reaches the figure of the clock. When the spring is relaxed, the detent is elevated by the cog-wheel; but when the spring of the alarm is wound up, the cog-wheel no longer suspends the detent in air, and the hooked end rests on the circumference of the disc until the notch encounters it and permits it to fall.

Chronometrical Indicator and Portable Alarm-Clock.

The method employed by M. Robert in his portable alarm-clock and indicator, consists in a double second-hand; one of these hands instantly stops when the finger acts on a detent arranged for this purpose,—the fractions of the seconds being reckoned in fifths upon the dial. This hand remains stationary until the observer has noted the time it has marked, when, on moving the detent in the contrary direction, the hand leaps forward and rejoins the other, which has continued to move, and does not quit it until the same process is repeated for a new observation.

By the aid of this instrument, all the observations in which the measure of time is required by astronomers, engineers, or mechanics, can easily be made with the utmost certainty and precision.

The indicators are small travelling-clocks composed—

1st, of a movement designed to measure the time; 2d, of a mechanism accessory to this movement, constructed in such a manner that a hand stops and marks on a dial the second and its fractions expressed in fifths, at the instant in which this mechanism acts on a detent, after which this hand leaps forward over the arc of the dial which marks the duration of its rest; 3d, of an alarm-train which strikes at an hour fixed in advance, and which can be used in the morning as an ordinary alarm-clock, and in other cases as a warning to notify the observer when engaged in other labors that the hour for making the observation has arrived.

This kind of striking-work may be varied to suit different tastes and wants; for persons who rarely have occasion to use it, it serves as a simple alarm, like those generally in use, being composed of a train which is wound up whenever the alarm is to strike.

But this alarm may be made to produce three effects for those persons whose habits or business require them to rise uniformly at the same hour, as it will strike every morning at the same hour while the indicator remains unchanged. When one does not wish to be awakened, he has only to turn a hand towards the word *silence*, but if he fears that he will not be awakened by the usual alarm, he turns the same hand towards the word *great alarm*, and the noise will be so great that it cannot fail to awaken the soundest sleeper.

4th. Of a striking-train similar to those of common mantel-clocks. This arrangement is better adapted to the simple alarm than to that producing three effects. In other respects, all the combinations used in clockmaking are compatible with the indicator.

Alarm Mechanism of M. Henri Robert.

To appreciate the utility of the invention of M. Robert, we must first review the mechanism commonly used to cause the alarm to strike at the proper hour. The case of the watch contains a bell and hammer; this bell is set in a rapid reciprocating motion by a train, which is moved by a barrel whose spring is wound when the alarm is required to strike at a later hour. A detent serves as a stop-work to this train, which is made to act by an ingenious machine; a central disc, placed beneath the hour-wheel, raises it up by continually rubbing on the end of a pin fastened to this wheel. This disk bears a notch on its circumference. The instant of the departure of the striking-work is determined by the fall of the pin into this notch, when the notch presents itself under the pin by the revolution of the hour-wheel. The detent then disengages the striking-train, and the bell is struck. The moment of departure depends on the position of the notch of the disc. This notch is carried to the required hour by turning a hand which draws along this disc; and the striking-work acts when the hour-hand is above the alarm-hand.

This mechanism is inconvenient, as the alarm-train constantly presses the hour-wheel, and impedes the movement, whether the alarm is or is not wound, thus requiring a greater force for the motive-power; besides which, the instant of the action of the striking-work is uncertain, as the radius of the disc which bears the notch is very short, while the movement of the pin that falls in it is slow, and the least eccentricity of the dial will occasion a great difference in the time of striking; thus the alarm often strikes a quarter of an hour too soon or too late.

The alarms of the common clocks are constructed a little differently. The notched disc is fastened to the hour-wheel and turns with it; a ratch-lever, pressed by a spring, rubs by its extremity on the circumference of the disc, and this extremity, which is beveled, falls into the notch when it comes beneath the level, thus extricating the striking-work.

M. Robert has adopted this last mechanism with a modification; but the principal objection still exists, as the spring constantly presses the hour-wheel.

In the construction of M. Robert, the detent has two arms, one of which presses the disc, but only when the watch is wound; in the other case a cog-wheel raises the detent so that it has no longer any action on the movement; thus the movement of the watch can only be affected by the alarm when the barrel of the striking-work is wound.

Besides, the instant of departure is more precise in this alarm than it can be by the ordinary detent, because the arm of the lever falls into a notch in the circumference of a disc whose diameter can easily be made large enough, and which is also concentric to the axis of rotation of the hands; the pieces, too, are not so numerous. In ordinary alarms, the detent acts by causing the hour-hand to rise and fall; the ratch of this detent is placed in a direction perpendicular to the dial, thus increasing the thickness of the watch.

The detent of M. Robert moves in a plane parallel to the dial, and his watch is therefore more convenient to carry, less complicated in its mechanism, and surer in its effects.

It is one of the principles of horology, to prefer a constant resistance, though it may be somewhat strong, to a variable resistance which can change the duration of the vibrations, and to give to the piece an equal movement; in this respect the watch of M. Robert, whose detent only affects the movement when the alarm-spring is wound, would seem to be irregular in its effects, since, when the alarm is wound, the movement is under the influence of an unusual pressure. But this variable resistance is not objectionable in this case, as it is not applied to the escapement, nor even to the last motive powers of the train; it is only when the first-mover is exposed to this slight accidental resistance that there can be any variation in the oscillations of the balance, and this mode of construction is certainly preferable to that which necessitates a greater motive-power which must finally encounter a variable resistance.

For these reasons, we regard the mode of construction of the alarm-watches of M. Robert as superior to that of ordinary alarms, as:

1st. It diminishes the sum of the resistance, and, consequently, the force of the motive-power.

2d. It is a simplification of the pieces beneath the dial.

3d. It secures greater precision in the action of the striking-work.

4th. It diminishes the thickness of the watch.

IMPROVEMENTS IN MANTEL-CLOCKS, BY M. ROBERT.

I.—*The Suspension of the Pendulum.*

One of the most essential things in a pendulum is that it shall be suspended in a manner best adapted to its movement; and the condition is, that its oscillations may be made as though around an axis which is the prolongation of that of the escapement-piece.

In general, no precautions are taken to obtain this result, and an unskilful apprentice is often intrusted with this part, which is, nevertheless, quite delicate and important. To arrive at this result, by direct and mechanical means, M. Robert prepares the surface which bears the suspension upon the turning-lathe, in order to render it parallel to the pillar-plates of the movement. The silk passes between two turned cylinders whose bases, also turned, rest upon the surface parallel to the pillar-plates of the movement, in such a manner that—the surfaces of the cylinder being perpendicular to the pillar-plates—the axis of rotation of the pendulum is also placed in this manner. This method is much less difficult than the one in general use, as the exactness depends on the fidelity of the execution of a turned piece, instead of the extreme skill which a workman must possess to pierce two holes in a straight line on the surface of a cylinder.

II.—*The Bearing.*

The bearing, or the part of the pendulum which receives the action of the fork, is usually a quadrangular rectangled prism, which enters into the crossing of the piece called the fork—and should enter freely without play into the fork—the least imperfection conduces to a defective transmission of force.

The cylindrical bearings of M. Robert do not present this difficulty; they are easily made on the lathe, and, if the fork opens parallel, the action is effected with precision.

Besides, the contact takes place in the plane which divides the weight of the pendulum into two equal and symmetrical parts; this condition is necessary in order to prevent the oscillations from experiencing any perturbation which might affect their duration.

III.—*The Pendulum Ball.*

The two surfaces of a flat pendulum-ball should be planes parallel to that of oscillation; without this condition, the pendulum-ball will continually vary by reason of the resistance which the air opposes, and by careful observation, the surfaces of the pendulum-ball may be seen, during an oscillation, to form angles differing from the plane of oscillation; this is a cause of irregularity.

To remove this difficulty, M. Robert replaces the flat pendulum-ball by a cylinder or sphere which always presents a like surface to the air; in fact, the cylinder, in its section by a plane perpendicular to that of oscillation, by offering a larger surface, experiences a little more resistance from the air; yet this consideration, although true in the abstract, cannot be of importance in machines of this kind, as the most minute observations can hardly detect a difference, and in truth, this difference only causes a slight absorption of superfluous force in these constructions. Besides, the inconvenience of a pendulum-ball which trembles in its action is much greater.

IV.—*The Fork.*

In well-executed clocks, a slide is fixed in the fork by means of an adjusting-screw; this part thus becomes a complicated machine which it is difficult to make with precision.

M. Robert produces the backward and forward movement necessary for the escapement-piece, by an arbor-adjustment, and an eccentric piece, thus rejecting the adjusting-screw with its surroundings.

The essential quality of the fork is the greatest possible lightness, and a perfect equilibrium; these conditions are easily obtained by the eccentric apparatus, while the adjusting-screw does not possess them.

V.—*The Execution of the Escapement.*

The escapement-wheel is made by the artisans who commence the movement, and when the latter is in the state termed *rolling*, the workman who is to cut the wheel, already riveted on its support, in receiving it has no other guide to centre it on the wheel-cutting-machine than its outer circumference. This operation requires a very precise and skilful man; but, as this cutting is ill-paid, it is necessarily done quickly, which is often one cause of imperfection; for the wheel, when badly centred, cannot have an exact division, even when there are no causes of inequality in the tool employed in this work.

Besides this wheel is taken from a plate of sheet-brass, which is never hard enough, and is often of a bad quality; these and other imperfections necessarily produce a bad escapement-wheel.

M. Robert chooses the best brass, which, after reducing to a suitable thickness, he tempers by hammering to the necessary degree of hardness, but not beyond this, as when it is too hard it is often broken roughly, which causes great inconvenience.

This wheel is pierced at the centre with a hole; it is then crossed and mounted on a tool, made expressly for this purpose, on which it is turned and cut; the outer circumference being exactly concentric to that of the central hole.

The verges in ordinary watches, and the anchors in clocks, are often injured in a very short time by the friction of the wheel. M. Robert has been convinced by the experiments and observations of ten years, that, beside the quality of the material of the wheel, several other causes exist which tend to the destruction of the escapement, and that one of the chief of these arises from the cutting of the wheel. This especially happens when the wheel is cut with a new cutting-file; the points of the teeth of this file are covered with very fine asperities, extremely hard and easily broken off; these asperities soon rub off in the operation of cutting, and become incrusted in the teeth of the wheel, thus leaving there particles of steel which will soon destroy the escapement by their friction. This cause of its destruction, which is certainly one of the most serious, has never before been noticed.

Various methods have been used by clockmakers, to prevent the destruction of the escapement. The best and the surest consists, 1st, in passing the teeth of the wheel through diluted nitric or sulphuric acid—these acids quickly destroy the atoms of steel which the cutting-file has deposited on the wheel, and also the particles of oxyd of copper which are often found in the material;—2d, in then polishing them with soft wood and pulverized water-stone, and afterwards with charcoal. This is the simplest and surest process.

The wheel thus finished is mounted on its support which is turned smoothly to receive it; it is not held on this support by the riveting made by the hammer in the usual manner, but by a bezel-setting made on the lathe, or sometimes by screws. These methods are not new in themselves, as they are practised by the best Parisian clockmakers, but the difficulty consisted in introducing them into ordinary clock-work without a sensible augmentation of the price, and in this M. Robert has rendered an essential service to horology.

Clocks running a Month.

The calibers of the clocks in commerce are still the same as those which were used sixty years ago, when the form of the teeth, and the imperfections of the work absorbed much motive-power; and it has generally been observed that there is much superfluous force in these machines, and that, in many cases, it is necessary to put in springs which are so slight that they roll round, and their bands cling together by the falling of the oils, thus rendering the drawing very unequal.

A spring should have a mean force in order to be good;

when too strong, it is apt to split or break, and when too slight, it has signal inconveniences; it is therefore necessary to arrange and number the train to suit the spring which may be applied to it.

To cause his clocks to run a month, M. Robert places the teeth of the barrel of the movement towards the large pillar-plate; the teeth of the two barrels crossing each other, he gains thus more than two turns of the spring; on the other hand, he brings the long rod from the centre of the wheel, which permits the barrels to be more highly numbered, all other things being equal, and finally, he makes the movement-wheel somewhat larger and more highly numbered than is usual.

He has thus succeeded in obtaining superior effects without changing the routine of the artisans, and without sensibly increasing the price of the works.

Alarm-Striking-Work.

M. Robert adds a small accessory mechanism to the striking-clocks, when required, which strikes one blow a minute before the hour is struck, thus permitting it to be easily counted in the night. This mechanism is very simple and inexpensive, and can be easily adapted to most clocks.

Regulators.

Ordinary clocks, when constructed with the improvements which we have described and with the care which they always require, both in respect to precision of execution, and to the harmony which should exist between the different parts of the machine, will doubtless be satisfactory for general uses, but we must admit that their movement does not yet accord nearly enough with well-made second-clocks to be able to count on their exactness in observations requiring the greatest precision.

But, as the defects of these clocks are well known, by removing the causes which produce them and remedying their inconveniences by the resources of art, we shall finally obtain machines of great precision. For instance, if we replace, 1st, the bases of light, hygrometrical wood, which are distorted by the slightest atmospherical changes, by a heavy base of marble; 2d, the light, ill-mounted case of wood, alabaster, or copper, by a strong metal frame, fastened solidly upon its marble base; 3d, if we require that the dimensions of the escapement shall be proportioned to the machine; an essential condition, as any disproportion conduces to variations and destruction; 4th, that a suspension formed by a silken thread shall be replaced by two steel bars whose solidity permits a very heavy pendulum, these bars possessing great advantages when well-made; 5th, that we also reject the rod formed of an iron wire, at the extremity of which the pendulum-ball is suspended, and the assemblage of pieces which is a ridiculous parody on the compensation gridiron pendulum; 6th, that we substitute simple constructions, and that the surfaces in contact with the air be arranged in the manner best suited to the movement of the clock, so that it may not experience any variation; 7th, that the correction of the effects of the temperature shall be produced by simple and certain means. We shall thus obtain pieces of great precision, which, although they may not rival the best second-clocks, will so nearly resemble them that no difference can be perceived, except by careful astronomical observations.

Pendulums used in Regulators.

Besides the pendulum of fir and brass, M. Robert often uses a simple fir ruler, whose lower part, which receives the pendulum-ball, is even larger than the pendulum-ball itself, and is compressed between the two brass discs which compose it, and which are called circular *followers.*

He also uses, in preference to every other construction, a pendulum with two branches, in the execution of which he has sought precision in the effects of the compensation and the other qualities which should accompany it. The correction of the effects of the temperature is produced by a single rod of zinc that removes all the difficulties attendant on the numerous adjustments of the gridiron-pendulum while it preserves its advantages.

Escapement with movable Rollers, by M. Perron.

The manner in which the escapement-wheel works in this construction is very curious. The teeth of this wheel are cut at the end in inclined planes, upon which the arms of the anchor act successively, in order that the motive-power may restore to the pendulum the motion which it loses by resistances. To diminish the frictions, M. Perron places a movable roller at each end of the anchor which changes the frictions. This is the Graham escapement reversed, as this celebrated artist also placed inclined planes at the ends of the arms of the anchor. The escapement of M. Perron is carefully executed in other respects; to avoid abutments, adjusting-screws are arranged at the anchor, which remedy this inconvenience. As to the priority of invention, we should say, that several years have elapsed since clockmakers projected the passing of a part of the inclined planes of the anchor upon the teeth of the escapement-wheel. M. Duclos did still more, he carried the entire planes on the teeth of the wheel.

M. Gille also took a patent for a dead-beat escapement in his alarm-clock, in which he employed a system of wheels and inclined planes.

The escapements of M. Duclos are recoil, but their recoil is less than that of M. Perron; M. Duclos has also used dead-beat. Those of M. Gille are dead-beat, but M. Perron's are recoil, as he causes the inclined planes to act on the movable rollers of the anchor; while they are not concentric to this anchor.

M. Perron places under the pendulum-ball a horizontal bi-metallic band fixed to the suspension rod, so that the influences of the temperature, distorting this band, may raise or lower the pendulum-ball in such a manner as to displace the centre of oscillation on the rod, and to give to it an invariable distance from the suspension.

Clock Indicating the Days of the Month, by M. Gille.

The clock of M. Gille has a dead-beat escapement, and indicates the months, days of the week, and days of the month upon distinct dials, whose hands skip at midnight. The most remarkable point in this mechanism is the very simple adjustment of the parts which cause the skipping of the hands, especially that of the days of the month, which skips over the number thirty-one when the month has but thirty days; also skipping the twenty-ninth of February except in the bissextile years.

Various methods were before employed in order to obtain this result, but the mechanism was very complicated, having generally a wheel with 366 teeth, which made an annual revolution, one of these teeth being useless in the common years. This apparatus required much room, was adjusted with difficulty, and was very costly. That of M. Gille can be lodged in a very small space, as it has but three pieces more than an ordinary clock indicating the days of the month, while the highest numbered wheel has but thirty-one teeth.

The large dial of the clock is pierced at the centre to permit the passage of the axles of the hour and minute-hands, and is also pierced at three other points of its surface for the passage of axles to the centres of three small dials for the days of the week, days of the month, and names of the twelve months. Each of these three dials is furnished with its indicative hand, the skipping of which is produced by the general mechanism of the piece.

First, the hand of the days of the week is mounted on an axle which carries a star-wheel with seven points, and the detent which causes it to turn one notch at midnight also causes the hand to pass over one-seventh of the circumference, thus passing from one day to the next.

The hand of the second dial—that of the days of the month—is mounted on an axle which carries a wheel of thirty-one teeth; this is the wheel upon which the mechanism of M. Gille acts in order to render one, two, or even three teeth of this same wheel useless, when the hand is to skip as many numbers at a time. For this purpose, the axle of the days of the month carries a sort of rack armed with four unequal pins. The limb of the month-wheel is not toothed, but carries pins implanted like those of the striking-hammer, except that these pins are of different lengths and are twelve in number. A pin is caught at the end of each month, making the month-wheel skip one notch; the result is, that according as the month has 30 or 31 days, such or such a pin of the rack acts, thus determining the skip. The month of February is furnished with a pin which causes the hand to skip three days at once, the short pins are for the months of 31 days.

As regards the bissextile years, there is a small wheel which revolves once in four years, and which carries a larger tooth, filed in a curve, in order to elevate the wheel on the 28th of February, so that the pin of that date, which is the longest, and which is always raised up by that of the rack, can pass, thus indicating 29 for the following day.

This mechanism is simple, ingenious, and easy of execution; its functions are guaranteed, and as it requires little space it will be generally adopted instead of the numerous pieces and the annual wheel formerly used. As clocks are now regulated by the mean time, and as equations serving to give the true time are rarely needed, the annual wheels will seldom be used in horology, and a mechanism of this kind, which dispenses with their use, will be very convenient.

Compensation-pendulum of M. Duchemin.

The variations in length which a pendulum experiences by the influence of the changes of temperature, cause alternate delays and advances in clocks; these effects, which change the uniformity of the movements of clocks, were long considered as an irremediable evil; and the idea was ingenious that first suggested the use of this same dilatation to counteract these effects by a suitable adjustment of bands of different metals. When the dilatation of metals in the same variation of atmosphere was perceived to be different, experiments were made to render this property available in securing a constant length to the pendulum. For this purpose, vertical rods of two metals were used, joined together by horizontal cross-bars, in the form of a gridiron, in such a manner as to raise the pendulum by the elongation which one of these metals experienced, precisely as far as the elongation of the other lowered it. This required that the total length of the bars of the first metal, supposed to be placed at the ends, when compared with the length of those of the second metal, should be in exactly the same proportion as the respective dilatations of these two metals. The two symmetrical and parallel rods of the same metal should be counted as but one in this calculation; by this the pendulum seems insensible to the variations of temperature, and its centre of oscillation remains at the same distance from the suspension, whether the weather be warm or cold.

But although this rule is exact in theory, it is difficult of application, as numerous experiments are necessary to obtain the exact proportion required, and each time the defects are only evinced by long experiments, which consist in submitting the pendulum to alternate proofs of extreme temperatures, then taking it apart to file the rods and unite them again in different proportions; this is difficult and expensive, and renders the compensation-pendulum costly and difficult of execution.

Now, the lengths of the bars of the gridiron are doubtless determined in advance by the law of the linear dilatation of each metal, and these bars may easily be cut in lengths according with this rule; they should be made of zinc or brass, and steel, and be cut and joined together in conformity with the lengths required by the rule. This rule is, that the bars of steel shall be to those of brass as 5 is to 3, and to those of zinc as 6 to 17.

To fulfil these conditions, the pendulums of brass and steel should be of nine bars, but those of zinc and steel require but three or five bars on account of the great dilatability of zinc; the last system, therefore, is now generally preferred.

The pendulum thus formed will not be an exact compensator, for reasons which we shall presently state, but it will so nearly possess this advantage that when we consider that the clocks in our apartments are not subjected to great changes of temperature we may be satisfied with it. We recommend this method because it does not require additional expense, and possesses advantages equal at least to those of the watch-compensations with bi-metallic arcs, invented by Breguet.

But when the compensation-pendulums of astronomical regulators, and other pieces which are valuable on account of the uniformity of their movements, are to be made, we should not rely on the simple rule which has just been prescribed, for the following reasons: Metals are never homogeneous; even the manner in which they are worked, according as they are cast, hammered, or filed, changes the quantity of their dilatation; and as the surest method of measuring this effect is that of making a pendulum, causing it to vibrate, and reckoning its oscillations in different temperatures, it is evident that a precise compensation-pendulum can only be obtained by submitting it to successive essays, correcting it, etc.

But M. Duchemin has succeeded in avoiding these difficulties by a method at once sure and simple. His pendulum is of precisely the same form as an ordinary gridiron-pendulum of five bars of zinc and steel. He makes these bars of suitable lengths in conformity with the known rule; but he has discovered a method of varying the bars of zinc in their place at will, in order to find the precise compensation by experiments made upon the movement of the pendulum without taking it apart.

It is difficult to explain clearly the adjustment of the bars without figures, we will but say that the rods of zinc are only connected to those of steel by cross-bars which support adjusting screws; and that these screws can be made to act upon different points of the rods, and, consequently, can lengthen or shorten them, according as the compensation may be found to be too great or too small. The pendulum remains mounted in its place; it is only stopped for a moment to move the screw and is then immediately set in motion without changing the general movement of the piece, the compensation alone being varied. This process is so easily executed that it is unnecessary to apply to a clockmaker to effect the change.

Compensation-pendulum of M. Jacob.

M. Jacob, a Parisian clockmaker, has also endeavored to find a method of substituting for the gridiron pendulum another performing the same condition—that of rendering the apparatus insensible to the variations of temperature. He avails himself of the unequal expansibility of the metals by heat, but the arrangement of his apparatus is new, and the joint responsibility which he has established between the zinc and the steel seems to fulfil perfectly the design of the author. This adjustment is made as follows:

The suspension-rod is of steel, cut in the form of an oval cylinder, and of a length suited to the duration required for its oscillations. At the lower part of its length, it is encircled by a sort of zinc cover or case formed of two tubes of this metal, which are joined on their edges by several adjusting-screws in order to fix the apparatus solidly by small cross-bars. The system of the steel rod and its zinc cover are free and independent of each other; but to hold back this zinc cover and prevent it from sliding on the suspension rod, the lower end of the steel rod is cut with a thread and furnished with a screw-nut upon which this cover rests; this screw-nut serves to obtain mean time in the usual manner.

The top of the cover is in the form of a screwed cylinder and carries a screw-nut, which, being underneath a ferrule, serves as its support; this ferrule serves as a point of support to two steel rods which, by their lower end, are fixed to the pendulum-ball and support it; it being understood, 1st, That the pendulum-ball is entirely independent of the steel rod, and that its zinc cover only serves it as a support; 2d, That the length of the zinc cover is calculated, according to the law of dilatation, to produce a greater effect than is needed, so that to regulate it, it will be necessary to shorten it by means of the screw-nut. His ingenious apparatus produces the following effect:

Let us suppose that, after having adapted the pendulum to a good clock, and regulated the length to a constant temperature, we wish to adjust the compensation.

We raise the temperature by the usual methods and find, for instance, that the clock gains more or loses less time than before; we therefore conclude that the heat lengthens the steel suspension-rod, which should produce a delay, but that the screw-nut serving as a support to the pendulum-ball on the zinc cover is also lengthened, and that the pendulum-ball has been elevated in the same proportion; so that it has raised more by the second effect than lowered by the first. The pendulum, therefore, has really been shortened, and the centre of oscillation brought nearer the suspension; the zinc part is thus too long compared with the steel.

To shorten this, we turn the screw-nut, which is beneath the ferrule of support of the pendulum-ball, in the direction proper to lower the latter; this produces two effects, 1st, that of shortening the zinc tube which produced too great a compensation; 2d, that of lowering the centre of oscillation, which would retard the clock; but as this last effect would tend to derange the general movement, we wind up the centre of oscillation again by turning the screw-nut of the end of the suspension-rod. As the threads of the screws are the same, or very nearly so, the desired quantities may easily be marked on both by means of an index and equal divisions on each screw-nut, so that the compensation alone may be influenced.

We can thus adjust this compensation-pendulum, not only without taking the clock or pendulum apart, but almost without stopping it, or at least by stopping it for a single moment, so that we can moderate the compensation without trouble, expense, or time; and nothing can be easier than to manage this apparatus and to obtain the highest degree of exactness by repeated essays, with the same facility as for a simple pendulum.

One of the results which the clockmaker should guard against in the construction of compensation-pendulums, and the one which is most injurious to gridiron-pendulums, is the bending and sinking caused by the heavy weight of the pendulum-ball on the adjustment-rods which support it; this weight is perpetual, and it therefore follows that the compensation cannot be perfect. When the pendulum is first constructed it is impossible to regulate it; the pieces must first produce their effect under the influence of the weight which draws them down. At the end of a certain time they are tried, and the regulation of the dimensions of the bars of the two metals is attempted; repeated experiments are necessary for this, and at the end of a long time, a year or more, a correct pendulum will finally be obtained. The weight of the pendulum still acts, but the band of the metals has learned to resist it.

We shall not attempt here to compare the compensative-pendulums of MM. Duchemin and Jacob; these two mechanisms, although constructed on the same principles, are of different natures; one only attempting to obtain a sure and easy method for the regulation of the gridiron-pendulum, while the other has invented a new pendulum which we will call the *cover-pendulum*, to distinguish it from the first;

both inventions are worthy of praise, and either can be chosen with the certainty of making a good choice.

M. Jacob is also known as the inventor of an indicator which has been well received; and which is declared, in a year's trial, not to have lost or gained more than half a minute per month. The pendulum-rod is of wood, properly chosen and prepared, so that neither the length nor the form may be changed by the variations of temperature, or the humidity of the atmosphere. We know, indeed, that the temperature does not lengthen the wood, and that the torsion of the rod, by the influence of the humidity, may be avoided by the application of a suitable coating.

Sphere-Clock, by MM. Soyez and Inge.

This apparatus is formed of a terrestrial sphere of metal or any other material, hollowed out, and containing a clock-movement in its interior which causes the globe to turn on its axis; the zones being of an equal weight in the whole length, in order that the rotary movement of the globe may be also equal.

Its axis, fixed by its ends on the half of the meridian, which is left as a point of support, is held on the horizon, the point where the half of the meridian reaches, to obtain solidity.

Upon the middle of the axis, an ordinary horary movement is also fixed, either with or without striking work, but whose minute-wheels are less; the globe making its revolution in twelve or even in twenty-four hours, if required.

At the top of the movement, and fixed by this means to the middle of the globe, is carried the pinion which belongs to the axle of the large hand in the ordinary movements at the top of the pillar-plates, so as to reach the extremity of the radius of the sphere, and thus to obtain a more powerful lever.

A wheel, whose cogs are twelve or twenty-four times more numerous than those of the pinion of the large hand (supposing a movement for each hand), is fixed in the interior of the globe, by three levers, upon three interior points of its circumference. This wheel works into the pinion of the large hand, and being attached to the globe, thus communicates the action to it by this point of contact with the movement.

The globe is movable on three points, namely:

1st, The two poles on the axle near the horizon and meridian circles.

2d, Upon the centre of the great wheel, the axle of which is fixed to the end of the movement.

The globe thus makes its revolution in the twelve hours inscribed in the great circle of the equator, and in that of the horizon and the meridian.

The hours and minutes are marked on the equator; by this method, each meridian and each point of the sphere passes successively and regularly under each hour and each minute; thus indicating the hour at every part of the world at a single glance.

It should also be remarked that the hours should be traced from the right to the left, in order to give the true position of the earth.

Universal Clock, indicating the Actual Time beneath every Meridian, by M. Duclos, of Paris.

This clock shows the hour of each meridian, and the general effect of the division of the day for the different longitudes.

The equator is drawn upon a circular and immovable band, this is divided into three hundred and sixty degrees by the intersection of meridians, which are numbered in tens, choosing any given place for the point of departure. The hundred and eighty degrees of west longitude are marked from right to left, while the hundred and eighty degrees of horizontal longitude are marked from left to right.

The most remarkable places of the globe are indicated above this division, according to their respective location (in longitude alone); these may be more or less numerous, according to the diameter given to this equatorial band.

A second circle, parallel to this fixed band, is placed above and somewhat in the interior; this bears twenty-four principal divisions, in which the twelve hours of the day, and the twelve hours of the night are marked. The divisions of the minutes are placed beneath, in such a manner that the lower border of this circle corresponds with the upper border of the equatorial band.

This hour-circle revolves horizontally once in twenty-four hours, moving from east to west, according to the apparent diurnal revolution of the sun around the earth; consequently each hour presents itself successively beneath each meridian, and all the meridians correspond continually to the hour which they should indicate as soon as this correspondence has been established by setting the clock at the hour of the first meridian, at which point a principal indicator is fixed.

The movement is communicated to the hour-circle, and to every part of the circle which invests it, without any apparent train in the interior of the model, which may be transparent; no piece of clock-work can be perceived.

All of this movable part is fixed through the centre of the hour-circle on a perpendicular axle; this axle is prolonged and passes through an obelisk which is placed between figures or columns.

A movement of clock-work is placed horizontally in the pedestal of the clock; one of the motive-powers of this movement revolves once in twenty-four hours, and the long arbor which it carries occupies the centre of the pedestal. This long arbor, which passes through the upper part of the pedestal, receives a socket inserted with a strong friction, on which the lower extremity of the axle is mounted, the other extremity being fixed to the centre of the hour-circle.

The movement of clockwork, whose caliber is arbitrary, provided that one of the motive-powers revolves once in twenty-four hours, and that its regulator is a balance, needs not to be described here any more than the escapement, which should be chosen from those best known. A remontoir is adjusted beneath the pedestal, which can be turned without a key. The whole piece can be moved without stopping it. The inventor proposes to make this clock in different sizes, with striking-work, and the days of the month; he also intends to apply the mechanism that has just been described, to indicate the actual time under every meridian without a dial, by the correspondence of two concentric circles; one of which will remain stationary while the other will revolve in twenty-four hours.

Alloy for Horology.

Mr. Bennet, an English clockmaker, has discovered an alloy which is well suited to the manufacture of the sockets of pivots of ordinary watches.

He has succeeded best with the following composition:—

Pure gold,	Parts,	31	100
Pure silver,	"	19	
Copper,	"	39	
Palladium,	"	11	

Palladium readily unites with the other metals; the alloy liquefies at a lower temperature than is required to melt the gold separately, and, after cooling, is harder than hammered iron. It is of a reddish-brown color. It is as fine grained as steel, and is worked almost as easily as brass, but its friction is much slighter on ordinary pivots. Its most valuable property is this; that the oil it absorbs is not decomposed, but remains pure, in a fluid state. It has still greater advantages over sockets of fine stone, as it is not apt to break, is susceptible of a perfect polish, and is much less costly.

Method of Measuring Mean Temperatures.

M. Jurgensen, a celebrated clockmaker of Copenhagen, who is known by a treatise on detached escapements, and by the excellence of his chronometers, has conceived the idea of employing these chronometers in the determination of the mean temperature of twenty-four hours. We know that to preserve a watch from the variations of temperature, we must adjust to the balance a band in the form of an arc of a circle, composed of two metals, whose unequal dilatation opens or closes the curvature, in such a manner as to retard or accelerate the movement.

Now, in order to apply it to the measure of mean temperatures, the concavity of the arc must be placed inside; this doubles the variation caused by the temperature. M. Jurgensen has added besides a second arc to render the effect still more sensible, and thus obtains a variation of thirty-one and a half seconds for a degree of temperature.

It is evident, therefore, that if the instrument is compared with a regular chronometer, one will know how far the temperature has been above or beneath a given temperature.

The movement of this instrument, however, must first be regulated to a fixed temperature, as that of zero for instance.

Method of Hermetically Covering Mantel-Clocks.

Every one has probably remarked the dust that penetrates into the interior of mantel-clocks, despite the balloons and bell-glasses with which they are generally covered, and that the quantity is greater in proportion to the carpets with which the rooms are furnished,—the inexhaustible receptacles of a fine and impalpable dust which is not the less real because not perceptible to our senses.

However firmly closed our clocks may be; however well made may be their glass and crystal coverings, they will not prevent the introduction of this dust, which tends to penetrate them still more when the air of their interior produces an equilibrium with that of the rooms.

We may easily judge of the effects which the introduction of this dust will produce in time on the delicate trains and movements of costly clocks, when we see the thick coating of dust which is deposited every day on the furniture of carpeted rooms, and those wherein numerous assem blies collect. To remedy this, M. Robert covers the edge or the lower part of the bell-glasses or balloons, not with a thick velvet or a double chenille, but with an elastic cushion, which forcibly enters into the conical part of the pedestal, so as to press strongly against the pedestal in its whole circumference, in order to prevent the air from passing between the two parts, at least unless impelled by a great pressure.

The pedestal is hollow, or in the form of a box, composed of a circumference, a bottom, and a cover; it is divided into two parts by a diaphragm or pocket of gummed taffeta.

The bottom and the cover are both pierced with an aperture; that of the bottom establishes a communication between the exterior air and the part of the pedestal beneath the diaphragm, while that of the cover establishes it between the air of the bell-glass and that of the upper part of the pedestal.

In consequence of this arrangement, which is as ingenious as simple, an equilibrium is produced between the outside air and that of the bell-glasses, according to the variations of temperature in the rooms, without any penetration of dust; since, when there is a dilatation of the air contained in the interior, the taffeta diaphragm yields and descends into the lower part of the pedestal; while if the air is condensed, it rises until the equilibrium is again established.

Inconvenience of the oak wood used in the construction of the Cases of Clocks and Astronomical Instruments.

A letter to the editor notices an important observation made by an astronomer relative to the effect produced by oak wood on the metals which come in contact with, or near it. The pieces of a costly clock were twice unaccountably covered with rust, though the other instruments in the same observatory were not thus affected. The clock was fastened between two pieces of wood, the front being mahogany and the back oak; these pieces were joined together by bars of copper screwed into their lower extremities. Suspecting that the evil sprang from the influence of the oak wood, these rods were taken out, when it was perceived that while that part of their length which had passed into the mahogany was bright, that which had penetrated the oak was covered with an oxyd, or salt of copper. A chemist, who was called to examine this case, attributed the whole evil to the influence of the oak wood. Small holes having been pierced into the piece of wood by means of a drill, some of the particles taken therefrom were heated in water over the flame of a taper, and this water instantly reddened litmus paper. It was needless, in fact, to have recourse to this process, as pieces of litmus paper, introduced into the holes made into the wood, were deeply reddened in a few seconds, proving that there was an extremely volatile acid in the oak wood; the same experiments failed to discover any trace of acid in the mahogany. The chemist was of the opinion that the influence of the oak could only be remedied by varnishing or veneering it. Other examples of the same effect on astronomical instruments have been cited. Nor will this action of oak on metals seem strange when we reflect that the bark of this tree contains tannic acid, and that it also bears the excrescences which, in certain species, take the name of *galls* and produce acid.

CHAPTER XI.

VARIOUS TOOLS USED IN CLOCKMAKING.

We do not intend to give here a list or description of the numerous tools employed in clockmaking, as a large volume would hardly suffice for this purpose, but shall limit ourselves to the description of some ingenious specialties of utility.

I.—GENERAL TOOLS.

1st.—*Method of Straightening the Pinions.*

When clockmakers have rounded and filed a pinion thin enough, they blue and temper it. This usually warps the rod of the pinion, which becomes crooked on the two points which served to turn it, and the workman is then obliged to straighten it with the file. If, on the other hand, the difference is small and the size of the rod permits, he straightens the rod by means of an edged hammer on a smooth hand-anvil by striking in the hollow in order to elongate this part, or, which is preferable, he places a very smooth file in the vise in such a manner that its cut side may be placed above. He then rests the hollow side of the rod on this edge, and strikes the opposite part with the head of a smooth hammer; the cuts of the file, being very fine and close, perform the functions of small chisels or edged hammers, and the straightening is made with greater speed and regularity.

This being done, the workman turns and rounds the points, and turns the rod and polishes it in the same manner as the leaves of the pinion.

Pinions may be procured in the shops ready made and polished, and of different lengths and numbers, which can easily be adjusted to the watches most in use; but these pinions are seldom round, and a careful workman should examine them in this respect before using them, in order to rectify the errors or to assure himself that none exist. The instrument of which we shall speak will be useful in both cases. Figures 1 and 2 (Pl. VI.) represent it; in profile in Fig. 1, and in front in Fig. 2. The same letters indicate the same pieces in both figures.

This instrument is simply a support of a finishing-lathe. The rod, A, enters into the rest of the lathe, which we have not thought necessary to engrave, and is fixed at the proper height by the screw of the holder. The plate, B, which is placed at right angles and riveted on the upper part of the rod, A, is brought near the turning-tools of the lathe; this is pierced with several holes, E, cut with the same thread of the screw, to receive the screw, C, which is introduced at the proper point by means of the thumb and forefinger. This screw is of steel, pierced in its axle, into which is adjusted a small piece of brass resembling the head of a pin. The rest of the machine is of brass. The screw is placed in one of the holes, E, which is the most convenient for the workman.

The tool is represented of its natural size, and is used in the following manner: The workman, after having fixed a screw-roller on one of the rods of the pinion, places it between the two turning-tools of the lathe, and turns it slowly with a horse-hair drill-bow which he holds in his hand, gradually advancing the screw until its point renders all the leaves of the pinion even. If the rod is crooked, he straightens it again by the method which we have indicated.

Clockmakers had previously used a similar method, but one less certain. They took a brass point, a large pin for instance, rested it on the support of the lathe, and brought it near the leaves of the pinion; but, having no means of fixing the distance in an invariable manner, the friction was not sensible enough to work accurately.

2d.—*Lathe for Rounding Pivots.*

A good lathe for rounding pivots is a valuable tool, especially in the present state of clockmaking. The holes made in the two puppets to receive the turning-tools should be exactly opposite each other, and in a straight line through their whole extent, so that if a turning-tool were passed from one puppet into the other, it would glide there with as much ease as if one of the holes only formed the continuation of the same cylinder. It is therefore necessary that the part of the turning-tool of the lathe which receives the extremity of the axle opposite to that which bears the pivot to be worked should be exactly in a straight line with the notch made in the extremity of the other turning-tool, parallel to the axle of this turning-tool; for when this does not take place, the pivot is cut at the bottom, or is conical, or breaks when it is rounded.

M. Vallet has remedied these inconveniences by the construction which we are about to describe. Figure 3 (Pl. VI.) represents this instrument in front, fixed into the vise by the foot, A. The two puppets, B, C, do not differ from the puppets of ordinary pivot-lathes; they carry the two turning-tools, D, E, which are fixed in the proper position by the screws, F, G, which rest upon the cushions, H, H, as in ordinary lathes. Each puppet carries a shaft, I, K, whose use we shall presently show. Each pike of the lathe carries a kind of wheel, L, J, divided into twelve large teeth, and the two shafts, I, K, enter exactly into the empty space left by two teeth, in order to fasten the turning-tool perfectly, so that it cannot turn, while the upper screw, F or G, hinders it from advancing or retreating.

The turning-tool, D, is terminated on the inner side of the lathe, by a steel turning-gauge, M, which is fixed by a strong screw to the end of the turning-tool. This plate, M, is pierced with a hole towards the extremity of one of its diameters. This hole, which is perfectly cylindrical and parallel to the axle, receives a pike, P, which serves first to mark the corresponding holes in the turning-gauge, N, of which we shall presently speak, and then to support one of the extremities of the axle, the pivot which is to be rounded being placed at the other extremity.

The pike, P, enters cylindrically and closely into the hole of the turning-gauge, M; its outer part is conical and pointed. It is tempered blue and then adjusted. When it has served to mark on the turning-gauge, N, the twelve holes of which we shall presently speak, its point is slightly filed, and a shallow hole is pierced in its centre, which afterwards serves to receive the extremity of the axle of the piece which bears at its other extremity the pivot that is to be rounded.

The other turning-tool, E, carries between the two puppets two pieces, N, O, whose construction should be understood. The part of the turning-tool concealed by the pieces, N, O, is turned cylindrically as a pivot smaller than the turning-tool, but large enough to receive a screwed hole and a strong screw. The turning-gauge, O, entirely covers the species of pivot of which we have just spoken. The turning-gauge, N, has one hole of the size of the screw which consolidates the whole; the head of this screw is sunk into the turning-gauge, as it might sometimes be injurious if it should project.

The turning-gauge, N, has, on its circumference, twelve notches, varying in size and depth according to the size of the pivots to be rounded. These notches should be carefully made; they should be exactly parallel to the axle of the turning-tool, and perfectly semi-circular.

To make these notches in such a manner that they will be exactly opposite the pike, P, it must be remembered that this pike is at first pointed and very sharp. The turning-tool, D, is brought in contact with the pike, I, by a tooth of the wheel J; the pike, E, is likewise connected with the pike, K, by a tooth of the wheel, L; the head of the pike, D, whose adjusting-screw, F, is not fastened, is struck, and a point is marked on the turning-gauge, N. The place of the wheel, L, is changed, and, consequently, the turning-tool, E, turns one-twelfth; another point is then marked, and so on until the whole twelve points have been marked. A hole, parallel to the axle, is pierced at each point, by means of drills proportioned to the size of the pivots to be rounded. These holes being made, the turning-gauge, N, is filed in facets, in such a manner as to remove half the cylinder which this hole has formed, making it so that the plane of this facet may be perpendicular to the vertical plane which shall pass through the axle of the turning-tool, and that the notch which has formed the uncovered hole shall divide the facet into two equal parts. Much care is necessary to obtain a perfect execution, but this is indispensable to a successful result.

The turning-gauge, O, is filed in facets parallel to the axle of the turning-tool; it carries twelve facets whose distance from this axle is proportioned to the size of the pivot before which they present themselves. The middle of each facet should correspond to the middle of the notch before which it is placed. These facets are designed to support the pivot-file or burnisher, which should be rested upon them in such a manner that the file may be parallel to the axle when the pivot is finished, so that it may be perfectly cylindrical.

3d.—*The Pivot-Compass.*

Berthoud demonstrated the importance of arranging the size of the pivots in watches in such a manner that the wheels which have the most rapid movement may have the finest pivots. He also proposed an instrument for attaining this end, but it was not satisfactory, and was therefore abandoned.

M. Vallet, being convinced of the importance of an instrument of this nature, has perfectly succeeded in the following invention.

Figure 4, Pl. VI., represents this instrument in elevation. Figure 5 gives a bird's-eye view of it, and Figure 6 shows the mechanism. The same letters indicate the same object in the three figures.

The machine resembles a watch-case, A, A, supported by three feet, B, B, B, in order to raise it to a convenient height. The mechanism is concealed by a dial, C, divided into 360 equal parts, numbered in tens, which a slender hand, D, passes over, to indicate the opening of the compass. The whole is covered by a convex-glass, E, resembling a watch glass. Upon the side, we perceive two arcs of a circle, F, R; R, G, which are the feet forming the compass-piece, in polished steel, and which only separate when some body is passed between them. This instrument is so susceptible that a hair will suffice to turn aside one of the feet, and the hand will instantly indicate the diameter of the hair on the dial.

The instrument is constructed in such a manner that the hand will pass over the whole circumference of the dial, when the movable foot is turned aside three lines; a line is therefore divided into 120 equal parts, with mathematical exactness.

Figure 6 shows the mechanism as disclosed by the removal of the dial. One of the feet, G, of the compass is fixed in the case by a screw, H, and two chicks. The other foot, F, is movable; it carries within the case an arm of a lever, K, whose centre of motion is at the point, I. This arm of a lever is riveted to a vertical axle, which moves on two pivots which roll in the pillar-plate, and in the bridge, S. This same axle carries a rack, L, whose teeth, N, work into the leaves of a pinion, M, of fourteen teeth, the pivots of which are also carried by the pillar-plate and by a bridge. A spiral-spring, O, strong enough to bring back this slender mechanism to its place, is fixed by one end to a ferrule carried by the pinion, M, and enters by the other end into the screw-ring, P. The whole is arranged in such a manner that when the two feet of the compass touch each other, the hand, D, rests on the number 360.

To find the size of the pivot which is to be made, it is passed between the two feet at the point R, and is reduced until the hand indicates the point at which it should stop. In order to give greater facility for opening the compass when the pivot is presented, the end of the fixed foot is imperceptibly turned off, so that the thickness of the movable foot slightly exceeds that of the fixed one. By this means the compass opens without any resistance when the pivot is rested against the movable foot.

4th.—*Compass for Turning Cylindrical Rods.*

In the construction of the compass for rounding pivots, M. Vallet experienced much difficulty in turning cylindrical rods by the aid of the calipers which were then used.

The invention of the pivot-compass, which we have just described, suggested the idea to him of applying it to the turning of rods cylindrically.

Figures 7 and 8, Pl. VI., will suffice to show this useful instrument. Figure 7 shows the tool in front; a plate, A, A, of well-hammered brass, whose form is indicated in the figure, shows in the upper part a rim divided into equal parts, which are marked in fives by figures. This plate is first turned round, and is then detached to give it the form of the figure. A hand, *a*, is placed at the centre of the tool, which marks the degrees of opening of the compass on the rim, *b*. This hand is fixed on the extremity of the pivot of a steel rod, which is in a frame on the back of the tool, between the plate, A, which constitutes it, and a small bridge fastened on this plate by a screw and two chicks. A ferrule is adjusted with a strong friction on the prolongation of the upper pivot; this receives the inner end of the small spiral-spring, *d;* the hand, *a*, is also placed above with a strong friction.

Two feet of a pair of compasses, constructed like those of the pivot-compass, are represented in Figure 8 on a double scale; the foot, G, is exactly similar to that of the compass (Fig. 6), and is fixed in the same manner. The other foot, F, differs slightly from that of the pivot-compass; it does not carry any rack, but its second arm of a lever, H, carries the screw-ring of the spiral-spring, or, to speak more correctly, is pierced parallel to the plate, so as to perform the functions of a screw-ring. The second foot of this tool is carried, like that of the pivot-compass, by a small axle and two pivots, one of which rolls in the plate, and the other in the bridge, D.

The mechanism of this instrument may be easily understood. When the point, R, is in contact with a rod placed on the lathe, the two feet of the tool separate, and the spiral-spring is carried to the left; this causes the hand to move on the rim, and marks the degree of opening. By conducting the tool along the length of the rod, the exact difference may be perceived, and the inequalities corrected.

At the top of the plate a knob, E, is riveted, which serves to hold it by the fingers when it is worked.

II.—SPECIAL TOOLS BY M. VALLET.

The workmen who were occupied in the construction of the cylinder-escapement had long demanded tools which would assure to them a perfect regularity in the manufacture of the teeth of the cylinder-wheel. They had already succeeded in perfecting the cylinders, but they had not taken the same precaution for the wheel.

M. Vallet perceived,—1st, that the inclined plane of every tooth should be perfectly equal in each one, in order that the lifting should be constantly the same; 2d, that the teeth should all be of an equal length, in order that the fall should invariably be the same; 3d, that the back of each tooth should be an inclined plane, in order to give to each tooth the same thickness towards the point, so that each should exercise the same friction on both surfaces of the cylinder; 4th, that the small columns which support the teeth should be uniform, and well-polished, so that the cylinder could not reach them in any case, as this would produce great irregularity in the movement of the watch.

1st.—*Tool for Uniformly Inclining the Teeth of the Cylinder Wheels.* Pl. VI.

Figure 9 shows the tool seen in elevation and profile from the side, *a*, *b*, of Figure 10.

Figure 10 shows the same tool seen in front, from the side of the artisan during the working.

Figure 11 is the elevation and profile of the same tool, seen from the side, *c*, *d*, of Figure 10.

Figure 12 shows the same tool, seen in front, from the side opposite the workman.

Figure 13 is the same tool, seen above, or a bird's-eye view.

The same letters designate the same pieces in the five figures.

This tool is all of brass, with the exception of the screws, and a few pieces which we shall mention.

The frame, A, A, is nearly square; it bears an opening, L, L, L, L, in which a piece of the same form and the same thickness as the frame moves, but which is shorter than the notch, in order to give it the facility of ascending and descending when impelled by the adjusting-screw, G. The four steel bands, *f*, *f*, *f*, *f*, two of which are fixed on the front, and two on the back of the tool, each by two screws, form the slide between which the piece, B, moves. This piece, B, carries a bridge, M, at the extremity of which a puppet, N, is riveted, which receives a small turning-tool, P, that is fixed at a suitable point by the adjusting-screw, O. This bridge is fixed on the plate, B, by two adjusting-screws and one or two chicks.

The piece, B, bears upon its other face (Fig. 11, 12, and 13) a piece, Q, upon which another puppet, R, is riveted, which receives the turning-tool, T, fastened by means of the adjusting-screw, S.

It is almost superfluous to add, that the two turning-tools, P and T, should be exactly opposite, and that a small, shallow hole should be pierced at the end of each to receive the ends of the two pivots of the cylinder-wheel. These two turning-tools are of steel.

The frame of the tool, A, A, bears a rack, D, and a driving-wheel, E. A horizontal opening is made beneath the rack, D, in the frame, which receives a rectangular piece riveted with the rack. The whole is fastened by a screw, *g*, which traverses,—1st, a steel plate which we see in front of the rack; 2d, the rack and the rectangular piece; 3d, another steel plate, J (Fig. 12), which serves as a screw-nut. By this means the rack can be moved to the right or left, according as it is impelled by the driving-wheel, E, which is moved by the knob, F.

The frame of the rack bears a piece of steel, C, U, in the upper part, which is called the *branch;* this moves circularly on the screw, *h*. This piece is of the form represented in the figure; it is thinned off in the parts approaching the turning-tools from C, as the dotted lines indicate. This branch passes between two pieces of hard-tempered steel, one of which, I, I, is fixed on the body of the frame, A, A, by two screws, and the other, V (Fig. 13), in the form of a bridge, is fixed upon the first by two screws.

A small piece of steel, bearing a little raised arm, is placed above the piece, I, I, as may be seen in Fig. 10. This piece bears an oblong hole (Fig. 13), and is fastened by a screw; it can be advanced or drawn back at will by means of a pin, which may be seen in the hole, and which prevents it from turning. This piece serves to hold back the file which, if it were free, might spoil the tooth following the one which is worked.

This tool is placed upon the ordinary centre-lathe. The turning-tools of this lathe enter into the holes *m*, and *n*, which are seen in the two profiles (Fig. 9 and 11). These two holes should be placed at the two extremities of a right line parallel to the upper surface of the frame, *a*, *c*.

This being understood, we will describe the operation. The workman places his finger on the end, U, of the branch, to cause it to rise, after having placed the tool on the lathe;

he then places the cylinder-wheel between the two turning-tools, P and T, and brings it forward in such a manner that it lightly touches the piece, B, which he raises in order that the wheel may rest the greatest part of its circumference on it, and thus be better supported. He next advances or draws back the branch, in such a manner as to support the tooth, and to raise it more or less in order to incline the plane more or less.

All being thus arranged, he files all the part which projects beyond the pieces I and V, and then passes to a second tooth without disarranging anything except the branch, which he detaches from the tooth just worked, in order to pass it beneath the following one. By this method the teeth will all obtain the same inclination.

2d.—*Tool Designed for Two Uses*,—1st, *to Reduce the Teeth or the Hammers to an Equal Length;* 2d, *to Form the Inclination of the Back of the Tooth.*

The tool we are about to describe is likewise of brass, with the exception of the screws, and a few pieces which are of steel, and which we shall point out.

Figures 14, 15, and 16 (Pl. VI.) represent the tool in its natural size, and in three different positions.

Figure 14 gives it in such a manner as to show the small lathe in front.

Figure 15 gives a bird's-eye view of it when it is placed on the vise and is ready to work.

Figure 16 represents it in front, in the vise, as it is presented to the artisan during the working.

The same letters indicate the same pieces in the three figures.

The frame, A, of the tool has a vertical grooving in its lower part, in which a slide, B, moves, which can be raised or lowered at will by the adjusting-screw, C.

The part, B, of this slide bears a horizontal grooving, in which another slide, F, moves, which advances or retreats to approach or recede from the frame, A, by means of the adjusting-screw, E, and is fixed at the proper position by the screw-nut, K, which presses the piece, *a*, against the lower part of the slide, B, by drawing the piece, F, which rests on the upper part of the same piece, B. The upper part of the slide, F, has a fork, M, which receives a tenon, M, that forms a part of the small lathe, D, D.

This small lathe, D, D, has two puppets, whose turning-tools are of steel, constructed as in the small lathe described in the preceding tool. The adjusting-screw, R, S, serves to fasten them. The screw that rests against the frame of the tool is designed to advance or remove the turning-tools of this frame as may be required.

The frame is surmounted by a thick piece of steel, H, which bears an arm, T, shown in Fig. 16. This piece is tempered hard, and is fixed on the frame by two strong screws (Fig. 15). We see (Fig. 14) that this piece, H, is notched to permit the passage in this aperture of the teeth of the wheel, and a small steel rest, I, I (Fig. 16), which is moved by the adjusting-screw. The tooth of the wheel reposes on this rest during the working.

This understood, the tool is worked in the two cases in the following manner:—

To Form the Inclination of the Back of the Tooth.

The wheel is placed between the turning-tools of the small lathe, D, D, in the proper direction, its crown passing into the notch, I, so that the tooth resting by its arm upon the small rest, I—the wheel presents the back of the tooth to the upper part of the steel-piece, H; that is, the inclined plane formed by the first tool (described Fig. 9, 10, 11, 12, 13) must rest on the small piece, I. The lathe is then raised by the aid of the adjusting-screw, C, and is inclined to the suitable position by the screw, G.

This done, the tooth is found, the point of which presents the smallest surface, and the wheel is raised until the file, guided by the steel-plate, H, reaches this surface; and by making all the teeth to pass in succession, an equal thickness is given to this point, and the back of all the teeth are equally inclined.

To Reduce the Teeth or Hammers to an Equal Length.

The cylinder-wheel is placed on the small lathe, between the turning-tools, P, Q, in the inverse direction to that which we have mentioned above; the lathe, D, D, is removed by the screw, G, so that the tooth rests by its arm on the small support, I, the point of the tooth or hammer being in air. All the teeth are then passed successively by drawing back or advancing the lathe until the shortest, which is on a level with the upper part of the steel-piece, H, shall be encountered. This point found, each tooth is passed in succession on the same rest, I, and all that part is filed away which projects beyond the piece, H; in this manner an equal length is secured to all the teeth. The file cannot slide against the wheel during this operation, as it is held back by the projecting arm, T.

3d.—*Tool for Polishing the Columns of the Cylinder Wheels.*

This tool is of brass, like the preceding ones, with the exception already indicated. It is engraved here in its natural size, the same letters representing the same pieces in the three figures.

Figure 17 shows the tool in elevation placed on the rise by its foot, G, and seen from the side of the workman.

Figure 18 shows the same tool seen on its opposite surface, in order to explain the adjustment and the utility of the slide-rest, E, E, which Figure 19 shows in front, as seen from the end, H.

The tool is a small chuck-lathe, whose frame comprises the body of the lathe, A, the foot, G, the puppet, B, which carries the steel turning-tool, C, which is fixed at the proper point by the screw, I, and the second puppet, M, to receive the neck of the arbor, H, L.

This second puppet is formed of two parts; of which the one, M, of brass is of the same piece as the rest of the frame; and of a second part, P, of steel, which is fixed by two screws on the puppet, M.

The slide, F, E, H, is fastened on the frame of the tool by the two screws, S, S, which are screwed into the frame. These two screws pass freely, and without play, into two oblong holes, R, R, so that the part, H, E (Fig. 19), which turns at right angles towards the puppet, M, can easily approach or recede from this puppet by means of the adjusting-screw, F, when the two screws, S, S, have been loosened, which are fastened after the slide has been drawn to the proper point, relatively to the wheel which is to be worked.

It is, doubtless, superfluous to remark, that the holes pierced in the puppet, B, in the second puppet, M, in the steel plate, P, and in the head of the slide, E, E, at the point, H, should all be in the same right line perpendicular to the surface of the plate, P.

The mandrel of the chuck-lathe is of tempered steel, and only extends, properly speaking, from the point, J, to the turning-tool, L, which is received in a hole pierced at the end of the turning-tool, C.

This mandrel is conical in the part which passes through the plate, P; it is cylindrical in the rest of its length, although of different diameters. The centre of the mandrel is pierced with a cylindrical hole through a great part of its length, reckoning from the point, J. A set of cylindrical cutting-files, which enter closely by their handle or rod into the hole of the mandrel, are fastened in it by an adjusting-screw, *a*. A roller, N, of brass, is placed on the extremity of the mandrel at L, and is fastened by the adjusting-screw, O.

The cylinder-wheel is placed flatwise against the front of the slide at the point H, at the side of the cutting-file; the slide is then advanced, or drawn back, by means of the adjusting-screw, F, until the base of the cylinder, which forms the cutting-file, comes exactly beneath the tooth, so that it does not leave any projection or unevenness against the tooth, and that this tooth seems placed flatwise on the top of the small column which supports it. The tool being thus arranged, a horse-hair drill-bow is placed on the roller, and the cutting-file is turned with one hand, while the other guides the wheel in such a manner as perfectly to form both the small column and the aperture in the form of a U, beneath the tooth or the hammer.

III.—LEVER INVENTED BY FERDINAND BERTHOUD FOR MEASURING THE FORCE OF THE SPRINGS OF WATCHES, AND DETERMINING THE WEIGHT OF THE BALANCE.

This tool, which is seen in perspective in Pl. V., Fig. 10, is described by Berthoud as follows:

"The part A is made of two pieces which form a jaw resembling that of the levers for equalizing fusees, with the exception of opening perpendicularly to the arm, C, in order that the different sizes of the squares of the fusees may change the centre, A, of the lever, C, as little as possible. The square of the fusee enters into the square hole, A, and this jaw is closed by means of the screws, B, *b*, so that the square of the fusee is drawn along with the lever. The arm, A, C, of the lever, is in equilibrium with the ball, D, when the slider, E, F, is removed.

"The arm, C, is graduated in its length in such a manner that when the slide, E, with the weight, F, which it carries, is placed on any division such as 3, 7, 12, etc., to 25, we shall have the number of drams which must be placed at D to produce an equilibrium with the weight, F.

"To graduate this arm, I fixed the jaw, A, upon the square of a fusee; this square was of a medium size, the fusee turned freely in its frame without a chain or communication with the spring; I then brought the arm, A, C, into perfect equilibrium with the weight, D; I suspended a small balance-plate at D, on a small grooving, *d*, made in the lathe with the point of a burin, in such a manner that its distance from the centre, A, of the lever was exactly four inches; and to prevent the weight of the plate from destroying the equilibrium, I attached a small piece of brass to the other extremity of the lever, C, which gave equilibrium to the balance-plate. All being thus arranged, I replaced the slide, E, with its weight, F; I then put one dram in the plate and moved the slide, E, until it was in equilibrium with the weight of this, when I traced a division and marked 1. This done, I added one quarter of a dram to the weight in the plate, and moved the slide until it was in equilibrium with this weight; then marking a division extending across one quarter of the width of the arm, to designate the quarter of a dram. I again added a fourth of a dram and found the equilibrium, then marked a division extending across half the width of the arm, to designate half a dram, then added the same quantity again, and marked a division of three-fourths. This done, I added one fourth of a dram more to the weight in the plate and marked 2 across the entire width of the arm, to designate two drams; and, thus adding quarters of drams in succession, I graduated the whole length of the arm.

"It is evident from the construction of this instrument, that if it is adjusted to the square of a fusee mounted in its frame with the spring and chain, and the slide, E, is moved to any division, 5 for instance, to produce an equilibrium with the spring, this number will designate the force of the spring, in equilibrium with 5 drams placed at the distance of 4 inches from the centre of the fusee; for the force of the spring represents here the weight that was placed in the balance."

We mentioned this instrument in Chapter Eighth, when speaking of the means of finding the weight of a balance by calculation.

IV.—IMPROVEMENT ON THE TOOL FOR FINISHING TEETH.

This improvement (see Figs. XI., XII., XIII, XIV., XV., XVI., Pl. V.) consists in having found the means of substituting a file (Fig. 11) that is flat on one surface which is cut very smooth, and the other surface of which is round and polished. The small figure, *m*, indicates the transverse section of this file. We have substituted this file, R, for the file, Q, which is generally used by the finishers of teeth, and the section of which is shown in the small figure, *n*. This file is represented here in its natural size; it is cut with much difficulty on the two circular surfaces, *a*, *b*, *c*, *d*, which renders them very costly; besides which, however many one may have, he is never sure that the assortment will be sufficient. The files of which we speak are easily made; five or six, at the most, are sufficient for a full assortment; only vary in respect to size, and they are inexpensive.

In making use of a flat file for rounding the teeth by the aid of a machine, we see that it must imitate in its movement the hand of the workman that rounds them with the ordinary file, and that simultaneously communicate a backward and forward, and a nearly semi-circular movement. These two movements are difficult to obtain at the same time, and a workman must possess great skill in order to succeed in them without a machine; this operation, therefore, is rarely executed with regularity.

To succeed in giving to the file these two indispensable movements, while using the ordinary machine for finishing teeth, we employ a mechanism, which we place on the hand which carries the rounding-off-file, in order to communicate to the latter a semi-circular and alternate movement by the backward and forward impulse which the workman necessarily gives to the hend. We make no other change in the instrument. As this mechanism is little known, we shall describe it in detail.

Figure 13 represents the section of the hand, taken in the middle of its length.

Figure 12 shows the top of the hand which carries the rounding-off-file. The same letters indicate the same pieces in both figures.

The wheel, A, has eleven teeth; these are cut, and it is held back by the catch, B, which is continually impelled between two teeth by the spring, C. This wheel is moved by a wheel-click-pin, placed on the upper part of the machine; this passes through the hand by the notch, D, and comes to encounter the tooth of the wheel. This wheel is inclined when the hand goes forward, and resists when it moves backwards; it is only then that the wheel turns.

The details of the wheel-click-pin are shown in Fig. 14.

The number of the teeth of the wheel, A, appear arbitrary at first sight; yet if attention is given to the effect which it should produce, it will easily be perceived that the number of teeth should be uneven. For this, the number eleven seems suitable, in order that the wheel-click-pin may encounter but one tooth, and that the rotary movement of the file may be made imperceptibly.

The lever, E, F, has its centre at E; it is moved by a pin, H, which is fixed vertically on the ratchet-wheel, A, and which enters into the notch, G, G, of this lever. This pin procures to the lever an alternate swinging movement from the right to the left, and from the left to the right, in proportion as the wheel turns. The centre, E, of the movement of this lever can approach or recede from the wheel, A, at will, by means of the adjusting-screw, L, which causes the piece, I, to move in the slide, K, K, which is fixed on the hand. By drawing the centre, E, nearer to, or further from the wheel, A, the extremity, M, of the lever is caused to describe a lesser or greater arc; by this means a rotary movement is given to the file which is greater or smaller, according as may be required in the different operations of rounding off the teeth, as we shall see in an instant.

This lever, E, F, carries a rack, M, at its extremity, whose teeth are beneath, so as to work into the pinion, U, whose axle carries the rounding-off-file. One of the pivots of this pinion rolls into the bridge, T, the other passes through the bridge, V, and emerges to carry squarely the apparatus, X, Y, which bears the file, Z. The thumb-screw, *a*, serves to fix the apparatus on the square part of the axle of the pinion. The adjusting-screw, *b*, raises or lowers the supporting-plate, Y, in which the file is fixed by its extremity as in a handle, by the thumb-screw, *c*. The adjusting-screw, *b*, causes the file to approach or recede from the axle of the pinion, as may be required in one of the three cases which may be presented in the rounding off, as we shall presently see.

The number of the teeth of the rack, M, is arbitrary; it is in proportion to the number of teeth given to the pinion, and should be such as to cause the pinion to make more than a semi-revolution in its movement.

The rack carries two bridges; one, Q, is fastened by two screws, the other is a little riveted block which is seen near the letter G; between these two bridges is the cylinder, P, whose pivots roll in these bridges; this is designed for the following purpose. The rack is at the extremity of the lever, E, F, which is so flexible on account of its length, that it would be thrown out of gear if we did not take the precaution of covering it by a bridge, S, which confines it in the gearing, while the cylinder, P, is placed on the rack to diminish the friction.

Figure 14 represents separately the wheel-click-pin which sets the whole mechanism in action; this is fixed on the frame of the machine for finishing the teeth, beneath the hand. The end, A, of the pin passes through the longitudinal aperture, D, of the figure 12, to cause the ratchet-wheel to turn. This pin is hinged at the point E (Fig. 14), and cannot move backward, as the end, B, rests upon the solid part of the tool, and is always kept in this position by the spring, C. When the file recedes, a tooth of the ratchet-wheel encounters the pin in front, the latter is immovable, and the pin is forced to recoil. When, on the contrary, the file advances, its pin touches the tooth of the ratchet-wheel from behind; it inclines, while the ratchet-wheel does not move; and when the pin has passed beneath the tooth, it rises up again and is brought back to its position by the action of the spring, C. We see at E, F, a part of the frame of the ordinary machine for finishing teeth.

This new hand is used in the following manner:—When the teeth are ready to be rounded off, the hand is set on the tool, after having placed the pin and fastened it by the pin, E (Fig. 14), in front of the rounding-wheel: a file is chosen whose width easily encircles two teeth without touching either of the others during its semi-circular movement, and the file is advanced or drawn back by means of the adjusting-screw, *b* (Fig. 13), until it can exactly round the half of each tooth; and it is clearly evident that, when the wheel has made a revolution, all the teeth will be rounded.

It would also be possible, with the same machine, to round each tooth by a single stroke, and by a single movement of the file, while, in the preceding operation, two are required for the rounding of each; but for this it would be necessary to use a file so narrow as not to touch the two adjacent teeth in its circular movement. A circular rounding would be obtained by this operation, but the form would be defective and it would not accomplish its purpose.

We have proved that these teeth should be rounded in an epicycloid. Heretofore one could not be assured of obtaining this exact form in practice; but the curve which we give, by the aid of the hand which we have just described, approaches so nearly to it as to show no perceptible difference, and it would probably be possible to give the precise form to the teeth by the absolute perfection of this machine.

If the form of the pinion, or the position of the wheel, demand that the teeth shall be still more a *point-tool*, to use the expression of the workmen, the file must encircle three teeth instead of two, the same precautions being taken as in the first example.

Figure 16 indicates the course of the file in the three cases which we have just surveyed. Care must be taken that the arc described by the rounding-off-file be greater in proportion to the greater number of teeth which it encircles in its course. To demonstrate this, take the three circumferences, G, H, I; A, E, F; D, B, C; the first of which encircles one tooth, the second two, and the third three. It is evident that when the radii include three teeth, they form a greater angle than when they include but two, and still greater than when they include but one; for this angle, whose apex is beyond the circumference at the point, K, has for a measure the difference of the half of the convex arc from the half of the concave arc comprised between the radii. This difference increases with the number of teeth included; that is, the convex arc increases while the concave arc diminishes as they form together the entire circumference described by the movement of the file.

As the rounding-off-file describes a larger arc in proportion as it encircles a greater number of teeth, we could not give it a uniform course; it was therefore important to cause it to describe larger or smaller arcs as might be required. This we have done by making the point, E (Fig. 12, 13), the centre of motion of the rack, E, F. Figure 15 will serve to demonstrate this truth.

Let us suppose C, D equal to the diameter of the circle described by the pin, H (Fig. 12), which impels the lever that carries the rack; we still suppose A to be the centre of the lever, A E, A F, the two radii of the arc described by the lever in its swinging movement, which pass by the two extremities of the diameter, C, D; the rack will then describe the arc, E, F. If we change the centre to B, the diameter, C, D, being still the same, the radii, B G and B F, which pass by the points C and D, will include the arc, G F, described by the lever; and this arc is the measure of the angle formed by the lever, when its centre is at the point B;

but this arc, G F, which is the measure of the angle, G, B, F, is smaller than the arc, E, F, which is the measure of the angle, E, A, F. The arc described by the extremity of the lever is therefore greater in proportion, as its centre approaches the centre of the wheel which carries the pin, H, and smaller in proportion as it recedes from this centre; but the greater or smaller is the arc described by the rack, the greater or lesser will be the movement of the pinion into which it works, and, consequently, the greater or smaller will be the arc described by the file. The hand (Fig. 12) cannot therefore pass from the mechanism designated by the letters I, K, K, L.

The experiments required for finding the exact point indispensable for obtaining the kind of teeth that may be wished will not occupy much time; experience has taught us that much more is often required, in the old system, for finding a suitable rounding-off-file, which one may not always possess.

In the tools for finishing the teeth there is no regulator for presenting the tooth at the precise point on which the file should act. The tongue, *a*, which the file carries as a regulator is used for this purpose, but if this tongue be too thick or too thin, the file acts more on one side than on the other, and the wheel is unequal. Our system had not even this resource, and we perceived the need of a certain regulator; the support (Pl. II., Fig. 17) which is used in ordinary tools for teeth, seemed to us to be suited to this purpose. This support enters as a slide by its two arms, A, B, into the box which slides on the branch of the lathe which supports the wheel. The arbor of the wheel enters into the hole, D of this support and rests against the plane of the round plate, E; it is confined in front by a piece which comes to rest on the other surface.

We have formed our regulator of this same support with some few changes, as represented in Figure 16. The form is the same; we have simply enlarged the branches to adapt the regulator to them. The arms, A, B, are larger, in order more easily to make two notches, C, D, in them; in the notch, D, a sliding-piece of brass moves, which carries the axle of the slide, E, F, and which can ascend or descend by means of the adjusting-screw, G, to fasten the teeth of large or small wheels; the notch, C, is designed to receive the neck of a screw whose head is behind, in order to prevent the end of the slide, E, from moving from the plate. The slide, E, F, is straight and carries a box, H, which slides along its length, to which the catch, I, is fastened; this box is moved by an adjusting-screw, K, to present to the file in a suitable position, but always diametrically opposed to the action of the file, the teeth which are to be rounded. The slide is constantly pushed upward by the spring, L, which presses against a pin, M; the catch, I, is freed by pressing the finger on the end, E, while the wheel is turned with the forefinger. We have designed this piece on a large scale, in order that all the parts might be distinct. This same mechanism can be easily applied to the piece which supports the crown-wheels.

CHAPTER XII.

DESCRIPTION OF EXPIRED PATENTS.

We have thought it advisable to add to the preceding chapters descriptions of some patents which have fallen into forfeiture, and which may convey some useful information, or suggest some available ideas. We must apprise our readers that we only transcribe them as documents which it is sometimes necessary to consult.

Patent of invention, taken for five years, for a mechanism designed to correct the striking-work of clocks, by M. Robert Houdin, of Paris; dated May 22, 1840.

DESCRIPTION OF THE MECHANISM.

The weight of a hammer tends to carry it beneath a detent when the latter is sufficiently raised to require its effect, when otherwise, it rests inactive above it; the pins fixed on the minute-hand-pin raise a second detent, as usual, every hour and half-hour; this, in its turn, raises the first detent by the aid of a longitudinal piece, yet not high enough to permit the entrance of the first-mentioned hammer beneath it.

A pin, fixed on the hour-wheel and representing noon, at each turn of the wheel, raises the second detent by means of another pin which is fixed on this piece, somewhat higher than usual; the hammer then, by its weight, falls beneath the detent and hinders it from falling back into the notches of the notch-wheel, and the striking-work continues to strike until a pin frees the hammer and permits the detent to stop the train after twelve has been struck; if the twelve of the striking-work, and the twelve of the movement agree, but twelve blows will be struck as the hammer will then be raised.

September 18, 1840. *Patent of addition and improvement.*

These new arrangements, like the former, are designed to cause the striking-work to accord with the hands once in twelve hours, in case that it miscounts.

The advantage of these arrangements is, that when the striking-work miscounts it is corrected at noon or at midnight, as the notch-wheel is then forced to cause as many strokes to be struck as may be necessary to strike the true hour; thus, if when the hands point noon or midnight, the notch-wheel is in a position to cause half-past twelve to be struck, the arrangements already described will make it strike eighty-nine strokes in order to make it agree with the hands.

Whatever may be the advantage of having a clock which cannot miscount during more than twelve hours, the result thus obtained presents the inconvenience of causing the spring of the striking-work to go faster than that of the hands, and thus demands, in a piece liable to miscount, a more frequent winding of the one than the other; besides which it is very annoying to be awakened at midnight by a prolonged striking.

To avoid these inconveniences, we would substitute for the preceding arrangements, these which we are about to describe, and which are designed to stop the striking-work when it has struck twelve hours, and to cause it to wait for the hands when they mark half-past twelve.

The modifications which produce this stoppage of the striking-work consist in the elongation of the beak of the detent, in which elongation a notch is made, in which the ordinary detent begins or ends; and in the placing of a pin on the crown of the notch-wheel immediately before the notch that follows the projecting arc which causes twelve to be struck; when the twelve strokes have sounded, this pin, which is terminated by an inclined plane, elevates the detent still more by sliding beneath its blade, so that the pin of the cog-wheel, which passes freely into the notch of the elongation of the detent during the striking of twelve as well as the preceding hours, then comes to prop against the solid part of the detent, placed beyond the notch, thus checking the striking-work after it has struck twelve hours, whether it has or has not miscounted.

A pin is fixed on the flat of the hour-wheel which, at twelve or half past, attacks a projection placed on a detent, and raises the detent far enough to permit its blade to pass above the pin of the notch-wheel and to fall back into the notch beyond it; this replaces the pieces in their normal state, and permits the striking-work to act as usual, because, when it has not struck twelve hours, the detent acts as if its beak had not been lengthened, the pin of the cog-wheel passing freely into the notch.

When the clock miscounts, the discord will last until the clock shall have struck twelve hours, when it will be corrected, as then the blade of the detent, raised by the pin of the notch-wheel, will draw the end of the beak of the detent upon the course of the pin of the cog-wheel, and will hinder all further movement of this wheel until the hands, which continue to move, mark twelve, or half-past twelve. The pin of the hour-wheel then attacks the detent by the projection, and thus raises the detent far enough to cause the blade to pass above the pin of the notch-wheel, thus permitting the striking-work to move in unison with the hands.

Patent of invention, for five years, for improved movements of Clock-work, by M. Brocot, of Paris; dated October 9, 1840.

The first arrangements of this patent relate to the methods of regulating the length of pendulums, and obtaining their compensation. M. Brocot, the inventor of the improvements which we are about to describe, perceived that he had been anticipated in the discovery of the principle of pendulum-compensations by M. Wagner, he therefore only claims the application of the material conditions of this principle, which consist in making the great dilatability of zinc subservient to the compensation of the pendulum. We shall first occupy ourselves with various constructions in which this last condition is applied to obtain a double result.

In the simplest form, the lower extremity of a rod of zinc is linked to a vertical piece which is fixed on the back pillar-plate of the mechanism, while its upper extremity props against a lever whose centre of motion is at its junction with the vertical piece.

To this lever the pendulum is suspended, whose thread or flexible blade passes into a cleft of a circular piece; the lower extremity of this cleft limits the length of the pendulum, which, in this case, we suppose regulated by a constant temperature.

It is evident that if the temperature should increase, for instance, the pendulum will elongate, and, consequently, that its movement would slacken if the dilatation of the zinc rod did not elevate the lever, and with it the pendulum, whose length will thus remain the same if the upper end of the zinc rod is properly adjusted beneath the lever; and we will perceive that the nearer this extremity approaches the centre of motion of the lever, the higher will the point of the lever be elevated by the same dilatation, and the more will the pendulum be shortened.

To secure the proper adjustment of the zinc rod, an adjusting-screw is screwed into a ring-screw fixed on the vertical piece, and is linked at its end to the zinc-rod. By turning this screw, in contrary directions, the upper extremity of the zinc-rod is drawn nearer to, or further from, the centre of motion of the lever, and is thus placed at the point at which the contraction or dilatation of the rod compensates the contraction or dilatation of the pendulum.

The condition which permits the regulation of the compensation and the length of the pendulum at the same time, is effected by means of a wheel on the flat of which is a spiral groove into which enters a pin fixed upon a piece which is movable about a centre.

It is evident that by turning this wheel, either directly or by means of a pinion furnished with a knob, the position of the system may so be modified as to regulate the length of the pendulum with the greatest precision. As the spiral-groove can be composed of a greater or less number of turns, it is much superior in this respect to the snail which is sometimes used and which cannot make an entire turn, for it is necessary to give a great movement to the spiral-groove to produce a sensible depression or elevation of the pin, and consequently, a corresponding change in the position of the system.

The lever, which is movable about a centre and which props on the extremity of the zinc rod, follows all the movements of the system, as well as the pendulum which is suspended to it, and whose length is thus regulated by the position of the pin in the spiral-groove.

We must also remark, that though the zinc rod in this construction seems fastened by its two extremities, the hole which the upper screw passes through is sufficiently oval to permit the elongation or contraction of this rod without inducing the distortion of the vertical piece.

In case it is found inconvenient to regulate the length of the pendulum from the back of the movement, it can be done in front by substituting for the pinion another pinion whose rod passes through the two pillar-plates and is terminated by a square arranged to receive a key.

In the third construction another application of the spiral-groove is made; the pin is placed at the lower extremity of the movable piece on the same arbor as the lever; but the movement of the spiral-groove still determines that of the piece, independent of the lever, and, by the medium of the zinc rod, that of the lever also.

A fourth construction may be substituted for this, which is also designed to regulate the length of the pendulum in front of the movement. As in the second construction, the piece has two branches, one rests by a pin on a snail or a spiral-groove, whose arbor passes through the two pillar-plates; the lever props on the zinc rod which transmits to it the movement communicated to the piece by the snail or the spiral-groove.

A fifth and a sixth construction represent arrangements having the same design, but in which neither the spiral-groove nor the snail is employed; for there is substituted an inclined plane which is adjusted to the piece, and against which a screw props itself, the movement of which causes the inclined plane to slide over its point and determines the movement of the piece about the centre; this movement, by the medium of the zinc rod, determines that of the lever.

The seventh construction is solely designed to regulate the length of the pendulum by means of the spiral-groove. It is composed of a potance whose horizontal branch carries the pendulum, while the vertical branch is maintained in its position by a collet which serves, at the same time, as an axle to the wheel by a pin placed on the pillar-plate; a pin, fixed on the potance, rests in the spiral-groove, the rotary movement of which, determined by a pinion, raises or lowers the potance, and, consequently, lengthens or shortens the pendulum.

Several of the preceding constructions have a click-spring which works into the teeth of the wheel, or into those of the pinion which carries it. This click is designed to show the degree of motion communicated to the wheel, and to cause it to retrograde when it has exceeded the point in a preceding operation.

The second arrangement of the patent of M. Brocot is a striking-work which offers the advantages of the striking-work of the notch-wheel and rack without their inconveniences, as it can never miscount, either when the hands are moved forward or backward, or when the mechanism is placed in one of those conditions which causes the miscount in ordinary clocks.

Upon the arbor of the striking-wheel is mounted a ratchet-wheel of ninety teeth, representing the number of strokes which the piece should strike in twelve hours. The detent is formed of two branches, one of which is bent and is concentric, in its outer circumference, to the ratchet-wheel at the same time that it is below the bottom of the teeth of this same wheel, when in a state of repose. Two pins are placed on the minute-wheel which raise the detent at every half-hour.

A lever is movable upon the same arbor as the ratchet-wheel and independently of this wheel, a part of which has sufficient weight, when nothing opposes it, to place a pin upon a snail which is fastened on the arbor of the minute-wheel. Upon one arm of the lever is a click whose pin is placed between two teeth of the cog-wheel, during the repose of the striking-work. When a pin places itself beneath a branch of the detent it raises the latter; another branch, bearing a claw at its end, frees the preparation and produces what in clockmaking is called the *delay.* The same pin still continuing to raise the detent, the pin of the click is extricated from the teeth of the wheel at the same time that another pin and the ess are raised by the branch of the detent, until the motion at which the pin of the minute-wheel ceasing to act beneath another branch, the detent falls by its own weight, together with the click, whose pin works again into the teeth of the ratchet-wheel. In this fall of the two pieces, the detent, placed on the axle of the ess, has freed the striking-work, which is then put in motion.

To describe clearly the action of this mechanism, we must remark that the two pins, though placed on the same diameter of the minute-wheel, are not at an equal distance from the axle of this wheel, so that the one of them, which is to cause the striking of the half-hours, does not raise the detent as far as does the other, which causes the striking of the hours; and that, in consequence, although the other effects may be the same, the first pin never raises the ess above the lower part of the outer branch of the lever, and always leaves a pin there. When the detent escapes from the pin of the minute-wheel, this pin, which had rested on the lower portion of the lever during this movement, falls back upon another portion and determines the arrest of the striking-work.

The outer edge of the detent is arranged in such a manner that, when the hands are turned back, the minute-wheel, which is susceptible of a slight movement on its arbor, recoils when one of its pins encounters this edge, and slides along the inclined plane, forcing the detent, which is flexible, to recoil, until the pin passes beyond the lower edge of the detent.

It is evident that this striking-work cannot miscount, as the action of the snail is conjointly with the hour-wheel.

In the second, third, fourth, and seventh constructions, the spiral-groove is in a frame between a part reserved for the escapement-bridge and a short plate. By this arrangement the escapement-bridge can be taken down without fear of affecting the regularity of the clock.

First Patent for addition and improvement. Nov. 14, 1840.

This patent relates to more precise methods for regulating the length of the pendulums than those already described.

In these arrangements, which do not exclude the conditions of the compensation before patented, the spiral-grooving is replaced by an adjusting-screw of a very fine thread. In the most simple application of this, a screw, passing through the bearer of the spring-band, which serves as a screw-nut, permits the raising or lowering of the latter, by means of a knob, and consequently, the shortening or lengthening of the pendulum. When this effect is obtained by acting in front of the clock, the knob becomes a wheel working at right angles with the pinion, whose rod, passing through the mechanism, projects on the side of the dial and receives from a key the movement which determines that of the screw, through the medium of the wheel.

In a second construction, the precision can be carried to exactness by the application of the principle of the differential-screw of M. de Prouy.

One half of the length of the screw is grooved with a thread differing from that of the other half. But this difference is very slight; a hundred threads of the part *a*, for instance, corresponding to ninety-nine threads of the part a'. The part a has its screw-nut fixed on the escapement-bridge, while the screw-nut of the part a' is screwed into the spring-band clasp.

At each turn of the screw, the clasp descends in a quantity equal to the thread of its screw; but at the same time the screw winds up a quantity equalling the thread of the fixed screw-nut, which is a hundredth less than that of the spring-band clasp; this clasp will therefore be lowered to the distance of the hundredth part of the thread of the larger screw by an entire turn, and consequently, to make it pass over a space of the tenth part of an inch, the screw may be caused to make several hundred turns; a condition which permits the length to be determined with mathematical precision.

In these constructions, a click-spring works into the teeth of the pinion; this is designed to show the number of divisions which have been made for regulating the length of the pendulum, and to enable it to retrograde when the point has been exceeded in a preceding operation.

Second Patent for addition and improvement. June 20, 1842.

These new and final arrangements consist:

1st, In more precise methods of adjustment of the systems before patented.

2d, In an economical process for obtaining the same result.

3d, In a new method of facilitating the regulation of pendulums.

In the first improvement the spring-band clasp was only cleft in the middle for the passage of the suspension-spring; much care was necessary in the adjustment of this clasp in its frame.

In the new arrangement the clasp has three clefts; that of the middle still receives the suspension-spring, while the two others, made nearly at the edge, form by drawing them a little aside, two springs which press on the inner cheeks of the frame and produce a good and indestructible adjustment. In the same manner the clasp was tapped, and an easy adjustment without play was impossible; these inconveniences have been remedied by prolonging the arm of the clasp; by cleaving this arm, and then reclosing the cleft a little, a good adjustment is obtained; the same effect will be produced by cleaving the clasp longitudinally and then reclosing the cleft a little. This method seems preferable to us, as it is less expensive.

A suspension-spring with a double band is also used, this possesses the advantage of avoiding torsion, and of carrying the balance more regularly, but it is very difficult to adjust, at least with economy.

The inventor of these constructions had before employed simple springs, but his balances sometimes turned; this led him to suppose that by hollowing out the centre of the band he would obtain the same result as with the suspension-spring with two bands; reiterated experiments have convinced him that this hollowed band possesses the same advantages.

The indicator of M. Brocot, which shows how many divisions have been lost or gained, is well adapted to the regulation of the lengths of pendulums; but the numerous inquiries which have been made of him to know how many divisions should be made in order to regulate a certain variation in a given time, have caused him to make some experiments which have been entirely successful. A figure placed on the dial, and adapted to the length of the pendulum, indicates the number of divisions which should be made for one minute of variation in twenty-four hours, and, consequently, the proportional number of these divisions for a greater or less variation.

Patent for Importation, for ten years, by M. Gallard Davies, of London, for Clocks running a year without being wound, dated February 15, 1841; *forfeited February* 2, 1844.

My invention consists in the application of a system of watch-movement to the fourth and to the last arbor of a system of clock-movement; this permits me to make a clock which, in running during twelve months, will require to be wound but a single time; this invention also consists in placing the second or the third wheel, or the second and third of the said system of clock-wheels, beneath the dial and in front of the large pillar-plate, or behind the small pillar-plate, or in any case at the outside of the frame. By this combination I can obtain a small and portable clock, which will only require to be wound once in a year, with a single barrel or motive-power for each part of the said clock; that is, one for the movement of the said clock, and one for the striking-work; while those which have before been made to run during this time have always been excessively large and troublesome by reason of their construction.

The barrel contains the main-spring, arranged for six revolutions, and carries at its circumference the great-wheel, divided into one hundred and forty teeth. The second wheel has one hundred and ten teeth with a pinion of ten leaves, and receives its movement from the great-wheel.

The third wheel has ninety teeth; this, although one of the principal wheels of the clock, is not placed between the two pillar-plates, or in the frame of the clock, as has heretofore been the custom, but quite at the outside of the large pillar-plate, and immediately beneath the dial of the clock, thus gaining much space.

In the large pillar-plate, at the circumference of the second wheel, a hole is pierced which receives the small pinion of ten teeth that forms the arbor of the third wheel. This arbor and this wheel are fixed to the large pillar-plate by two rackets. The arbor of the third wheel receives its movement from the second wheel. The clock-movement being put together, as we have just said, the frame containing a part of the watch-movement, commencing with the centre-wheel, is fixed to the large pillar-plate, by two screws, in such a manner that the pinion of nine leaves, forming the arbor of the first or of the second centre-wheel, is encountered by the third clock-wheel, which impels it and causes its movement.

It is useless to describe the other watch-wheels, as any system with any escapement, commencing with the centre-wheel, can be employed; and when one is sure of having put the motive-power which the third wheel possesses, in connexion with that of the great-wheel or fusee of any ordinary watch, the dimension of the watch system to be employed can be easily determined from it.

The wheels which regulate the velocity relative to the hands, and which are technically called the movement, are the same as those generally used.

The arm itself is moved by a small pin which slides into a groove made in the dial; the other end of the pin is inserted between the fork.

It is unnecessary to say more on this article which does not form a part of the improvements of the patent. Other means may be employed for the regulation of the velocity. It suffices to say that, when it is unimportant that the clocks should be smaller than those just described, the second part of my invention need not be employed; that is, the placing of the second or third wheel with a fusee and chain; in this case the first part of my invention, that is, the application of a system of watch-movement to the fourth or the last arbor of a system of clock-movement, will be sufficient. But I claim as my invention:—1st, The application of a system of watch-wheels (commencing with the centre-wheel) to the arbor commanded by the third wheel of a system of clock-wheels; the centre-wheel of the watch system being that which is placed on the said arbor, and the wheels being arranged in the manner before described, permit me to cause the clock to run during twelve months without winding more than once. 2d, The manner of placing the wheels as has been said before, in order to save space.

Patent for ten years, for a System of Public Clocks, called Polygnomones, by M. MALO, *of Paris. Dated July* 19, 1841; *annulled, by order of the king, September* 10, 1844.

Several particular properties of this mechanism produce a result which the inventor describes as follows: With a polygnomone one can,

1st, Retrace the hour indicated by a regulating clock upon an unlimited number of dials.

2d, Place these dials at considerable distances, either from each other or from the regulating-clock.

3d, Maintain the most perfect concordance in the indication of the hour among all the dials and the regulating-clock.

A polygnomone is composed:

1st, Of a motive-power; 2d, of a regulator; 3d, of one or several groups of conductors, and of dials carrying their minute-wheel-work.

The motive-power is a train entirely distinct from the regulating train, it serves to set in motion the conducting wires, and, consequently, the hands of the dials.

Its action is periodical; it is regulated and moderated by the regulating-clock. The motive-train is composed: 1st, of a barrel; 2d, of an intermediate-wheel; 3d, of a pinion carrying a lever with two arms and a crank. The lever is held in check by the leaves of a pinion carried by the regulating-clock.

The power of the motive-train is proportioned to the resistance to be surmounted; that is, to the number and the dimensions of the dials.

The regulator is a common clock; its dimensions are rendered somewhat indifferent by the intermediate levers of which we shall presently speak; but this clock must contain, or be able to conduct, a pinion of four, six, or eight leaves, and each leaf of this pinion must be replaced by the following leaf in the interval of a minute. The effects of the motive-power and the regulator are combined in the following manner:

The pinion makes a revolution in six minutes, and, consequently, each of its leaves takes the place of the preceding one in the interval of a minute; and, as the lever is held back by one of the leaves of the pinion, it will be disengaged at each interval, will make a semi-revolution on its axle, and will be again checked by its opposite arm by the following leaf of the pinion, and so on from minute to minute. In the same time in which these movements are accomplished, the crank passes alternately from one position to another.

The extremity of this crank enters into a small socket connecting two ends of iron-wire, one of which is placed in the prolongation of the other. These wires are forced to move in the direction of their length, following the swinging impulse which they receive from the crank.

I have said that the dimensions of the regulating-clock are somewhat indifferent; I have also said that the dimensions of the motive-power increase in proportion to the number and the size of the dials; a great disproportion between the motive-power and the regulator results from these two circumstances, and if, on the one hand, the motive-power having to conduct several hundreds of dials would represent, for instance, the force of a man working without interruption, and if, on the other hand, the regulator was no larger than an ordinary apartment-clock, it would be necessary, under penalty of seeing this regulator broken by the shocks of the lever of the stop-work of the motive-power, to avoid all immediate contact of these two parts of the polygnomone.

For this I use one or several intermediate levers; the lever of the stop-work, instead of acting directly upon the pinion of the regulator, strikes the leaves of an intermediate pinion which carries four arms which are shorter and lighter than those of the lever. Each of these four arms strikes, in its turn, a second pinion carrying four arms still lighter and shorter than the preceding ones; each of these four arms is checked by the leaves of the pinion carried by the regulating-clock. In this manner one can accurately regulate the movement of a polygnomone, however colossal it may be, by means of a simple watch-movement. It suffices for this to place between the double lever and the pinion, a proper number of intermediate pinions, as the intensity of the forces of these levers always continues to weaken until the last, which holds all the others in check by means of the pinion of the regulator.

The conductors are simply iron wires, arranged in such a manner that, however numerous they may be, all repeat, in the same time, the backward and forward movement communicated by the crank. The principal wire attached to this crank is subdivided into several other wires, from which spring still others, and so on to the last, which end in the minute-wheel-works of the dials, the hands of which they impel from minute to minute by means of the escapement-pieces to which they communicate their backward and forward movement; this is transformed into a rotary movement to turn the hands, by means of a peculiar escapement which I shall presently describe. The changes in the direction of the wires are obtained by elbowed levers, whose points of support rest on blades of tempered steel, precisely like the points of support of the beams of a balance. At the extremity of each conducting-wire is placed an adjusting-spring designed for two purposes: 1st, to keep the conductors constantly extended; 2d, to bring back the escapement-piece to the extremity of the lifted piece opposed to the traction of the wire.

To regulate the motion of the crank in rising, another wire is placed opposite the first, and in the same direction, at the extremity of which a spring or counter-weight acts, whose power produces an equilibrium among all the springs of which we have just spoken; or, which is still better, instead of the spring or counter-weight, another system of conductors or of dials analogous to the first is placed beneath the second wire, taking care that the sum of all the aggregate resistances of the second wire shall be in perfect equilibrium with the sum of all the resistances of the first wire. The impulse-crank will thus have no other resistance to overcome than that of the friction of the wires and the minute-wheel-works, which is but trifling. The dials and their minute-wheel-works may have two hands, for hours and minutes, and may be of any size.

In the minute-wheel-work, the escapement-piece which I have mentioned is fixed with an arbor on which it turns. To the arm or lever of the escapement, which forms part of the same piece, is attached the conducting-wire as well as the adjusting-wire, drawn by a spring.

Three small groovings, whose union forms a Y, are made in this piece which they traverse in a zigzag manner.

A wheel, carrying two pins, receives the action of the escapement-piece.

Improvements.

1st. To regulate the action of the motive train, a fly of a certain weight is added, which, at the end of its course, will transfer its acquired force to a spring which preserves it during the minute of repose, and then restores it to the fly to aid its departure, and so on from minute to minute.

I also employ for the same purpose, in some cases, a heavy pendulum whose oscillations from minute to minute perform the functions of the fly.

2d. The minute-wheel-works of each dial should be so arranged that the hands of the dial can always be set at the hour if deranged by any accident.

3d. Instead of a weight, I can employ any other power if necessary, whether air, water, or steam, to set the polygnomone in motion.

Applications of the Polygnomone.

The polygnomone, furnishing the means of indicating the hour in all the rooms and halls of a building, will be especially applicable to hospitals, barracks, schools, manufactories, hotels, and public buildings in general.

Its use may even be extended to the entire district of a city, in which each room of every house may have its dial.

Patent for Invention, for five years, for a Dead-beat Escapement-wheel, by M. Delor. *Dated September* 28, 1842.

The principal piece of this escapement is the arbor of the balance, which carries two rollers serving, in turn, as lever and dead-beat, while this balance describes its arc of vibration.

The escapement-wheel is of tempered steel, in the usual form, and cut in an inverse direction.

The arbor of the balance is placed at a suitable distance for working into the escapement-wheel. A tooth seizes the lever of the upper roller and carries the lower roller on the next tooth; this lower roller holds the wheel in repose while the balance makes its vibration.

The two rollers form a cylinder, horizontally, whose diameter is the half of the distance from one point of the tooth of the escapement-wheel to the other point, without regard to the size of the wheel and the number of the teeth. The distance between the two rollers is eight degrees; it is through this that the wheel escapes to the right and the left.

This escapement, which is easily executed and very successful, sustains its motion and its regularity better than the cylinder-escapement.

Patent for Invention, for five years, for a Balance marking the fixed Seconds, by MM. Berolla, *of Paris. Dated Oct.* 15, 1842; *annulled by order of the king, May* 21, 1845.

This mechanism is composed of a ratchet-wheel of sixty teeth, and of a click; the whole being placed at the centre of the pendulum-ball of the balance; a lever, which is placed higher, works into the teeth of the wheel by an end armed with a small spring; the other end of the lever comes to the top of the small fork of the pendulum, and the vibrations of the balance are maintained by this lever, which, after having forced one tooth of the wheel placed at the centre to escape, conducts the balance to the right and left as usual. There are two banking pins which hinder the lever from making a longer course than is necessary to cause the escaping of the tooth; the lever sustains the vibrations of the balance by these pins. This mechanism is applicable to every description of balance, and to all clocks, and can be placed in the interior or at the exterior of the balance; there is a second-dial and hand at the centre of the balance.

The most important point of this invention is the lever; which is conducted to the right and left by the little fork of the pendulum, and which, after having caused the second-wheel to move, moves the balance as usual.

Patent for Invention, for five years, for Tools suited to the Manufacture of the Wheels of the Cylinder-Escapement, by M. Rogier. *Dated August* 27, 1844; *expired July* 28, 1846.

This invention is designed to enable all workmen to manufacture cylinder-escapements with facility, and consists in processes of execution, and tools of the greatest simplicity for the construction of the escapement-wheel.

One of these tools is designed to disengage mechanically the semi-circular spaces of the teeth of the wheel when the wheel is cut; the other is used to facilitate the regularity of the extreme inclination of the teeth.

Pl. V., Fig. 17, 18, represent the elevation and plane of the space-column tool.

Fig. 7, 8, 9, the principal parts in detail.

The design represents the apparatus on a scale large enough clearly to show the forms and arrangement. A is the fixed part of the space-column tool; it is placed by the ear, downward at *a*, between the jaws of the vise.

The puppet, *b*, is penetrated by the cylindrical turning-tool with friction, which is then received by the opposite extremity, into a conical collet fastened into the body of the upright, A.

A small screw, *g*, passing through the axle, *e*, serves as an abutment against the upright, A.

The axle, *e*, is terminated by a cylindrical cutting-file, *h*, whose diameter is determined by the space to be preserved between each tooth.

Beneath the frame, A, is fixed a slide, B, which is prolonged at right angles outside the frame, A. Two thumb-screws, *i*, *i*, secure the maintenance of the slide, B, when its position is regulated, permitting it, however, to receive the backward and forward movement communicated to it by means of the screw-nut, *j*, and the adjusting-screw, K.

The vertical prolongation of the slide, B, assumes the trapezoidal form, to serve as a guide to the division-plate, C; this division-plate has a vertical reciprocating motion, the course of which is regulated by the screw, *m*, which slides freely into the collet, *m*, screwed against the frame, A.

This division-plate, designed separately in Fig. 7 and 8, is loosened towards the top for the passage of the cutting-file, *h*; it is fastened flatwise in a circular form to regulate the position of a disc, *n*, also cut sloping at the top for the passage of the cutting-file; this disc is furnished with two slides with screws, *s*, to vary its position, a crank-pin, *o*, *y*, is inserted at the centre, and a second pivot, *p*, *y*, is fixed near the circumference.

A face-plate, *q*, pierced towards its circumference with as many holes as there are teeth in the escapement-wheel, is also pierced at its centre to receive the central crank pin, *o*, of the disc, *n*; the holes towards the circumference alternately serve as a stop-work to the disc, *n*.

This division-plate, *q*, receives the escapement-wheel, R, flatwise, whose semi-circular spaces it is to clear; it is kept in its place by a coating of wax, and, in order to set it concentrically, it is adjusted on an axle in such a manner that it can turn quite round; a little Spanish sealing-wax is placed on the divider, *q*, which is fixed against the wheel, and the whole is put on the lathe. The division-plate, *q*, is gently warmed to melt the wax, it is turned with the drill-bow, and then, by lightly resting a piece of wood against the divider, it is easily placed concentric to the escapement-wheel, R, and on the side of the teeth.

The plate and the wheel, united in this state in a single piece, are removed from the arbor which passes through them, and the divider is adjusted on the space-column tool; for this, the centre of the escapement-wheel is placed on the central pivot, *o*, of the disc, *n*, while the hole of the divider, *q*, which will cause the clearing at the necessary point, is placed beneath the crank-pin, *p;* the placing is regulated in other respects by the relative change of position of the disc, *n*, by means of two screws, *s*.

The escapement-wheel is thus placed beneath the cutting-file and ready to be cleared of an entire tooth, and of about two thirds of the following one, only preserving a strength sufficient for the column; for this, the axle of the cutting-file is worked by means of the drill-bow; and the division-plate, C, furnished with the escapement-wheel, is then pressed upward in proportion to the working of the cutting-file.

The operation of the space-column tool should be preceded by the previous division of the escapement or cylinder-wheel; the number of teeth which must be arranged on this wheel is calculated to make it beat about fifteen thousand vibrations.

The same tool is used to round the column beneath the inclined-plane by removing the division-plate, C; the wheel, which is still joined to the division-plate, *g*, is placed against the piece B, the position of which is regulated by the adjusting-screw, *k*, and the screw-nut, *j;* the cutting-file is then turned, which successively rounds the bottom of each inclined-plane in proportion as the wheel, R, is displaced by the other hand, in order to present all the teeth alternately.

This operation is very easy; it is only necessary to remark that the wheel, R, rests against the plate, *q*, opposite to that which is indicated by the design.

Inclined-Plane Tool.

This tool is also designed on a large scale.

Figs. 19, 20 show the elevation and plane.

A′, the fixed part of the tool which is placed in the jaws of the vise. Two puppets, B, B, are fixed on this piece, A, by a common screw, each traversed by a distinct turning-tool, *c*, *c*, these turning-tools slide with friction into the fixed sockets of the puppets, and the screws, *a′ a′*, retain them in the proper position.

A detent of tempered steel, D, pivoting upon a piece, *b*, sliding against the upright, A′, can take any inclination, which is given it by means of graduated parts; the opposite extremity of this detent is terminated by a small handle, *c*, and is fixed into a movable notch adjusted against the upright, A, and retained at the desired height by the thumb-screw, *d*. The piece, *b*, is regulated to the suitable position by the adjusting-screw, *e*.

The cylinder-wheel, R, mounted on its arbor, is placed between the two turning-tools, *c*, *c′*; a spring, *f*, maintains the wheel, R, in its position by its pressure, by resting under one of its teeth, and all that part of the tooth which projects beyond the upper level of the detent, D, should be removed by the file.

It is evident that, by the previous inclination given to this detent, if the wheel is successively turned, in order to cause it to present all its teeth to the slide, *g*, of the detent, D, the inclined plane of the teeth of the escapement-wheel will be filed in a regular manner.

The length of all the teeth of the wheel can also be equalized, as seen in Fig. 21; a slide, *j*, whose position is regulated by the adjusting-screw, *l*, is surmounted by a piece of tempered steel, *m*, in the form of a fork, in order to receive the steel spring, *p*, which is maintained at the interior by the small screw, *n*; the position of this spring is such that, in placing the wheel between the two turning-tools, *c*, *c′*, the foot of the tooth rests on this spring-band, while the top of the tooth is level with, or exceeds the upper level of the piece, *m*.

By turning the wheel by the hand, the shortest tooth is found, the position of the spring is regulated with respect to this tooth, which is placed on a level with the first, and by this method an equal length is secured to all the teeth.

The screw, *r*, holds the slide, *j*, immovable when its position has been determined by the adjusting-screw, *l*.

The working parts of these tools are movable, and are regulated according to the diameters and the number of teeth of the wheels.

Patent of M. Merle *for a Movement of Clockwork.*

The improvements of M. Merle relate to the adjustment of anchor-escapements on their rod, and to the barrel of the movement.

The part which concerns the adjustment of anchor-escapements, says the inventor, is designed to remedy the inconveniences of the systems which necessitate the bending of the conducting fork of the balance, and of those which require the use of a heavier balance than usual.

It consists in the idea of adjusting the anchor on its rod, in such a manner as to be able to cause the rod to turn in the hole of the anchor to a required degree, in order to give the necessary inclination to the fork without being obliged to bend or to twist it, and of checking it in its position by a thumb-screw, still preserving to the anchor the possibility of a slight friction on its rod.

The anchor, instead of being fixed on a square, is adjusted on a round rod, in which a circular notch is made to receive the extremity of a screw designed to maintain the anchor on its rod, or rather the rod in the required position so as to guide the fork fixed at the other extremity of the rod to the right and left.

It is evident that, when the movement of the balance is to be regulated, it will not be necessary either to bend the fork to the right or left, or to raise the pendulum from one side to the other; it will suffice to loosen the screw in order to permit the rod to turn, and thence to direct the fork, and consequently the balance, a little more to the right or left. The slight friction permitted the anchor on its rod, is designed to facilitate the connexion of the anchor with the escapement-wheel.

The improvement made in the barrel consists in the idea of adding to it a second set of cogs, in order to simplify the striking-movement. In fact, by this second set of cogs, the necessity of employing two barrels is obviated; that is, one for the striking-work and one for the movement, since one of these two sets of cogs, which the single barrel will carry, will correspond to the trains of the striking-work, and the other to the trains of the movement; and the striking-work and the movement cannot stop without each other, as the winding of the barrel will serve for both by reason of the joint action on the two trains by a single agent.

Patent of M. Allier, *for Clocks running Six Months and a Year without being wound up.*

"As my method," says M. Allier, "is applicable to all kinds of clockwork, I use every kind of striking-work without distinction.

"I suppress the other movements, the barrel-movement, the time-wheel, and the pinion of the centre-wheel; only preserving the centre-wheel, the third wheel, and the escapement-wheel.

"My centre-wheel is supported by a bridge at the interior of the large pillar-plate; the arbor, which passes through the wheel, carries a steel arm which is adjusted above.

"In front of the pivot of the centre-wheel, I place a small barrel surmounted by an arm which seizes that of the centre-wheel. The arbor of my small barrel is a pinion which is carried, outside the large pillar-plate, by a wheel adjusted with friction by the rod of the striking-wheel, between the pillar-plate and the notch-wheel; it is sustained by a spring so as to permit the clock to strike to set it at the hour.

"The pressure-spring, which is placed between the notch-wheel, and the auxiliary-wheel, gives to this wheel the power of winding the small spring, in order to make the clock go.

"By a certain process, I suppress the pressure-spring and make a slide-spring which is adjusted in my little barrel, which, when the small spring is all banded above, lets the striking-work go and slides with friction into my small barrel. The arbor-pinion of my small barrel is sustained outside the small pillar-plate by a bridge; its other pivot rolls in the steel ferrule which is adjusted to the pivot of the centre-wheel, and which holds the arm of this same wheel.

"The clock is wound continually from half-hour to half-hour, as the small spring constantly draws uniformly on the trains of the movement and gives a constant force.

"I make my clocks go by a similar process; instead of placing my small barrel-movement independent of the centre-wheel, I fix it on a rod and it serves as a wheel as I make a set of cogs equal to that of the centre-wheel; I pierce my pinion, which forms an arbor and works with the wheel which winds the small spring, which is held by a slide so as to permit the clock to strike.

Explanations.

"I place in a barrel-remontoir, to which I give the force and the number of teeth necessary to keep the spring of the striking-work wound, which also winds the small spring of the movement, as may be seen from the previous descriptions; I cause the large barrel-remontoir to work with a wheel which I substitute for the ratchet-wheel of the striking work barrel, which is adjusted on the arbor of the same barrel, and which keeps it wound during the time required for the clock to run, whether a year, thirteen, or fourteen months: I usually fix on a year because it is a certain period, which always preserves constant force.

"On the same principle of constant force, I make watches with no more motive-power than that of twenty-four hours, with but five wheels, which run for a month and several days; these are as well regulated as the most accurate marine chronometers.

"My escapement-wheel is more highly numbered than others; I place a time-wheel before the centre-wheel, and adjust a small barrel to the centre-wheel as in my clocks, and thus obtain the time with perfect regularity.

Patent for Addition and Improvement.

"The change which I have made consists in the suppression of the auxiliary-wheel which is between the notch-wheel and the small pillar-plate; when this is done, the great-wheel works with two pinions which simplifies the work and gives more force to the escapement.

"Besides, I remarked that the suspension with a silken thread was subject to the hygrometrical variations of the atmospheric air; to remedy these variations, I propose to use a metallic suspension which can be easily regulated by a knob which is turned to the right or left, to put an eccentric piece in motion which will communicate the movement to the balance by means of a lever, to lengthen or shorten it.

"The wheel of the striking-barrel acts upon the pinion of the striking-wheel ; the striking-wheel acts upon the pinion of the pin-wheel.

"In the first arrangement, the arbor of the striking-wheel carried, at the extremity of the back pillar-plate, an auxiliary wheel which acted upon the pinion of the small barrel.

"In the last arrangement, the striking-wheel acts upon the pinion of the pin-wheel and also with that of the small barrel, which gives greater force and regularity as this is effected by a first-mover.

"The small barrel of the centre is surmounted by a finger which connects itself with another, fixed on the rod of the centre-wheel.

"The spring of the small barrel is grappled by a slide-spring, moving with friction into the small barrel. The other gearings of this mechanism are the same as those described in the first patent."

Patent of M. Jacot for a Movement of Clock-work.

"The numerous inconveniences which the vibratory movement of the pendulum presents," says M. Jacot, "whether by the dilatation or contraction of the metals, which is caused by the changes of temperature, or by the constant percussion which takes place in order to effect this movement, have induced me to seek a surer method by which to avoid these difficulties.

"The action of the spring or motive-weight in watches or clocks, is checked momentarily by the shock which each oscillation of the balance produces; this results in a sensible deterioration of the whole machine, and especially in those parts most exposed to the immediate contact with the shock.

"This invention does not change the gearings, the motion of the hands, or the ordinary movement, but instead of the spiral-springs of watches or the pendulums of clocks, it employs an eccentric piece, whose movements are relative to the velocity of the balance, which turns constantly in the same direction, moved by the alternate force of the eccentric piece.

"This rotary movement of the balance is governed by the centrifugal force which, acting at the extremity, opposes a resistance at the centre, regulated by a spring whose pressure is increased or diminished by means of screws, in order to obtain a fixed number of revolutions in a given time.

"This mechanism is composed of a barrel of eighty teeth; a centre-wheel of sixty teeth, and pinion of ten leaves; a third-wheel of sixty teeth, and pinion of six leaves; a second-wheel of sixty teeth, and pinion of ten leaves; and a fourth wheel of sixty teeth, and pinion of ten leaves.

"This last wheel acts upon a pinion of twelve leaves which impels the eccentric bar and causes it to describe an ellipsis.

"This bar, being pivoted loosely at each end, produces an alternate movement, and communicates a rotary movement to another wheel of one hundred and eighty teeth, which works into a pinion of six leaves, fixed on the balance.

"This balance is a steel bar, cleft at one of its extremities, and pierced to receive a lever; this lever carries a metal weight at one side. The centrifugal force compels the weight of the lever to throw itself outside when the balance has acquired a certain velocity, and the other extremity effects a friction against a cylindrical piece of steel, or any other metal, fixed to the pillar-plate, and having the arbor of the balance for its centre.

"A small spring is fixed by a screw on the same side of the balance and on the bar itself, which serves to regulate the effect of the centrifugal force in acting on the lever.

"A steel piece, carrying a weight designed to establish the equilibrium, is fixed by a screw to the opposite extremity of the balance.

"The impulse being given to the whole series of the train by the weight or spring, will continue to increase the velocity until the friction opposes a resistance equal to the action of this weight or spring. By placing the eccentric piece at the end of the rotary movement of the train, it becomes itself an alternate movement, and thus produces a fall at each end of the ellipsis which it is forced to describe, acting in some sort like the balance of a clock every time that the pallet comes in contact with the rencounter-wheel; but this fall is not left to itself but is raised up again by the balance; each oscillation equalizes the movement, and the shock becomes almost insensible on the pinion of the balance.

"The eccentric piece both governs the balance and is itself governed by it; and the balance is governed by the centrifugal force, for, the number of turns being fixed, it cannot increase without finding a proportional resistance, and cannot possibly diminish as long as the spring or weight acts on the gearings."

Patent of M. Rabinel for an improved Watch.

By this new pillar-plate, extra flat watches are obtained which have more force than the ordinary Breguet pillar-plate watches; the click and spring-work of these watches is enclosed in the shell of the barrel. The barrel is held by a steel-bridge of the thickness of the hour-wheel, this bridge is placed beneath the dial.

The bridge which carries the barrel, and on which the click and spring-work is placed in ordinary watches, is not found in this; that of the centre-wheel, which is no longer at the centre, is, with the others, on a level with the barrel. The barrel determines the depth of the watch.

The motive-force is communicated to the centre-wheel by two pinions placed on the pillar-plate, between this wheel and the barrel.

The bridge on which the centre-wheel turns holds these two pinions in a frame when the depth of the watch permits; when this is not the case it is suppressed and replaced by the small bridge which only holds the pinion of the centre; the other, which we shall call the pinion-wheel, is held by a screw, which is screwed into a steel-stud riveted in the pillar-plate; the head of this screw does not extend beyond the pinion-wheel; this wheel is of steel.

The arbor for setting the hour is at the centre.

No change is made in the number of the wheels, although there are two more pinions; that of the centre carries ten teeth, and the pinion-wheel thirty; the number of the latter is unimportant.

Patent for Addition and Improvement.

In certain watches in which the inventor has not thought it advisable to put his click and spring-work arbor, he has replaced it by the Breguet arbor modified, using the same barrel-system of the ordinary flat watches.

This improvement only relates to the barrel-arbor; it permits the use of higher springs, and a longer winding-up arbor than in the common flat watches.

The octagon of the arbor enters into that of the ratchet-wheel; these two pieces thus jointed and riveted forming but a single piece.

CHAPTER XIII.

CLEANING AND REPAIRING WATCHES.

The art of cleaning and repairing watches demands as much care as that of making them, and the workman who cannot execute a new watch will certainly be incapable of mending one well that is broken or worn. We shall not attempt to describe here the art of repairing, which would demand several volumes in itself, and we should not then be certain of including every case which might be presented.

Crespe, of Geneva, has devoted a 12mo. volume of three hundred pages to a single kind of repeating-watch, without describing all the difficulties which may be encountered in it. Volumes on volumes would be required to treat of all the pieces of clockwork with the same details. We can therefore only speak here of generalities.

With this view, we advise the repairer of watches to examine each piece of the machine with scrupulous care, to assure himself that the teeth of the wheels and the pinions are precisely alike and perfectly rounded, that the pivots are cylindrical and well polished, and that their ends do not rub upon the plate, that the holes are not too large and have not become oval; that the escapement, whatever it may be, is well made, that the wheels have sufficient play to avoid friction; that the balance turns horizontally and does not rub on any piece; that the spiral-spring is flat and is turned in such a manner that the coils do not rub on each other, or on the pillar-plate or balance; that the gearings are good, etc., etc. In all these cases, as well as in those which we have not mentioned, the defects should be remedied, and the machine rendered as perfect as though it had just been made, this will insure its regularity.

The cleaning of clocks and watches is more difficult and demands more minute care than ordinary workmen imagine. They often rub the pieces with a brush and Spanish white, and remove the gilding in a short time. The whiting which they use fills the teeth and the leaves of the pinions, and they are not always careful to remove it, so that the watch is often dirtier when they have finished than when it was brought to them. Care in respect to the details we have mentioned, added to a thorough knowledge of the construction of the watch, will insure success in this art to the workman.

TIME AND MEAN TIME.

The time that elapses between the departure of the sun from and its return to a meridian, is called by astronomers the *natural* or *solar* day. These days are not uniformly twenty-four hours in length, as the movement of the sun is variable, consuming a few seconds more or less each day in its departure from and return to the meridian. For this reason, astronomers have suppposed fictitious days of equal length, which they call *mean time;* this is that which is indicated by clocks. The time measured by the meridian, that is, by the noon of the sun, is called *true time*, and the difference that occurs daily between the noon of the sun and the noon of the clock, that is, between the true time and the mean time, is called the *equation of time.* To mark this variation, equation tables are arranged which indicate the precise difference between the true and the mean time each day in the year, and serve as a guide in the regulation of clocks and watches.

REGULATION AND CARE OF CLOCKS AND WATCHES.

The longer a pendulum is, the slower are its vibrations, and, on the contrary, the shorter it is, the faster are its vibrations; it is, therefore, necessary to lengthen the pendulum to make the clock run slower, and to shorten it to make it run faster; this is done by means of the screw nut underneath the pendulum ball, or if this is inaccessible through the form of the case, by turning an arbor in the dial with a key, or by other constructions which produce the same effect.

The hands of a clock should never be turned backwards more than half an hour, and even this should be done with care, stopping at once in case of resistance. The minute hand should never be turned backward when the clock is on the point of striking; as, in this case, the clock will strike at the moment of turning the hand, then strike again when the hand has reached the same place on the dial to which it was turned, thus causing a discord between the striking-work and the hour. When this occurs, the minute hand should be turned forward till it is within about two minutes of the hour, then turned backward till the clock strikes, then again turned forward till it strikes a second time, which will put the hands in accord with the hour.

When the striking work of a clock is not in accord with the hands, that is, when it strikes one at twelve, the hour-hand should be turned separately till the right hour is struck, when the minute-hand should be turned to its place on the dial.

Clocks are regulated to mean time, either by a regulating clock, or by the passage of the sun in the meridian. For the latter, the variation of the true from the mean time is found from the equation tables; then, supposing, for example, that on the 6th of October the sun is twelve minutes in advance, at the instant that the sun passes the meridian, the clock is set at twelve minutes before noon. It is then tested daily by comparisons made in the same manner, by the aid of the equation tables, and the regulation made in accordance with the variation, until a uniformity of movement is attained. Equation clocks are constructed, which follow the variations of the sun by the aid of machinery arranged for that effect.

In setting up a clock, great care should be taken that it should be exactly perpendicular, and firmly secured in its place, so as to prevent all possibility of jarring, as the regularity of its vibrations, and consequently, its accuracy, depend on this in a great degree.

When a watch is not regulated, it is commonly said that it varies, yet there is a great difference between a watch that is not regulated and one that varies; for a watch may be perfectly constructed and run regularly, yet not be regulated to the mean time, as may be seen by comparing it with a regulating clock, from which it will deviate in a uniform ratio from day to day; while one that varies from this irregularly, being sometimes faster and sometimes slower, is, on the contrary, a watch that varies. When these variations amount to several minutes in the course of the day, the regulator will have little effect on them, as the evil lies in the mechanism itself, and can only be remedied by the hand of a watch-maker.

To judge of the accuracy of a watch, it must be set by a regulating clock, and left to run for twenty-four hours in the same position, noting at intervals of six hours, or thereabouts, the variations it has made from the clock. If it loses or gains time at a uniform rate, say one minute in every six hours, it is a proof that the mainspring acts uniformly upon the train, and the latter in turn upon the balance. After the watch has been thus tested for several days, it is worn for a time, and the variations noted as before; if these continue in the same ratio, it is a proof that the watch runs well, and that to regulate it, it is only necessary to have recourse to the regulator, which is turned forward or backward, according as the watch is required to go faster or slower. The distance which this must be turned varies in different watches, and can only be determined by actual test.

But if the watch, after having varied four minutes in twenty-four hours while suspended in one position, varies more or less than this when worn, it is evident that it varies from some defect in the mechanism, and can only be corrected by the skill of a watchmaker.

To set a watch to the hour, the arbor of the minute-hand is turned with the key till the watch indicates the correct hour and minute, care being taken to turn the hour and minute-hands together.

When the repeater indicates one hour and repeats another, the hour-hand is turned separately to the hour and quarter which has been repeated; if this turns easily, it may be concluded that it has been put out of place accidentally; this having been done, both minute and hour-hands are turned to their places on the dial. But if the hour-hand turns with difficulty, the derangement of the hands and the repeating has been caused by the pieces beneath the dial, and requires the aid of a watchmaker.

When the hands of a watch are in advance of or behind the hour, they must be turned to their place by the nearest way, whether forward or backward; there is no more harm in the one than the other. Many persons, who have let their watches run down, in the fear of spoiling them, turn them forward eleven hours rather than backward one; but in this manner they do precisely what they seek to avoid, as in turning the hands so frequently, they loosen the canon-pinions which carry them, so that the least thing deranges them, and the watch runs while the hands remain stationary. When a striking, alarm, or any other watch is in question, the mechanism of which involves risk in the retrograde movement of the hands, and the minute-hand does not turn backward with ease, both hands had better be turned forward.

The hands of a repeater should not be turned while the watch is striking. When it strikes too fast or too slow, the defect is corrected by turning a small regulator placed inside the watch by the side of the cock.

The seconds-hands of watches should not be turned at all. To set these to their place, the balance is checked, until the seconds hand marks the correct time, when the hour and minute hands are set right, and the watch again set in motion.

Many causes contribute to the variation of watches; heat and cold in watches without compensations, of which many are in use; inequality of the force of the main-spring; friction, jarring, thickening of the oil, etc. In view of these, care should always be taken to wind the watch at the same hour; as many watches lose time during the first twelve hours after winding, and gain the same amount during the successive twelve, and *vice versa*, the loss of the first twelve hours is thus compensated by the gain of the last; whilst, if the watch is suffered to run more than twenty-four hours, the gain will continue without compensation, and the watch be subjected to greater variation.

The watch should be carried as nearly as possible in the same position. In the fob, for example, it is usually suspended by a chain; when not worn, it should therefore be hung on a nail, taking care that the case may rest on the wall, so that the vibration of the balance may not be communicated to the watch.

A watch without compensation should be kept as nearly as possible in the same temperature, and care should be taken not to lay it on marble, or similar conductors.

A watch should be cleaned once in three years.

Earnshaw's Detached Escapement.

For the following description of the Earnshaw escapement, now in general use for pocket as well as marine chronometers, we are indebted to Mr. Reed's excellent Treatise on Clock and Watchmaking.

The balance-wheel is plain, or flat, made of steel, and sometimes of brass, the teeth have somewhat of the ratchet form, and are considerably undercut on the face, the number of teeth being twelve, and calculated so as to give half seconds, by the step of the seconds hand on the seconds circles in the same way as is effected in Arnold's. The steel-roller or main-pallet has an opening on it, the face of which is also much undercut, having a piece of some fine stone, such as hard ruby or sapphire, set into it, for the purpose of making the points of the teeth work smoothly on it, and prevent any wearing from their constant action. A stud is fixed to the potence-plate, and to this stud a detent-spring is screwed, and made very slender and weak near the stud. It is by yielding at this place that any motion can be given to the detent on which the wheel is locked; and here is its centre of motion. When acting, a tooth of the wheel becomes locked on a flat side of the stone-detent, which is fixed in the thick part of the detent-spring, by means of which it presses against the inside of the head of an adjusting-screw which works in a fixed stud, so that when it is screwed in this stud, the detent will have less hold of the tooth, and *vice versa.* A delicate spring, called the lifting-spring, is attached to the inner-side of the detent-spring. The end of the detent-spring is bent a very little, so that the free end of the lifting-spring may bear only on the inward bent point. Concentric with the main-pallet is the small lifting-pallet, which is flat on the face, or lifting-side, and tapered or rounded off on the opposite side. When the mechanism is in motion, this comes with its face against the lifting-spring, which it would carry away with it; but this cannot take place without taking along with it the detent-spring, and consequently the detent is carried out from locking the tooth, D, of the wheel. By this time, the main-pallet has got so far forward as to be in the way of receiving impulse from the tooth, B, and before it can escape, the lifting-pallet parts with the end of the lifting-spring, and leaves the detent and detent-spring immediately to resume their place. The detent will be then ready to receive the teeth, C, by which the wheel is again locked. The balance, having performed the vibration by the impulse given, returns, and with it the lifting-pallet, the tapered side of which will press the lifting-spring inwards, but cannot carry the detent-spring with it, this being prevented by the inside part of the head of the adjusting-screw; after passing the lifting-spring, it goes along with the vibration of the balance, on whose return the face of it will again meet with the lifting-spring; unlocking then takes place, and so on. The unlocking here is performed by carrying the detent outward from the centre of the wheel, which is locked by the extreme points of the teeth. Mr. Earnshaw gives as a rule for making the inclination of the faces of the teeth and main-pallet, that they should be in a line drawn from the points of the teeth, as a tangent to a circle whose diameter is half that of the wheel; and the same rule is used for the face of the pallet. The detent-spring lies above, and clear of the wheel, and the detent stone-piece may be either a semi-cylinder or an angular-piece. A flat side is, however, in either case, requisite for the wheel to lock on it, and the height or length of this stone should be a little below the under side of the wheel, so that the teeth may at all times have a sure hold on it. The diameter of the roller or pallet is larger than that of Arnold's, which allows the teeth of the wheel to give a more direct impulse to it. The diameter of the roller, however, if carried too far, would lessen the hold of the teeth on the pallet. Where a wheel of twelve teeth is used, it will give scope for getting in a pallet of considerable length. The proportion between the diameter of the balance-wheel and roller seems to be the same, or nearly the same, in Arnold's and Earnshaw's escapements.

APPENDIX

CONCERNING AMERICAN CLOCK AND WATCHMAKING.

To complete this Manual for the use of American artisans, it only remains for us to give a brief history of the rise and progress of clock and watchmaking in America.

At the beginning of the nineteenth century, the art of horology was unknown on this side the Atlantic, and though clocks and watches were imported to a considerable extent, the number then in use was small, indeed, in comparison with the present multiplicity of time-keepers. In some of the more pretentious dwellings might have been seen the heavily-cased English clock, the bizarre time-pieces of French and Swiss manufacture, and the German clock with its uncased dial and long swinging pendulum, yet a large proportion of the population eschewed these luxuries as beyond their means, and contented themselves with marking the lapse of time by the hour-glass, the noon-mark, or the sun-dial. It was reserved for the ingenuity of American mechanics to devise the means of manufacturing these useful machines so cheaply as to place them within the reach of the million, and, at the same time, with precision enough to render them available for all practical purposes.

Perfect as may be the theory of European clock and watchmaking, its practice has always been marked by a strange want of system. The different parts that go to make up these useful machines are manufactured in different places by different workmen, then sent to other localities for adjustment and finishing, and, though with sufficient time and pains, these may be and are executed by skilful artisans with marvellous accuracy, it is obvious that this pains can only be bestowed upon a few costly timepieces, while the majority will be liable to be more or less defective. The American mechanics have obtained the advantage of systematizing their work by manufacturing all the pieces in one establishment under the supervision of a single workman, then duplicating them rapidly by means of machinery. By this labor-saving process, they attain both cheapness and accuracy, since work executed by well constructed machines must be more uniformly perfect than that which is made by handicraft, whilst the rapidity of the process of multiplication is so great that the cost of manufacture must be almost nominal in comparison with that of the latter. This advantage, which has lately been obtained in the manufacture of watches, has for many years secured to the mass of American clocks a world-wide reputation for their cheapness and accuracy.

About the year 1800, Eli Terry of Plymouth Hollow, Connecticut, first commenced the manufacture of the famed American clocks, which now form so large a part of our exportations. This was on a small scale enough at first; after manufacturing two or three clocks, he would sling them on his saddle and traverse the country till he had disposed of them to advantage, then return and resume his work. The movements of these earliest clocks were of wood, of a construction similar to the common English clocks; the introduction of sheet brass was of later date. Ere long, the "wooden clocks" gained popularity by their convenience and cheapness, the manufacture was extended by the original projector; other manufacturing establishments were founded, and by degrees Connecticut and a part of Massachusetts became the seats of a flourishing clockmaking business. Machinery was applied to the manufacture, the wheels, instead of being cast separately as in the old method, a process of infinite delicacy and precision, were rapidly cut from sheet brass by this labor-saving device, the pivots were made of inexpensive iron-wire and the whole adjusted in the same establishments, thus affording facilities for cheapness combined with uniformity of execution superior to those of any method hitherto pursued. The sheet-brass used in the manufacture of these movements also possesses many advantages over the cast brass, being finer, more easily wrought, and free from the inequalities so often caused by the hammer of the workman.

Eli Terry, the father of the enterprise, continued in the business until his death a few years since, after which the manufacture was for some time conducted by his sons under the name of the Terry Manufacturing Company, now become extinct. Next in the ranks came Seth Thomas, of Plymouth Hollow, who died in the beginning of the present year, and whose manufacturing establishment, still conducted under his name, is the oldest now in existence.

The clockmaking business, though carried on to some extent in New York, Massachusetts, and Maine, still remains principally confined to Connecticut. The following list of the principal manufactories of the state, with the approximate number of clocks of their manufacture, will give some idea of the extent of the business at the present time.

New Haven Co.,	New Haven . . .	150,000
Elisha Welch Co.,	Bristol	100,000
Seth Thomas Co.,	Plymouth Hollow .	75,000
Waterbury Co.,	Waterbury . . .	50,000

Gilbert Co.,	Winsted	40,000
Ansonia Brass and Clock Co.,	Ansonia	10,000
Pomeroy & Parker,	Bristol	10,000
Maurepas,	Bristol	5,000

The census of the state of New York, for 1855, gives the following statistics of clock manufacture:

Number of factories.		Capital invested. Real estate.	Tools and material.	Raw material.	Manufactured articles.	Persons employed.
MADISON CO. Cazenovia,	2	3,200	2,200	1,100	4,610	5
N. Y. CO. New York,	5	51,000	9,100	64,000	163,000	87
SUFFOLK CO. Southampton,	2	4,500	5,000	4,375	11,000	12
TOMPKINS CO. Ithaca,	1	500				4
Williamsburg,	1				15,000	

Besides these, there are five chronometer manufactories in New York, with a capital of about $17,000, employing forty-nine men.

These clocks form an important item in our exportation. Large numbers are annually exported to Europe and South America, and the demand even reaches as far as China and Japan. The price usually varies from one to ten dollars, a fair average price being two dollars and a half. A few higher-priced clocks and regulators, worth from two to three hundred dollars, are also manufactured in these establishments; but these are more usually supplied from Europe, the demand not being great enough to warrant the outlay necessary to produce that exquisite accuracy in time-keepers, which is required in comparatively few conditions. This matters little, as these specialties in the art can be imported from those countries where labor is cheap, at a less cost than they could be manufactured here. Most of these come from England and Switzerland. As a master-piece in timekeeping machinery we may mention a turret-clock that has fallen under our notice, made by Thomas Leyland of Prescot, England, and imported by Messrs. Tiffany and Co. of New York, as a regulator in their establishment, the greatest variation of which, as tested by a transit instrument under the charge of Prof. Bull of the New York University, has not exceeded nine seconds within the last ten months. This movement, compensated by means of a mercurial pendulum with a steel rod and glass bulb, and cased in a heavy carved rosewood frame of admirable workmanship, firmly secured to the wall by marble brackets, so as to obviate all possibility of external disturbance, affords a fine illustration in its perfection of the triumph of horologic science.

Although these fine timekeepers are not usually executed in the large manufacturing establishments, there are several artisans in America who have made their manufacture a specialty, and whose work will compare favorably with the most celebrated European clockmakers. Chronometer-making has received special attention from these, and the American marine chronometers are acknowledged as equal to any in the world.

The following statistical table, compiled from the last census (1850), will give some idea of the present state of clock-making in America :—

NUMBER OF CLOCKMAKERS IN THE UNITED STATES IN 1850.

Maine,	16	Connecticut,	837
New Hampshire,	22	New York,	173
Vermont,	10	New Jersey,	15
Massachusetts,	59	Pennsylvania,	105
Rhode Island,	6	Delaware,	0

Maryland,	22
District of Columbia,	2
Virginia,	8
North Carolina,	5
South Carolina,	6
Georgia,	6
Florida,	0
Alabama,	34
Mississippi,	1
Louisiana,	7
Texas,	0
Arkansas,	0
Tennessee,	3
Kentucky,	9
Ohio,	46
Michigan,	6
Indiana,	8
Illinois,	13
Missouri,	12
Iówa,	2
Wisconsin,	3
Total,	1,436

Although the same or even greater advantages must accrue from the duplication by machinery of the parts of watches as of clocks, no attempt has been made till within a few years past to adapt this process to the manufacture of these machines. While we have supplied the world with American clocks, we have continued to import watches from England, France, Switzerland, and Germany, at a cost of over five millions dollars per annum, while the annual cost of repairing has amounted to as much more. The value of the watches imported into the United States from 1825 to 1858, inclusive, as shown by the published returns of the Treasury department, is $45,820,000, almost equally divided between England and Switzerland, at present the great European depôts of the watch-trade; while the number of watches supplied by the latter is almost three times as great as that of the former, owing to the lower price and less substantial character of their workmanship. Coventry and Prescot in Lancashire and Warwickshire, England, and Locle and Chaux-de-Fonds in the northern Cantons of Switzerland, near Geneva, are known as the great central emporiums of watch manufacture. Denmark too, through the watches of Jurgensen, has recently acquired a reputation in the art. It is but just, however, to say, that the greater part of the movements of all are made in Switzerland, where whole cantons are engaged exclusively in the manufacture, one hamlet taking one piece of the watch as its specialty, and another others. These pieces, after being cast, turned, and drilled, are sent to the finishers at London or Paris, where they are adjusted, cased, and set in motion. From this process it results that each watch will necessarily have a distinctive character of its own, and that it is only by the merest accident that the movements of two watches can be found in exact correspondence, or that a piece once broken can be replaced by another precisely like the first. From this want of system then, and not from any deficiency in theory, arises the imperfections that are so annoying in the mass of imported watches. This fault, remedied with such success in the manufacture of American clocks, is now receiving the attention of American watchmakers, and, though the experiment has but just been commenced, it is safe to predict that it will prove a success, and that the time is not far distant when American watches will form as valuable an article in our commerce as have the American Clocks. Meanwhile, while availing themselves of the advantages of the iron fingers of machinery, our artisans will do well to study and improve upon the ingenious theories of European horologists, in order to bring these delicate machines to that perfection of which they are susceptible.

Although it is only within a few years that the manufacture of watches has crystallized into a substantial form in this country, they have been made by individuals from time to time since the period of the first introduction of clocks. During the war of 1812, good watches were made by Goddard and others in Worcester, Massachusetts, some of which are still in existence; but after the close of the war, the importation of watches was resumed, and the home manufacture failed for want of capital and patronage.

In 1830, Henry Pitkin, of East Hartford, Connecticut, made an attempt to revive the enterprise, and manufactured about a thousand watches there and in Boston, but, not meeting sufficient encouragement, he at length relinquished the undertaking. Other spasmodic efforts at the manufacture of watches were made from time to time, but all proved unsuccessful; and, though watchmaking still remained a distinct profession, the watchmakers became a sort of ingenious factotums, whose business it was to repair watches of foreign manufacture in addition to clocks, jewelry, and silverware, and not unfrequently locks, guns, etc.

It was not until 1850, that A. L. Dennison of Brunswick, Maine, an ingenious mechanic and practical watchmaker, first suggested the idea of systematizing the manufacture of watches by making and adjusting the whole movement in a single establishment, and duplicating the pieces by a connected system of machinery, thus securing, not only a great economy of time, but also an exact correspondence in the parts of an infinite number of watches. Under the direction of Mr. Dennison and others a company was formed, under the name of the Warren Manufacturing Company, subsequently known as the Boston Watch Company, and a manufactory was established at Roxbury, Mass.; but this locality was soon found unsuitable, as, the soil being light and dry, and the place one of the leading thoroughfares to Boston, the clouds of dust that were raised in consequence interfered with the operations of the workmen, and materially injured the delicate mechanism. The establishment was accordingly removed to Waltham, Mass., where extensive buildings were erected on the banks of the Charles River, and the manufacture continued until 1857, when the original company failed, and the establishment and business passed into the hands of Royal E. Robbins and associates, who, uniting with the Waltham Improvement Company, were incorporated during the winter of 1858–59, under the name of the American Watch Company, with a landed property of over one hundred acres, upon which it was proposed to erect houses for the artisans employed in the establishment, of which Mr. Dennison, the original projector of the enterprise, still retained the superintendence.

Since this time, the American Watch Company has extended its operations, until more than two hundred artisans, men and women, are constantly employed, producing twelve thousand watches per annum, varying from the simplest form of the lever movement to the adjusted chronometer balance. These movements are of one uniform size, measuring one and thirteen-sixteenth inches across the dial, and are constructed after the English fashion, with a two-plate frame opening at the back, with dome-cap attached to the case. The English patent lever escapement is used, wisely modified after the Swiss method, by the omission of the main-wheel, fusee, and chain; the power being communicated direct from the barrel to the train. This suppression of the fusee has long been advocated by the French theorists as securing greater simplicity, less friction in the transmission of the motive power, the use of a lighter spring which is surer and more uniform in its action, and more room for play in the frame for the other parts of the movement; and this construction, so vigorously defended by them, is now beginning to be accepted by the English horologists themselves, and is adopted in the system of the American manufacture.

The chief distinctive feature in this system is the duplication of every part of the watch by machinery, so that every movement is the exact counterpart of every other.

These, with the exception of the jewels and the pivots that run in them, are cast by machinery, adjusted to a certain gauge, and so delicate as to mould tiny steel screws in its grasp, 100,000 of which are required to make a pound. The jewels are drilled with a diamond, and opened with diamond dust on a soft iron wire. The pivots that are to run in these are turned and polished, then tested by a gauge adjusted to the ten-thousandth part of an inch, and fitted to a jewel drilled one degree larger in order to afford the pivot sufficient play. Both jewels and pivots are carefully classified, and the sizes used in each watch recorded under its number, so that any that may be broken can be easily replaced. A steam-engine of twelve-horse power forms the pulse of the whole establishment, giving motion to a net-work of shafting that traverses the building. By this process, a far more extensive adaptation of machinery to the manufacture of watches than has hitherto been made has been successfully effected—four-fifths of the whole work being done by machinery, while but one-fifth is thus made in the European establishments—and manifold advantages are secured in the uniformity of the movement of the time-pieces, as well as in the facilities for repairing them when broken or out of order. The watches thus manufactured have proved themselves good time-keepers, and the cheapness of their execution affords earnest that they will follow in the wake of the American clocks in their journey over the world.

We subjoin the following statistics of watchmakers in America from the last census (1850), premising that the number has increased largely since the enumeration.

NUMBER OF WATCHMAKERS IN THE UNITED STATES IN 1850.

Maine,	45	Louisiana,	155
New Hampshire,	37	Texas,	22
Vermont,	10	Arkansas,	4
Massachusetts,	213	Tennessee,	42
Rhode Island,	41	Kentucky,	55
Connecticut,	28	Ohio,	152
New York,	708	Michigan,	22
New Jersey,	122	Indiana,	28
Pennsylvania,	712	Illinois,	57
Delaware,	3	Missouri,	51
Maryland,	93	Iowa,	15
District of Columbia,	14	Wisconsin,	39
Virginia,	69	California,	30
North Carolina,	17	Minnesota,	1
South Carolina,	36	New Mexico,	0
Georgia,	31	Oregon,	1
Florida,	6	Utah,	2
Alabama,	14		
Mississippi,	26	Total,	2,901

VOCABULARY

OF DEFINITIONS AND SYNONYMOUS TERMS.

A.

Alarm.—A simple and ingenious machine adjusted to the clock, by means of which a hammer strikes upon a bell at a given hour or moment of the night, making a noise sufficiently loud to awaken a sleeper.

Anchor.—Piece of the escapement, used in clocks and lever watches.

Arbor, axle, rod, or axis.—Synonymous terms for the designation of a piece which turns upon itself by means of its pivots.

B.

Balance.—The balance is a bar, balanced by two weights, or a circular ring, with a rim concentric to an axle carrying two pivots, upon which the ring can turn freely; it therefore remains in equilibrium with itself by its nature, whatever may be its position, and should keep up a uniform movement in whatever position may be given it. The balance, joined to the first known escapement—that of the verge and crown-wheel—becomes the moderator or regulator of the old clocks, watches, etc. The balance alone cannot produce oscillations.

Balance-Regulator.—The balance, when joined to the regulating spiral-spring, becomes the regulator of the modern portable clocks, known as *watches*, and also of the marine and astronomical portable clocks. The elasticity of the spiral-spring is to the balance what the weight is to the pendulum.

Balance-wheel.—Crown, scape-wheel, rencounter-wheel.

Balance-wheel, known also as verge and crown-wheel watches.

Barrel.—A piece hollowed on the lathe, in the cavity of which a spring, bent in a spiral form, is placed, designed for clocks and watches.

Bridge.—A piece bent at right angles at each end, so as to form a small frame to a part of the clock or watch.

Burin, also "graver."

C.

Caliber.—The plate on which the arrangement of the pieces of a clock is traced—the pattern-plate.

Centre of motion.—The point around which a piece revolves.

Centre of oscillation.—This is, in the pendulum, the point about which all the force of the weight of the rod and the ball are united. This centre is below the centre of gravity.

Centre of suspension.—The point around which the pendulum oscillates.

Centre-wheel, small, known also as "third wheel."

Chain-guard.—Mechanism employed in watches, with a fusee to form a stop-work, strong enough to prevent the main-spring from being wound up too far, so as to avoid breaking that or the chain.

Chick.—A synonym of "steady pin."

Click.—A small lever movable on its centre, which pressed by a spring, acts upon a ratchet or saw-toothed wheel, or rack, to prevent its return, sustains the effort of the motive-power, and facilitates the winding of it.

Click and spring-work.—The mechanism by means of which the motive-weight, spring of a clock, or barrel of a watch is wound.

Clock.—The proper word used to designate any machine which divides and marks the fractions of time. Clocks are divided into several classes, according to the uses for which they are designed:—1st, portable clocks, commonly called *watches;* 2d, apartment or mantel-clocks, usually known as clocks; 3d, clocks for steeples or towers which are designated, *belfry clocks.* To these denominations epithets are added descriptive of the functions which they perform, as *repeaters*, *alarms*, etc.

Cog-wheel.—A tooth or projection of a wheel which works into those of another weeel or pinion. This term is also applied indiscriminately to all toothed wheels, as the term "cog" is applied indiscriminately to teeth cut in every form.

Compensation.—A mechanism by means of which we correct or destroy the variations of the clock which are independent of the machine itself, as the compensation in the pendulum or the balance of the variations caused by the dilatation or contraction of metals, by the different degrees of heat and cold.

Concentric.—Those which have the same centre of motion. We say that two hands are concentric when they turn separately around the same centre; thus the hour-hand is attached to a socket which turns on the arbor of the minute-wheel and carries the minute-hand.

Condensation or Contraction.—Terms expressing the diminution of the volume of a body by cold.

Contrate-wheel, also "fourth wheel."

Cutting-file.—Circular files used to cut the teeth of the wheels and the pinions. The cutting-files are small wheels made of tempered steel, and are cut in saw-teeth.

Cycloid.—Curved line formed by the revolution of a point of the circumference of a circle on a right line.

Cylinder-wheel, also cylinder scape-wheel.

D.

Degree.—The 360th part of a circle.

Detent.—Piece of the striking-work which checks or impels the train, in order that the hour may be struck, also the locking-spring of escapements, especially of the Earnshaw chronometer.

Dilatation extension.—Terms expressing the increase of the volume of a body by heat.

Dial-wheel, also "hour" and "minute-hand-wheel."

E.

Epicycloid.—The curve which should terminate the extremity of the teeth of the wheels, and the leaves of the pinions, in order that the action of the wheel may be uniform—an indispensable property in the gearing. The *epicycloid* is a curve formed by the revolution of a point of the circumference of a circle around another circle.

Escapement.—That mechanism of clock-work whose functions are: 1st, to restore to the regulator, whether pendulum or balance-regulator, the force which it loses at each vibration, by the friction which it experiences, and by the resistance of the air; 2d, while the regulator measures the time, the escapement regulates the velocity of the wheels, which indicate on the dial by their hands, the parts of time divided by the pendulum or by the balance. Two periods must be considered in the effect of the escapement; that of the impulse restored to the regulator during which the wheel advances a part which equals a vibration; secondly, that by which the action of the wheel and that of the motive-power remains suspended, while the regulator completes its oscillation.

Escapement: dead-beat.—Those escapements in which the wheel, after having given the impulse to the balance, remains stationary, while the latter completes its vibration.

Escapement: recoil.—That escapement which, after having received the impulse of the wheel—the balance finishing its vibration—causes the wheel to recoil; such as the verge-escapement, the double-lever, anchor, etc.

Equation of time.—The difference which exists each day of the year, between the true time measured by the sun, and the mean time, measured by clocks.

F.

Ferrule.—This, in the barrel, is the circle which contains the main-spring.

Ferrule of the spiral-spring.—A small cleft socket which is adjusted on the axle of the balance, to receive the inner end of the regulating spiral-spring; also collet.

Fly.—The fly is the moderator, or regulator of the trains of striking-work, repeaters, etc. It is formed by two large and light wings which, by the resistance that they experience in the air, serve to moderate the velocity of the wheels, and to regulate the intervals between the strokes of the hammer.

Force or Power: motive.—In fixed astronomical clocks, this is the weight; in portable clocks, the spring.

Frame.—That which contains the wheels and the mechanism of the clock; this is composed of four pillars, and of two plates called *pillar and upper-plate, or fire plate.*

Fusee.—A truncated cone, formed somewhat like a bell. The most important property of the fusee is, that of equalizing the force of the main-spring of watches; so that the spring, by this valuable invention, becomes nearly as equal and constant a motive-power as that of the motive-weight.

G.

Gearing or Pitching.—The action of the teeth of one wheel upon those of another wheel or pinion, in order to make it turn around its centre of motion, and to transmit its motion to it.

I.

Isochronal.—Movements of the same duration. We generally call the oscillations or vibrations of a body *isochronal*, when they are of the same duration. These oscillations are naturally isochronal when the body that measures them constantly passes over the same extent, and consequently has the same velocity; but oscillations of unequal extent may also be isochronal.

J.

Jumper.—A species of click in the repeater, preventing the motion of a wheel in either direction.

L.

Lathe.—A tool used for turning or rounding the various pieces employed in machines.

Lever.—A simple machine which is the first mechanical power. The lever is a rod which, forming two unequal arms, and being supported by a rest at the point which divides them, increases the limited force of a man, and raises weights by the action of the longer arm. The lever enters into the composition of all machines, or rather these machines are but composite levers.

Limb.—Circle, or portion of a circle, graduated in degrees, etc.

Line.—The twelfth of an inch.

M.

Minute-wheel-works, or Dial-wheels.—These wheels are placed between the pillar-plate and dial, and guide the hands which mark the hours and minutes.

The minute-wheel-works, in watches and ordinary clocks, are composed of the canon pinion; the end of the socket of this, formed in a square, receives the minute-hand; the socket of the canon pinion is adjusted with friction on the pivot or elongated rod of the wheel of the train which revolves once in sixty minutes. The canon pinion gears into a wheel, the diameter of which is three times larger than that of the pinion, has three times as many teeth; this pinion consequently makes three revolutions while the wheel makes one; this latter, which is called the minute-wheel, therefore revolves once in three hours. This wheel is fixed on a pinion which conducts the dial-wheel, whose revolution is performed in twelve hours. The dial-wheel is fixed on a socket whose end carries the hour-wheel; this socket turns freely on the socket of the canon pinion.

MOTIVE-POWER.—Any agent which gives motion to a machine. In fixed astronomical clocks with pendulums, the motive-power is a weight; in portable clocks, it is a spring.

MOVEMENT.—We call the *movement*, in clockmaking, the interior part of the clock, which measures the time, and which marks it on the dial by means of the hands: this is also called the wheel-work.

O.

OIL.—Oil, when applied to the parts of moving bodies which rub against each other, diminishes their friction. Clockmakers have always considered olive oil to be the best adapted to lubricating the pivots of the numerous axles which they employ in machines for the measure of time; but experience has taught them that the best and purest of these oils contain some injurious properties which they sought to remove. Their attempts have hitherto been unsuccessful, without excepting the process of M. Laresche, which has not effected what he promised of it. The learned academician, M. de Chevreil, in his important analysis of oleaginous bodies, has opened a way which should lead to the solution of this interesting problem. He has proved that oily bodies are composed of two distinct substances; one always fluid, which he calls *oléine;* the other always solid in its pure state, to which he gives the name of *stearine.* M. Braconnet, a celebrated chemist of Nancy, has ascertained that olive oil contains one hundred parts; twenty-eight parts of *stearine*, and seventy-two parts of *oléine*. He employs the following process to effect the separation:

He freezes the oil during the most intense cold of winter; he then compresses it during several days between several sheets of bibulous paper, by the aid of a strong press and in a temperature below zero, taking care to renew the paper until it ceases to soil it. He then presses it again in a temperature of 15° Reaumur, and thus obtains a white material, which is as brittle as the hardest tallow and resembles it in taste and smell; this is *stearine.*

To obtain the *oléine*, he moistens the blotting-paper in which the frozen oil had been compressed, with tepid water; he then twists it in a knot which he subjects to the action of the press, and extracts from it the *oléine* which is perfectly fluid. Several clockmakers who have used that, admit that it possesses the qualities that they have long desired.

Oscillation or Vibration.—The motion of a body which swings backward and forward; the backward and forward movements of this body form two oscillations.

P.

Pallet.—A small lever carried by the arbor of the balance in the verge escapement.

Pinion.—A small toothed wheel.

Pyrometer.—An instrument designed to show, in high temperatures, the different degrees of dilatation and condensation, by different degrees of heat of metals and other bodies.

R.

Ratchet-wheel.—A notched wheel the teeth of which are straight on one side and directed towards the centre, and inclined on the other side. The ratchet-wheel is employed for different uses;—the first has been to serve for the winding of the main-spring in the mechanism called the click and spring-work; the second use of the ratchet-wheel has been that of being substituted for the verge and forming the escapement-wheel of the anchor-escapement, whether the recoil or dead-beat, etc.; it is then called the *ratchet-wheel of the escapement.*

Remontoir.—An especial mechanism designed to render the force which sustains the movement of the escapement or balance perfectly equal and constant, so that it may not participate in nor receive the unequal forces caused by the variations of the friction of the train, inequality of the motive-power, etc. Also, winding-up arbor.

Repeater.—A mechanism adjusted to a clock or watch, by means of which one can cause the hour or the fraction of an hour marked on the dial, to be struck at any moment of the day or night.

S.

Second-watch, also "seconds-hand watch."

Star-wheel.—Wheel formed by angular radii; a part of repeating-clocks.

Screw.—An instrument of general utility in all mechanical arts. The screw is a cylinder spirally grooved, and when conducted by a lever, acquires a force capable of moving and strongly pressing the bodies on which it acts.

Snail.—A piece of the repeater, figured spirally, and formed by the degrees which proceed from the circumference to the centre. The hour-wheel is divided into twelve parts or degrees; this snail determines the number of strokes which the repeater should strike, by means of the rack, one of whose arms rests on one of the degrees of the snail.

The quarter-snail is divided into four parts.

Stop-work.—Mechanism employed to supply the place of the chain-guard.

Spiral or hair-spring.—A band of tempered steel, bent in a spiral form; when adjusted to the balance it becomes an integral part of the regulator. The spiral spring is to the balance what the weight is to the pendulum; the spiral-spring produces the vibrations of the balance and determines, conjointly with the mass and the diameter of the balance, the duration of the oscillations.

Support.—A piece forming a base which serves to fix a wheel, etc. The support of a wheel is a socket forcibly driven on a rod in order to rivet the wheel there.

Suspension.—We generally term that portion of the clock which supports the pendulum, so that it can oscillate freely, the suspension.

T.

Train.—An assemblage of several wheels and pinions which, placed in a frame, gear together successively in such a manner as to transmit to the last wheel the movement which the first received from the motive-power.

Tempering.—The operation by which steel acquires all the degrees of hardness of which it is susceptible, either for a spring or cutting-tool, being blue for the former, and strawberry-red for the latter.

V.

Vibrations.—The swinging movement of the pendulum. These vibrations regulate the movement of the clock and form the measure of the time.

The balance joined to the spiral-spring has, like the pendulum, a vibratory movement which regulates the movement of the clock or the watch.

W.

Watch.—Pocket clock.

Plate I

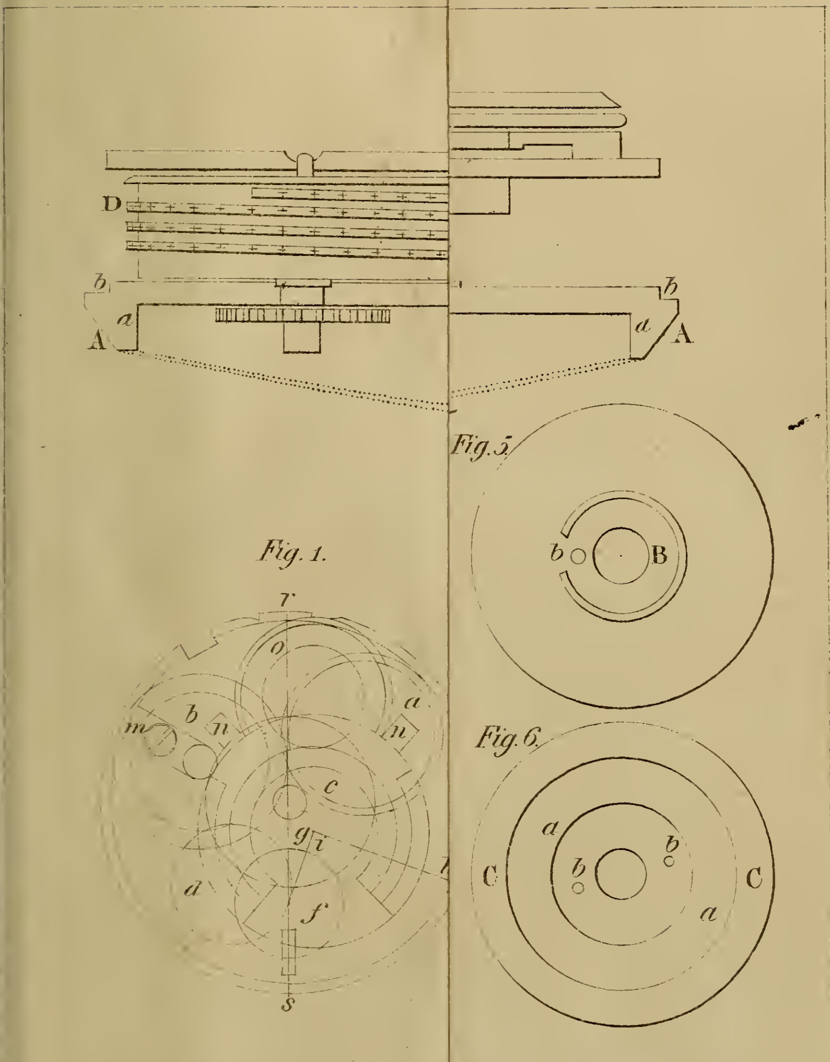
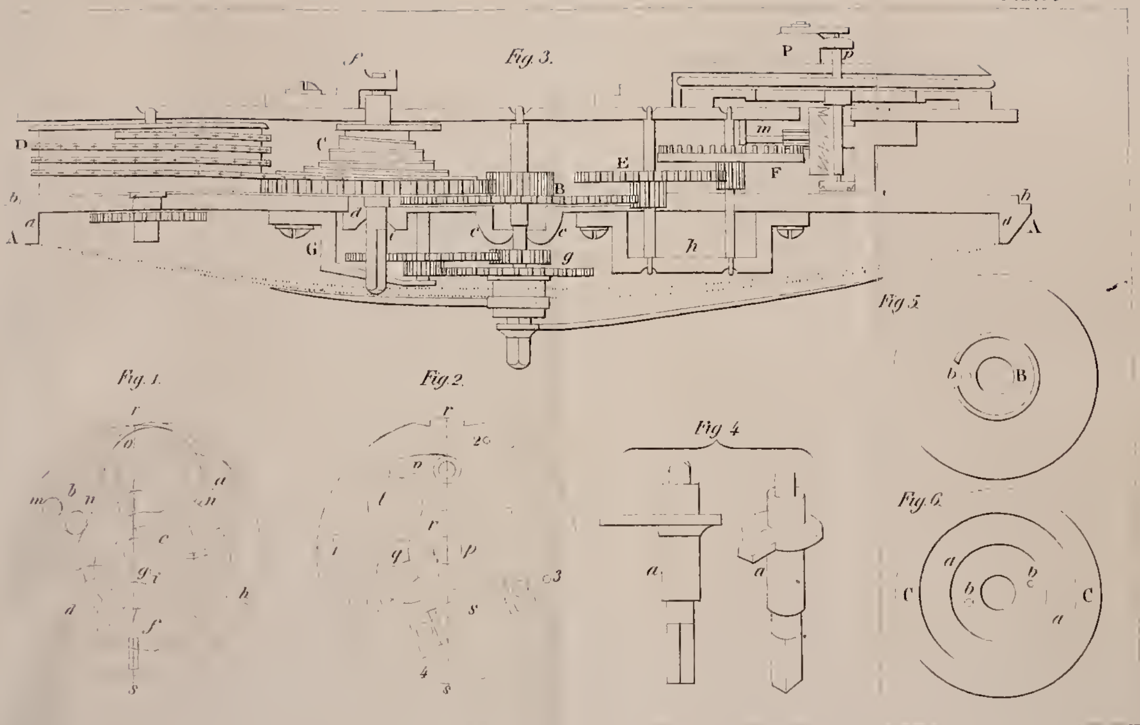


Fig. 1. Fig. 5. Fig. 6.

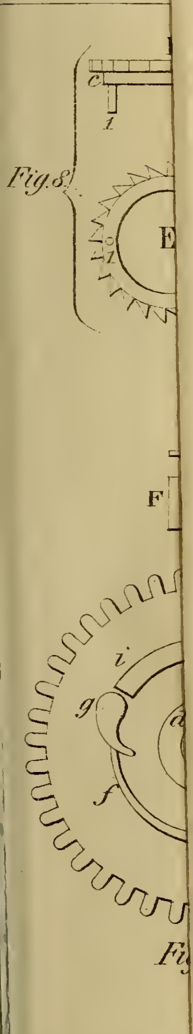
John Wiley, 56 Walker St.   … & Andrie, 104 William St. N.Y.

Plate 1

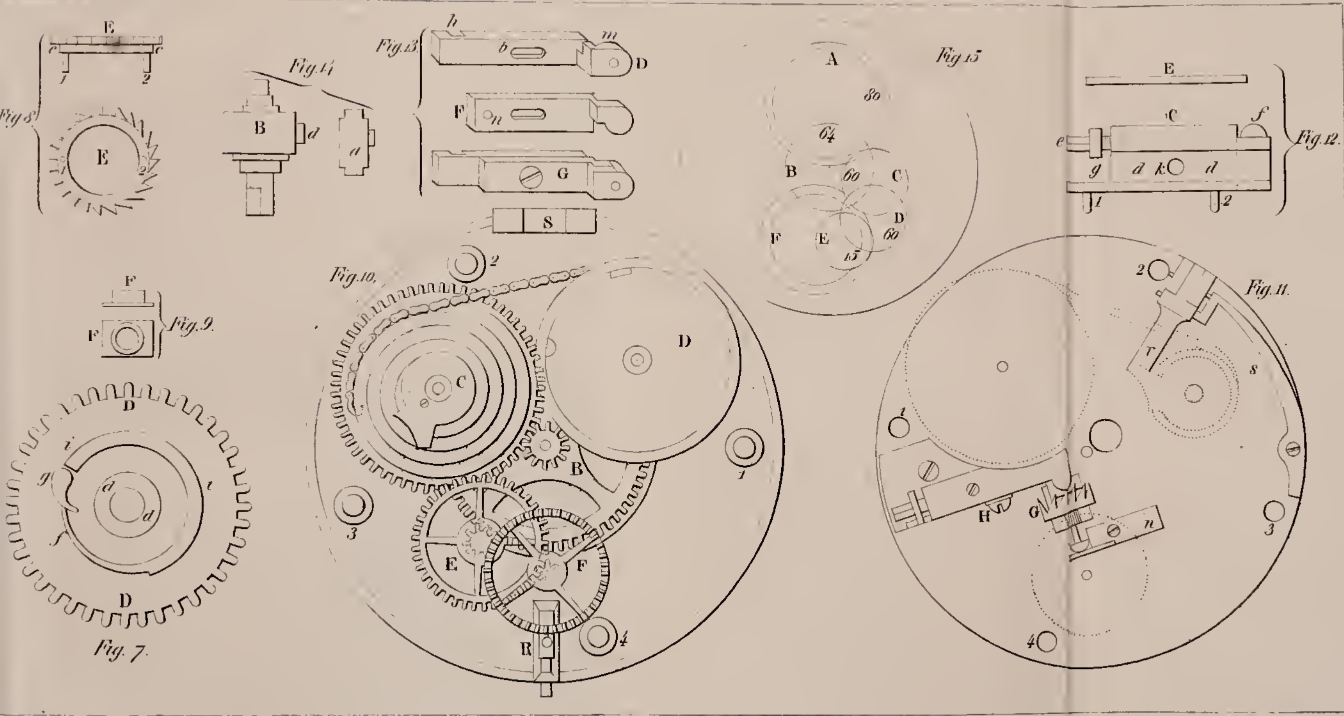


John Wiley 56 Walker St

Lith of Johnson & Andrie, 104 William St. N.Y.



John Wiley, 56 W



John Wiley, 56 Walker St

Lith of Johnson & Andrie, 104 William St N.Y.

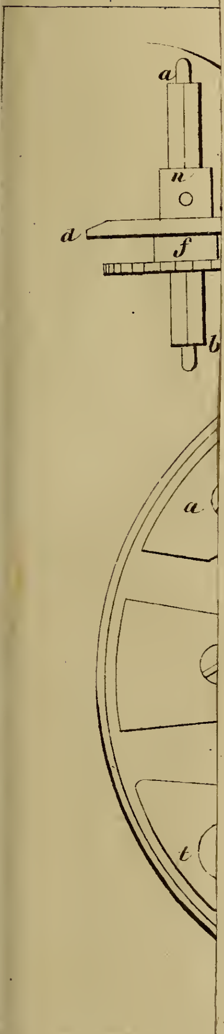

a
n
d
f
b
a
t

Plate II.

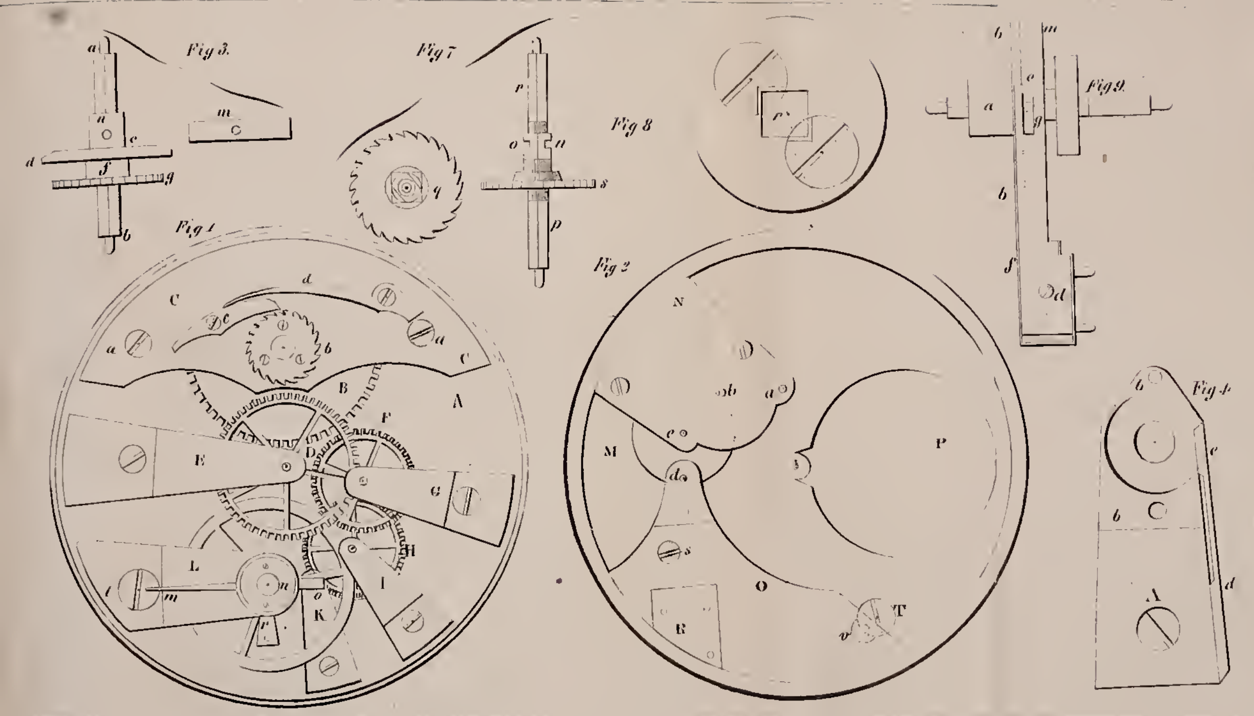


Plate II. Continued.

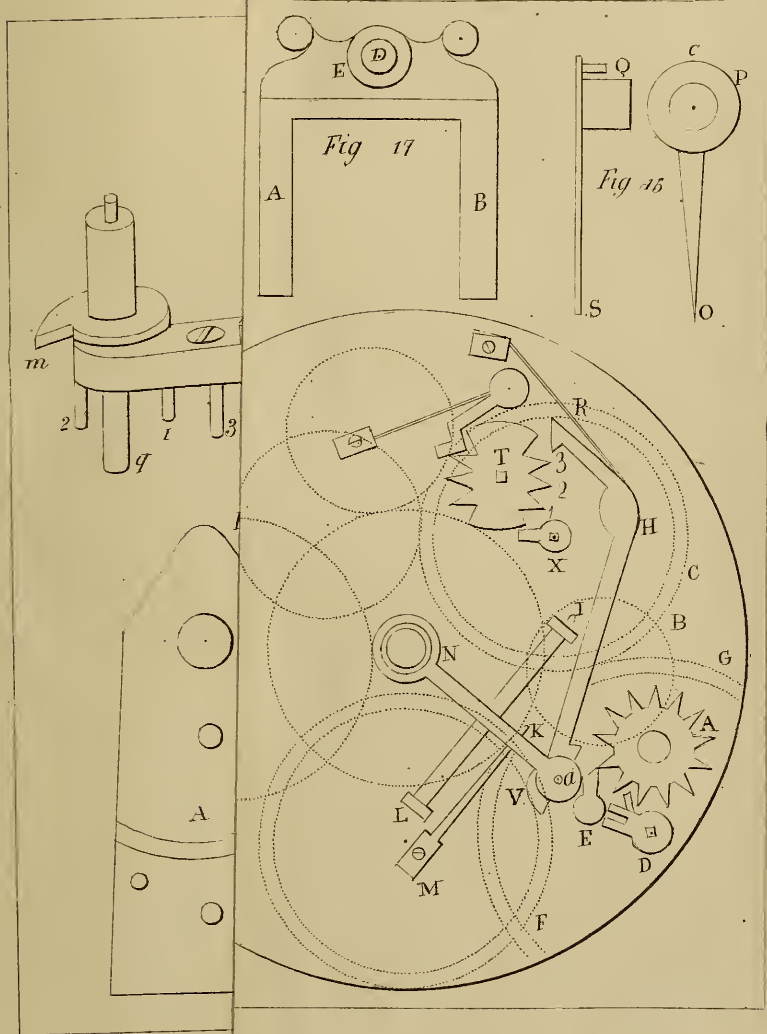


Plate II Continued.

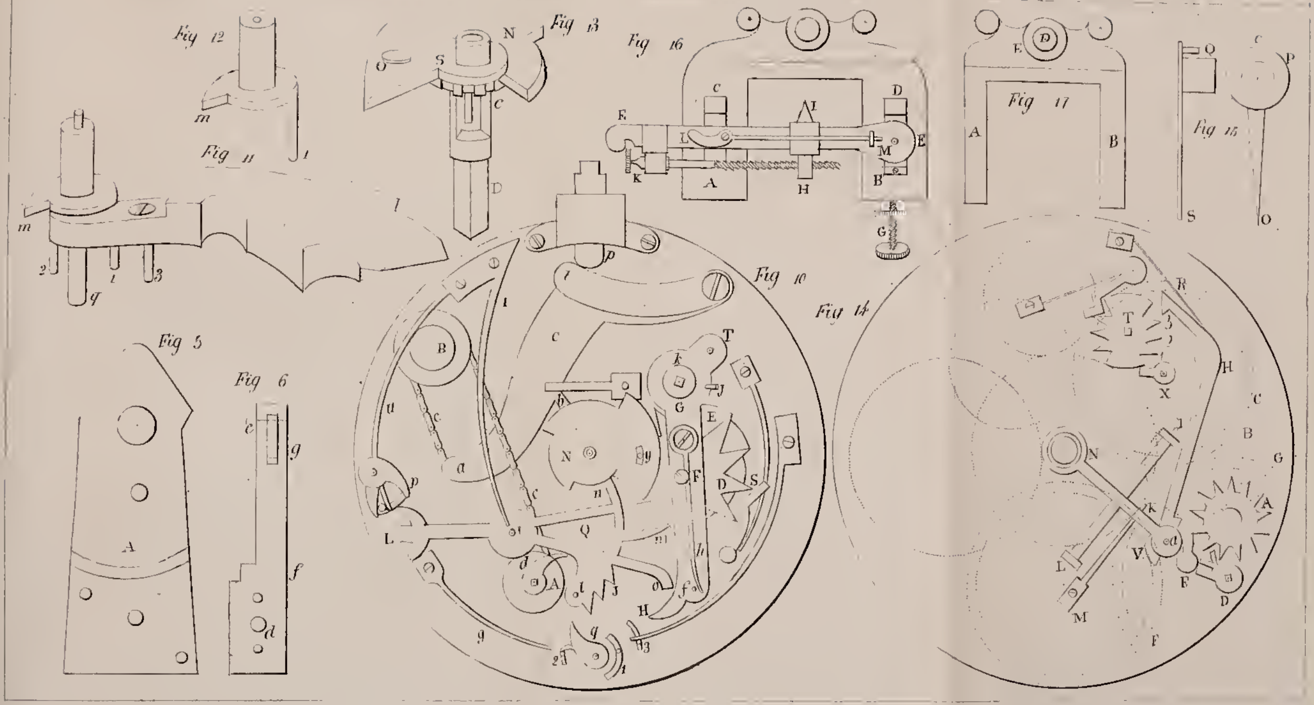
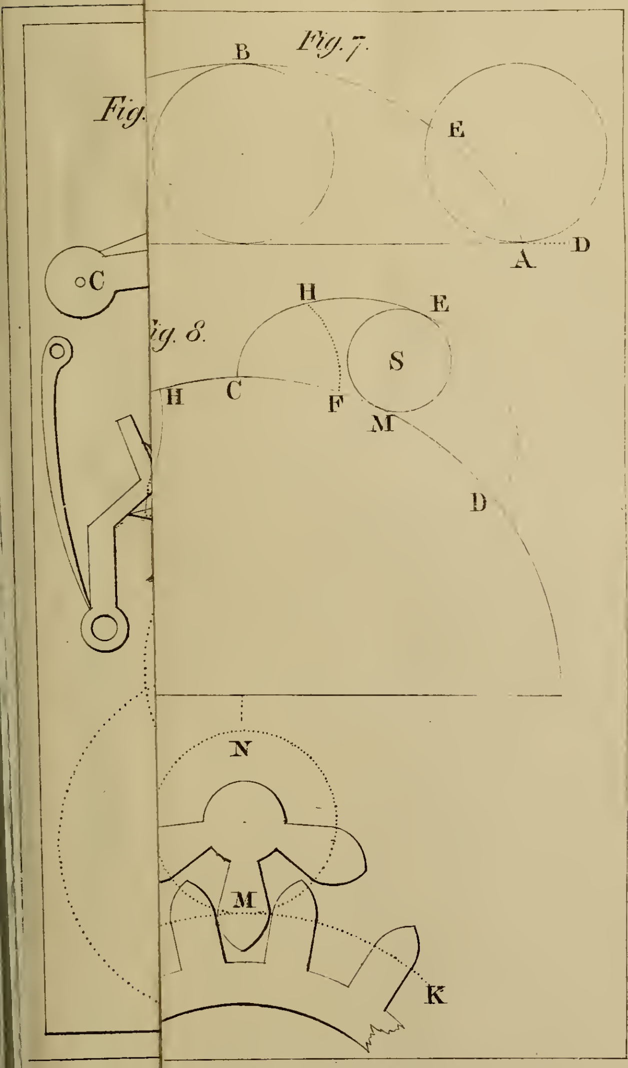
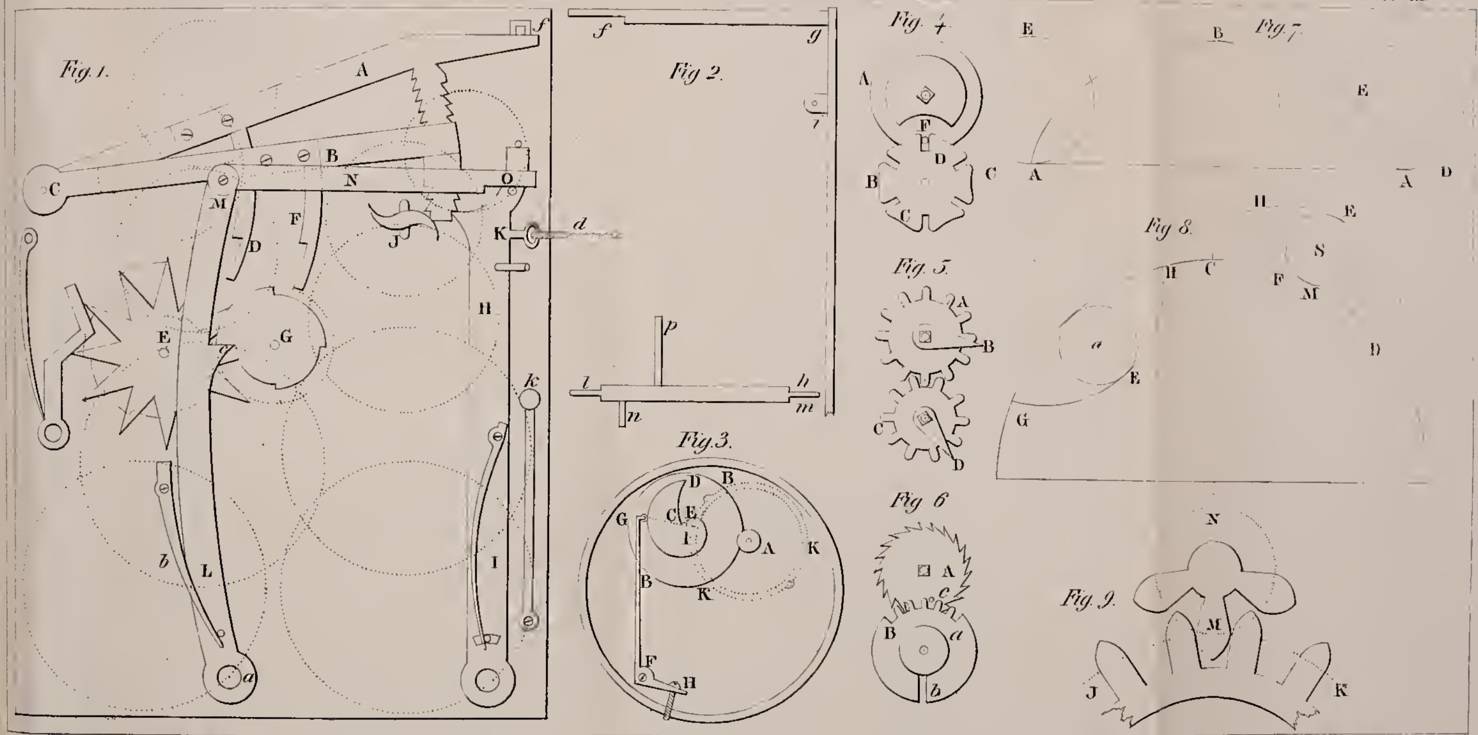


Plate III.



John Johnson & Andrie, 104 William St. N.Y.

Plate III



John Wiley, 56 Walker St.

Lith. of Johnson & Andrie, 104 William St. N.Y.

Plate III. Continued.

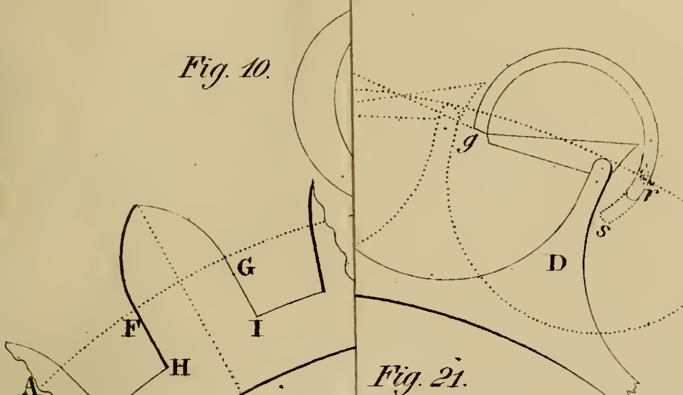


Fig. 10.

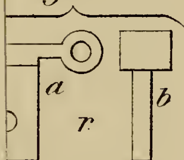


Fig. 21.

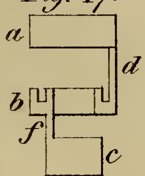


Fig. 17.

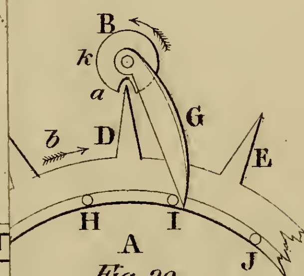


Fig. 22.

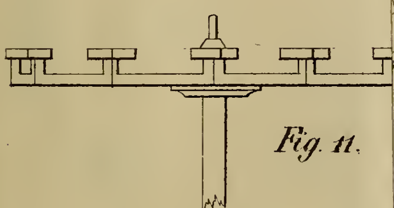
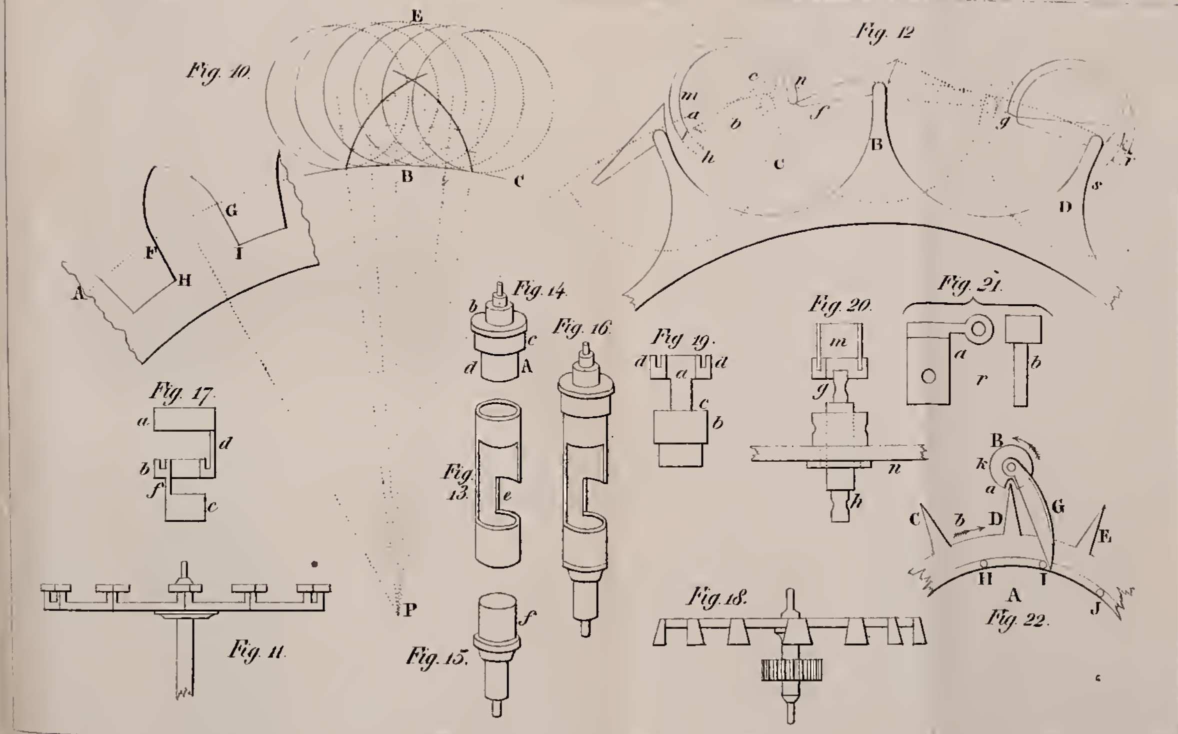


Fig. 11.

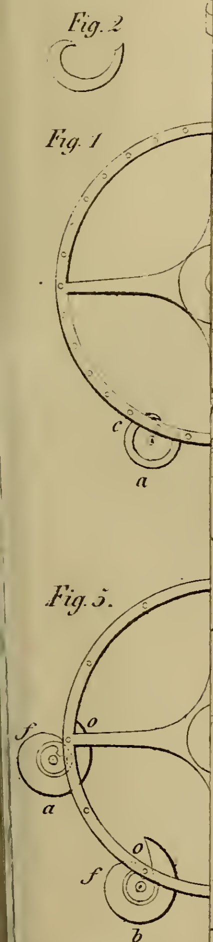
John Wiley, 56 Walker St. & Andrie, 104 William St. N.Y.



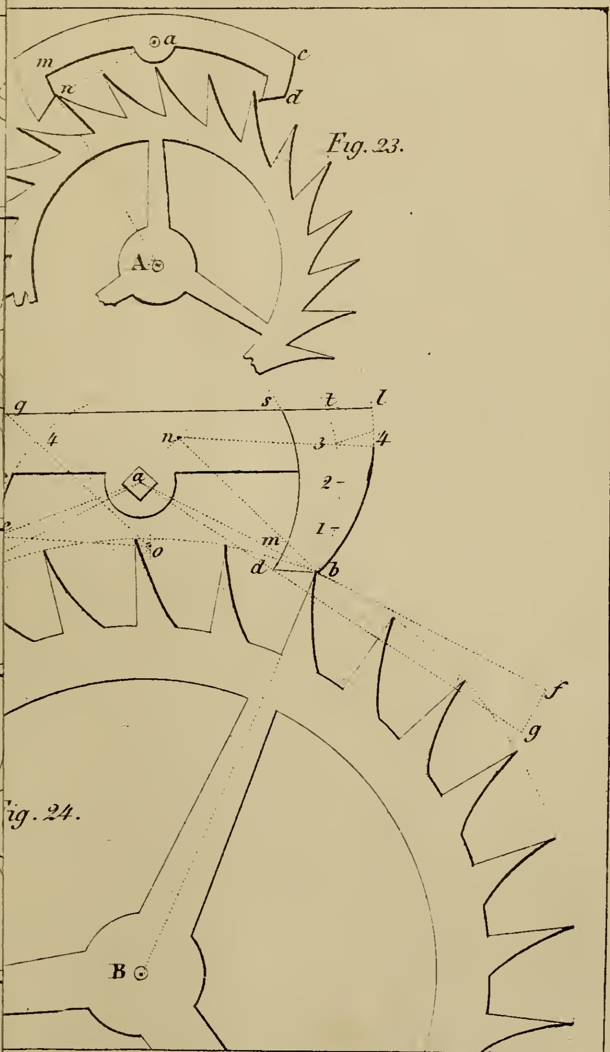
John Wiley, 56 Walker St.

Lith. of Johnson & Andrie, 104 William St. N.Y.

Plate IV

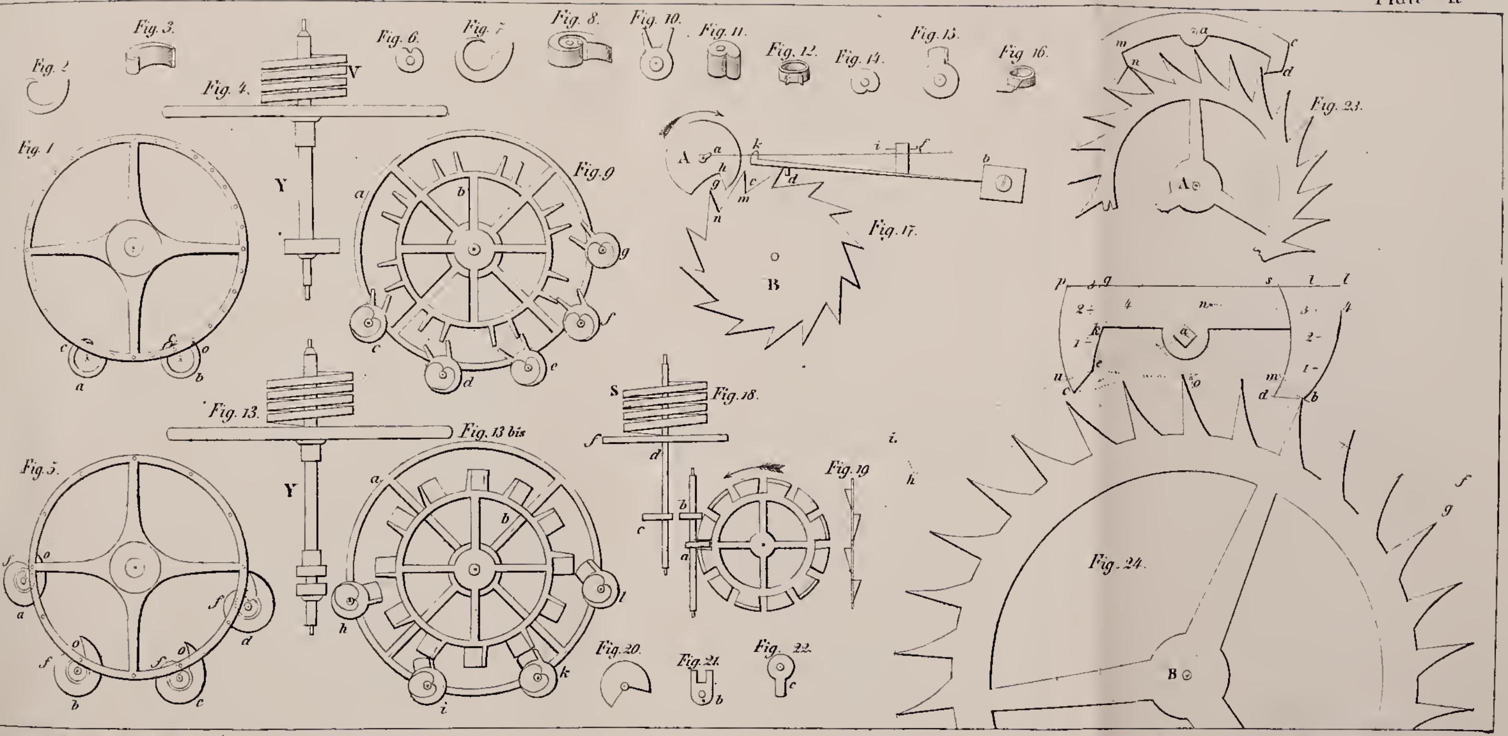


John Wiley, 56



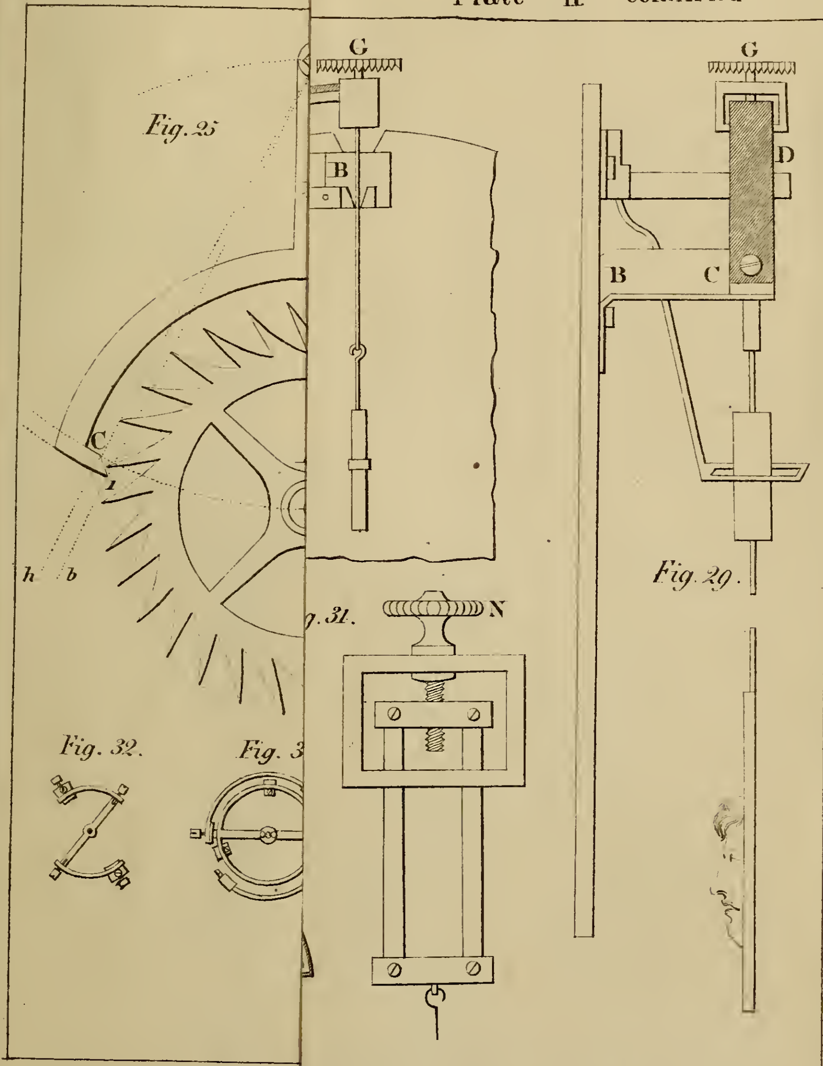
Lith. of Johnson & Andrie, 104 William St. N.Y.

Plate IV.



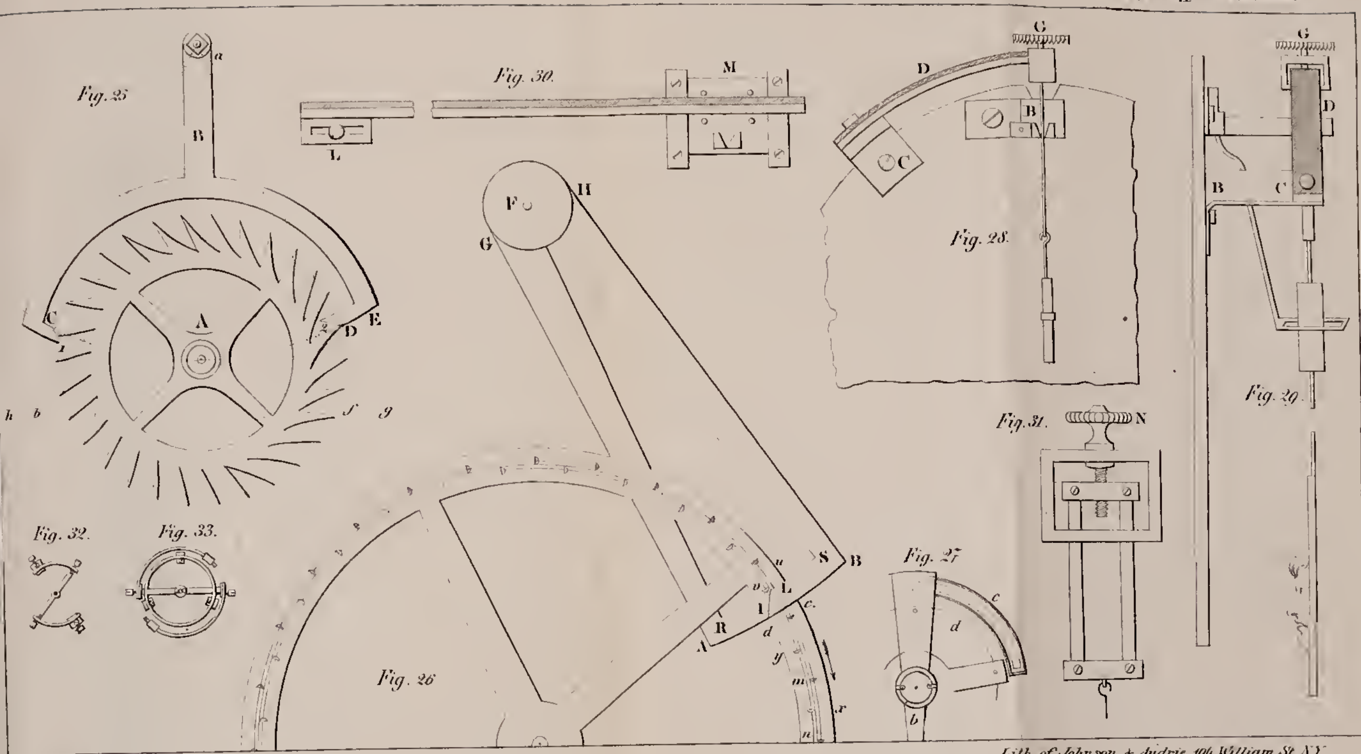
John Wiley, 56 Walker St.
Lith. of Johnson & Andre, 104 William St. N.Y.

Plate IV Continued.



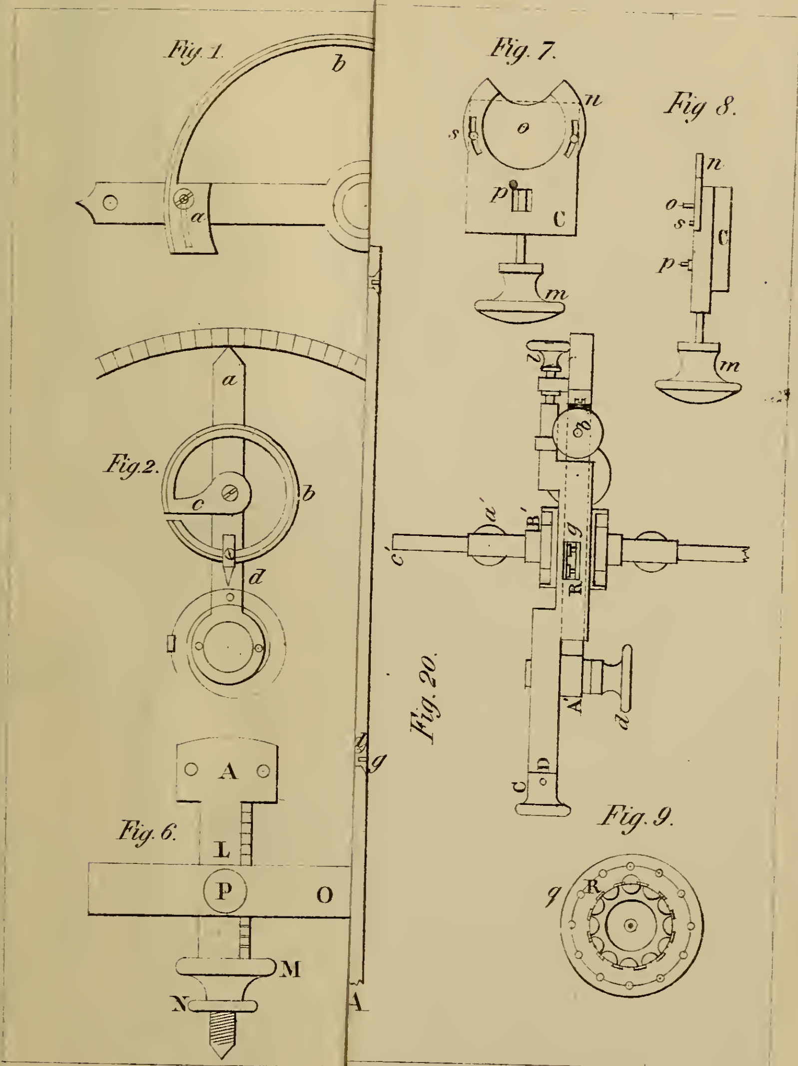
John Wiley, 56 Walker S h. of Johnson & Andrie, 104 William St. N.Y.

Plate IV Continued.



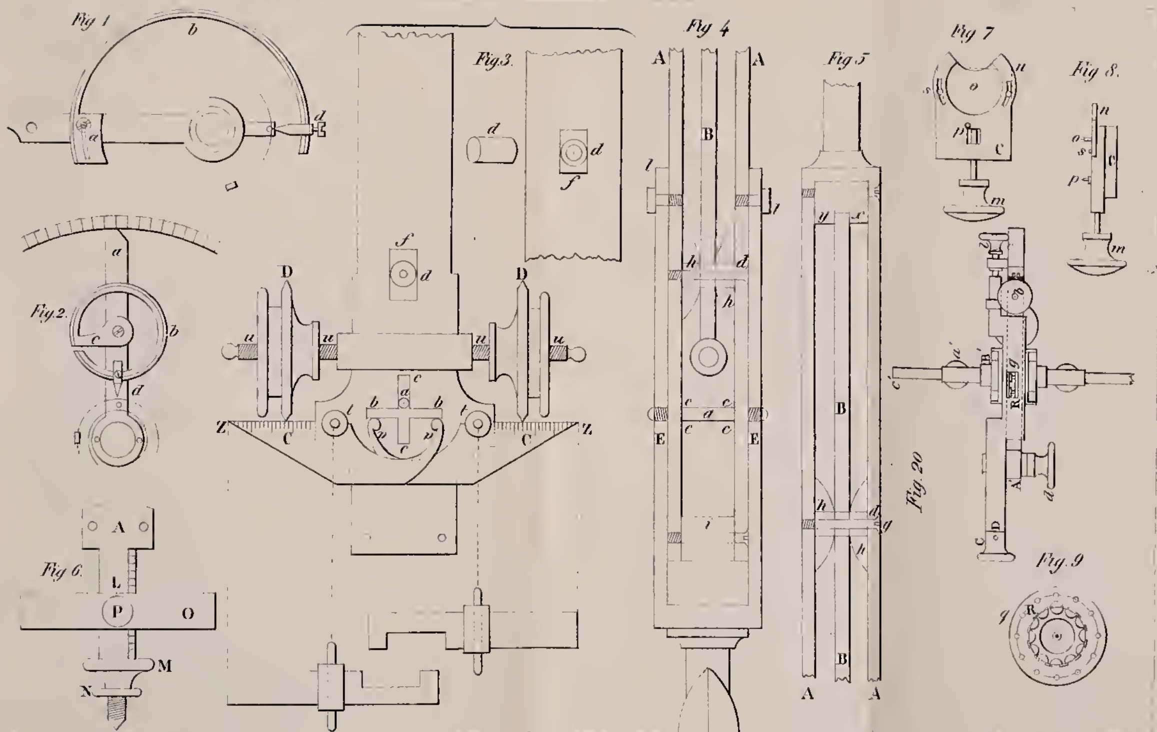
John Wiley, 56 Walker St
Lith. of Johnson & Andrie, 104 William St N.Y

Plate V.



John Wiley, 56 Walker St. Johnson & Andrie, 104 William St. N.Y.

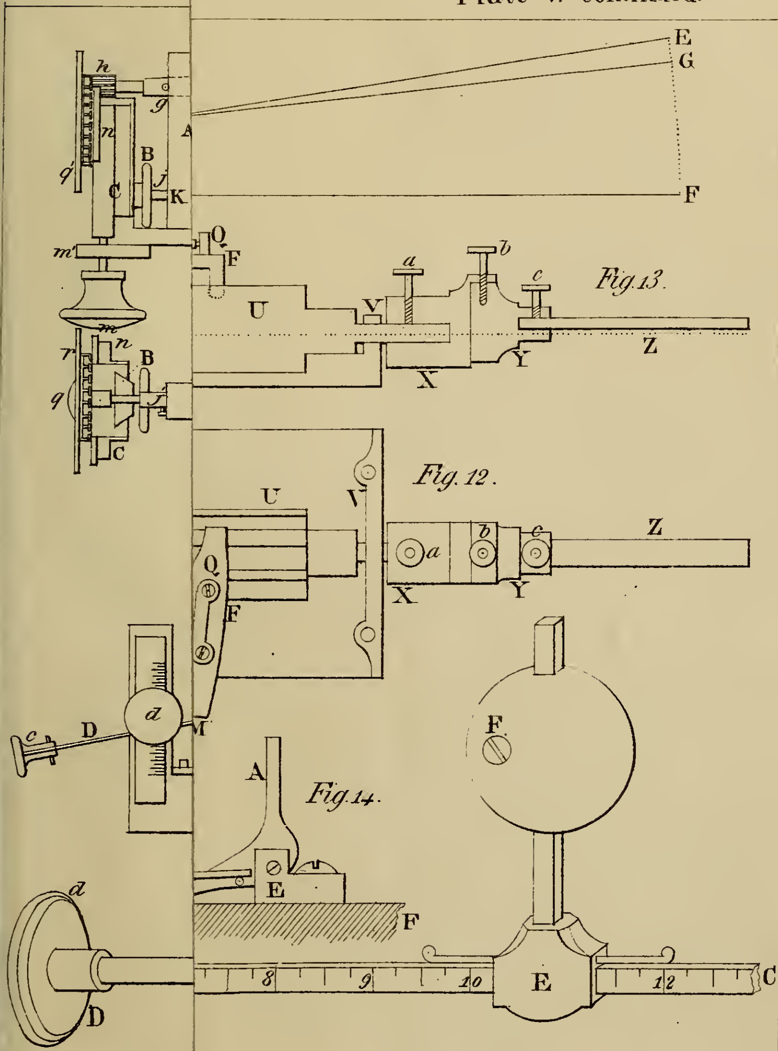
Plate V



John Wiley, 56 Walker St.

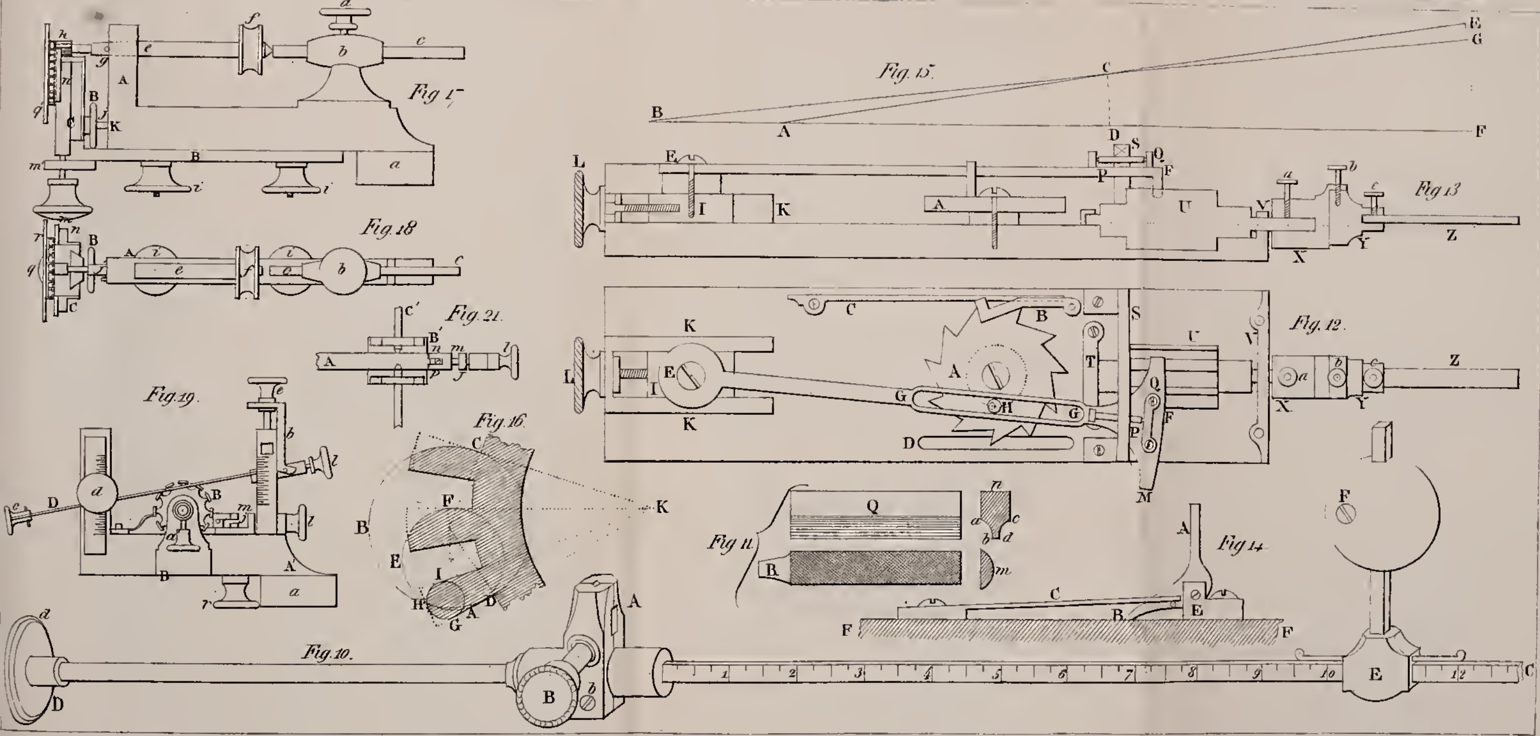
Lith of Johnson & Andrie, 104 William St N.Y.

Plate V. Continued.



John Wiley, 56 Lith. of Johnson & Andrie, 104 William St. N.Y.

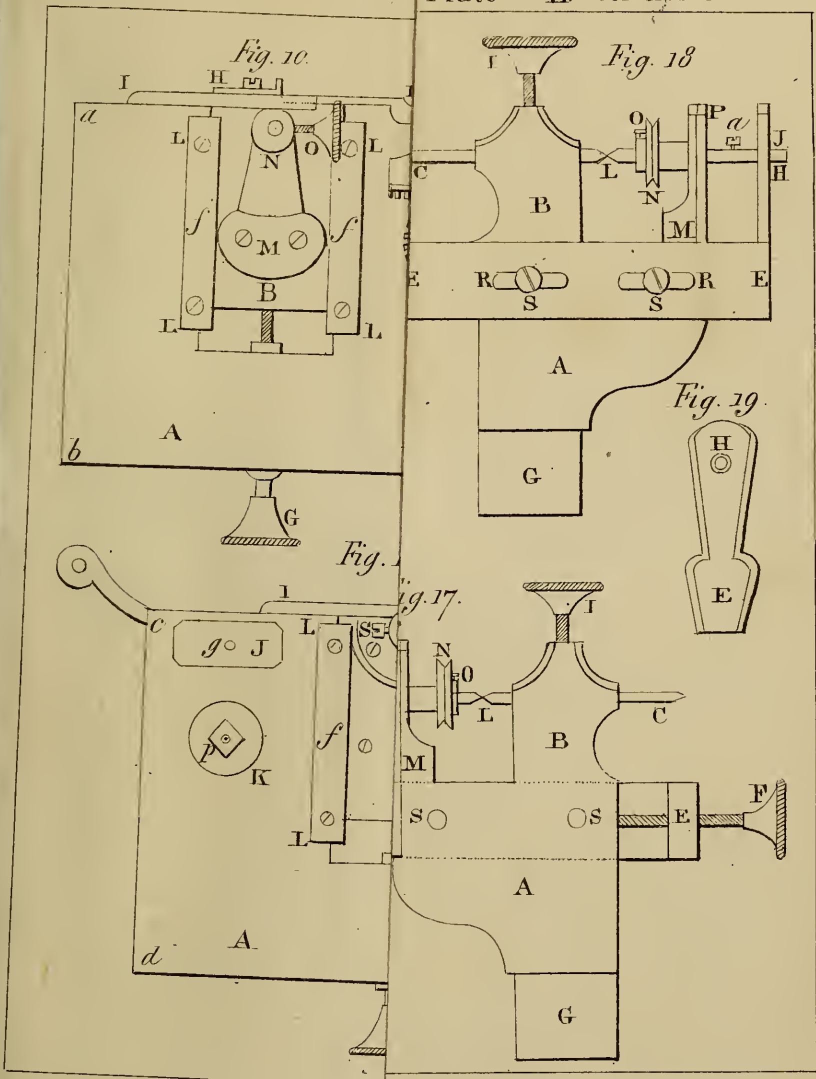
Plate V Continued.



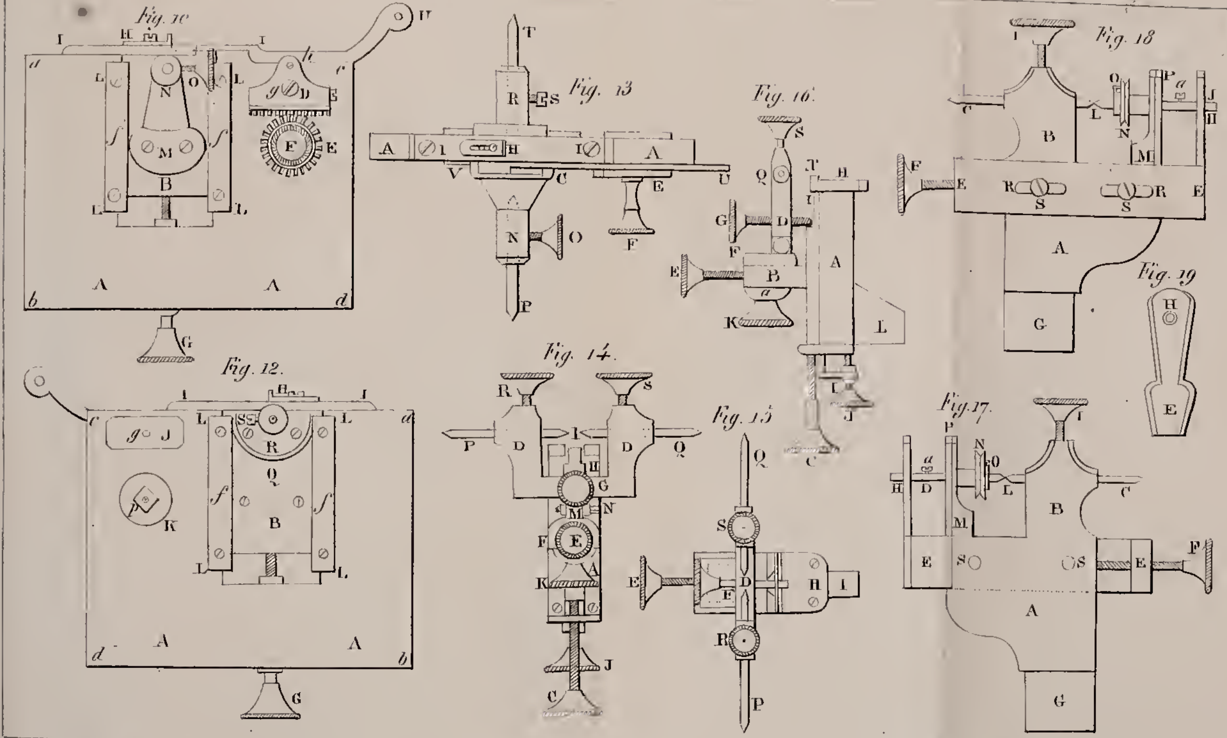
John Wiley, 56 Walker St.

Lith. of Johnson & Andrie, 104 William St. N.Y.

Plate VI. Continued.



John Wiley, 56 Walker St.



John Wiley, 56 Walker St.

Plate VI.

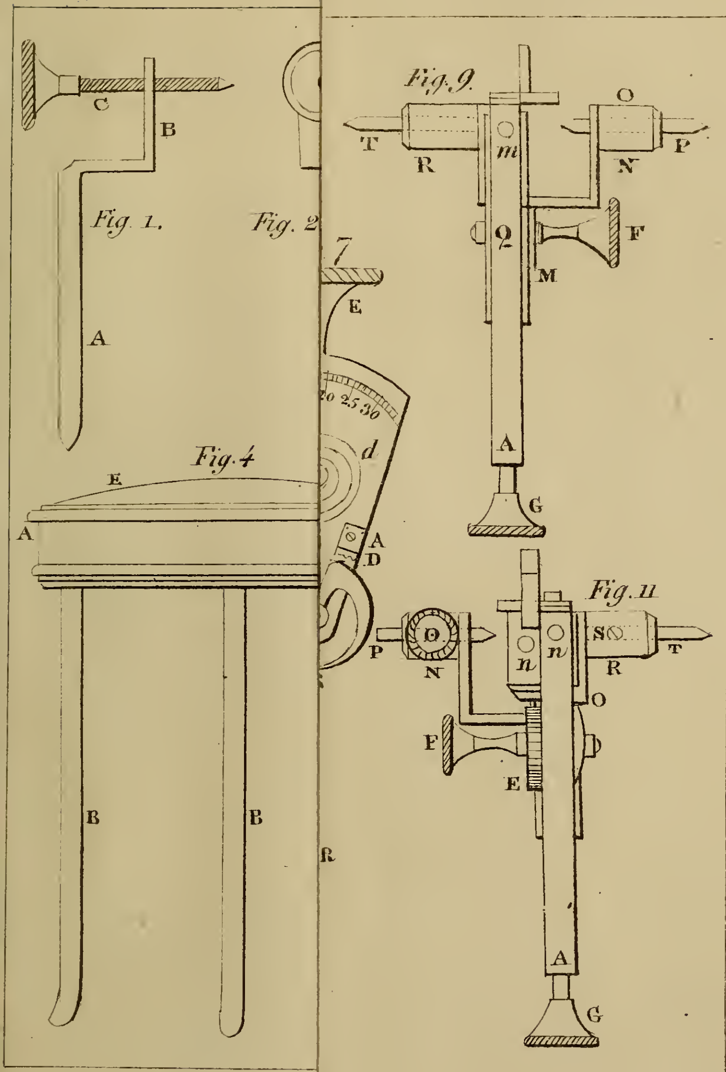
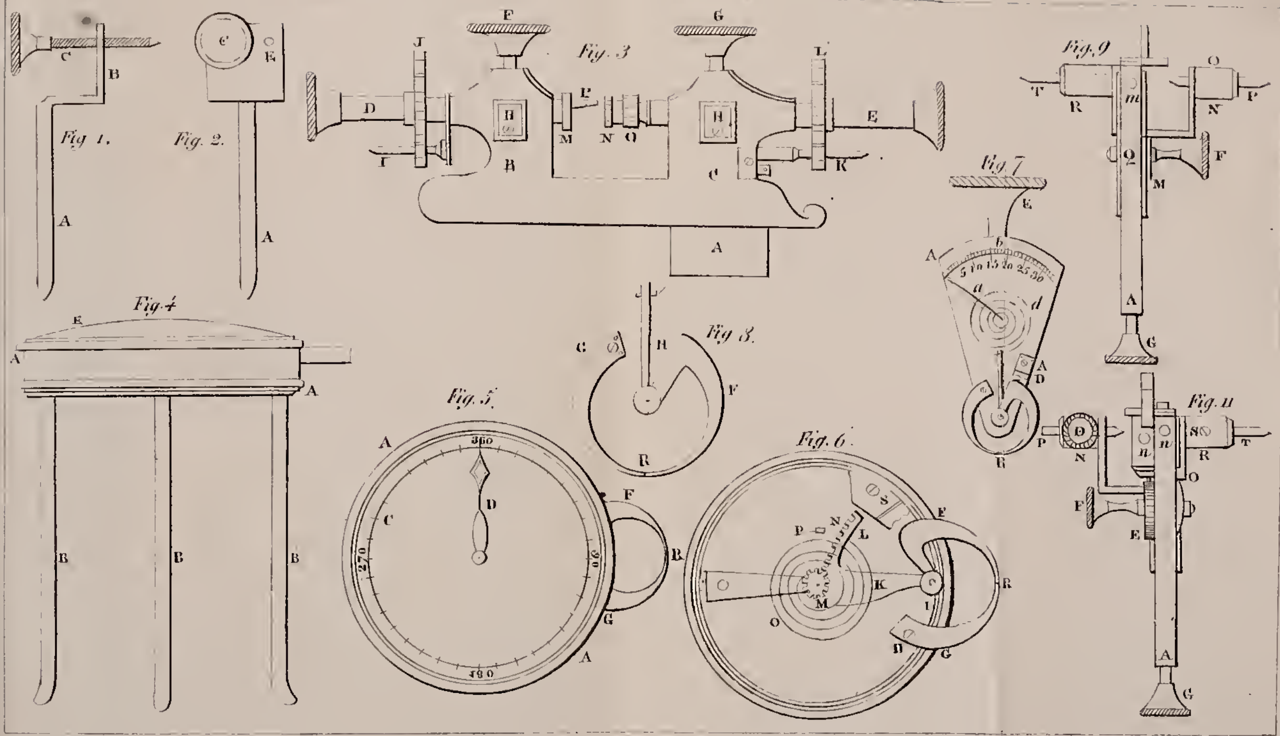


Plate VI



NORTON. TREATISE ON ASTRONOMY. In Four Parts. Containing a Systematic and Comprehensive Exposition of the Theory, and the more important Practical Problems; with Solar and Lunar Tables. Designed as a Text-book for Schools and higher Academies. A new stereotyped edition, enlarged, with wood-cuts and large steel plates. 8vo Sheep 2 00

"A monument of industry and learning, and it affords us pleasure to state that it has made its way into some of the oldest colleges in the country."

NORDHEIMER (DR. ISAAC.) HEBREW GRAMMAR. New and revised edition. 1 vol. 8vo. Cloth. (*Shortly*) 2 50

NORDHEIMER (DR. ISAAC.) CHRESTOMATHY; or, a Grammatical Analysis of Selections from the Hebrew Scriptures, with an Exercise in Hebrew Composition. 8vo. half bound 1 25

JONES'S BOOK-KEEPING AND ACCOUNTANTSHIP, Elementary and Practical In Two Parts, with a Key for Teachers. The elementary part presenting its principles in an easy, clear, and demonstrative order, in strict conformity to the recognised principles of teaching, as manifested in our most popular school-books. The whole being adapted to Schools, Self-Instruction, or Counting-House Reference. By Thomas Jones, Accountant, Principal of the Initiatory Counting-Room, 247, Broadway. 8vo. Cloth 2 00

JONES. The same. Two Parts, without the Key. 8vo. Half-roan . . 1 00

JONES The same. School Edition. 8vo. Half-bound . 75

RUSKIN'S WORKS, &c.

RUSKIN (JOHN.) MODERN PAINTERS. By a Graduate of Oxford. 2 vols. 12mo. Cloth 1 87

"A very extraordinary and delightful book, full of truth and goodness, of power and beauty."—*North British Review.*

"One of the most remarkable works on art which has appeared in our time."—*Edinburgh Review.*

RUSKIN (JOHN.) MODERN PAINTERS. Vol. III. 12mo., with numerous fine plates and cuts. Cloth 2 50

RUSKIN (JOHN.) THE SEVEN LAMPS OF ARCHITECTURE. By the author of "Modern Painters." 1 vol. 12mo., with fourteen Etchings by the author . . 1 25

"The brilliant manner in which the present and other works of Mr. Ruskin are adorned, has placed them at once among the books that *must* be read."—*North British Review.*

RUSKIN (JOHN.) THE STONES OF VENICE. The Foundations. By the author of "Seven Lamps of Architecture," &c. 1 vol. 8vo. Illustrated by twenty-one plates and numerous woodcuts from Drawings by the author 3 50

"No one who has studied art in Venice will go through this book without such pleasure as belongs to a revival of some of his warmest admirations, and the refreshment of his most delicious associations. It is full of fine things, and of true things."—*Athenæum.*

RUSKIN (JOHN.) PRE-RAPHAELITISM. By the author of "Modern Painters." 12mo. Paper covers 18¾

"We wish that this pamphlet might be largely read by our Art-Patrons, and studied by our Art-Critics. There is much to be collected from it which is very important to remember."—*Guardian.*

RUSKIN (JOHN.) NOTES ON THE CONSTRUCTION OF SHEEPFOLDS. By the author of "Seven Lamps of Architecture." 8vo. Paper cover 12½

RUSKIN (JOHN.) LECTURES ON ARCHITECTURE AND PAINTING. Delivered at Edinburgh in November, 1853. By John Ruskin, author of "Stones of Venice," "Seven Lamps of Architecture," &c 1 vol 12mo., with fifteen illustrations, on tinted paper, after Drawings by the Author. Cloth 25

HAND-BOOK OF OIL-PAINTING. HANDBOOK OF YOUNG ARTISTS AND AMATEURS IN OIL-PAINTING—being chiefly a condensed compilation from the celebrated Manual of Bouvier, with additional matter selected from the labors of Merriwell, De Montabert, and other distinguished Continental Writers in the Art, in Seven Parts; adapted for a Text-book in Academies of both Sexes, as well as for Self-Instruction. Appended—a new Explanatory and Critical Vocabulary. By an American Artist. 12mo. Cloth 1 25

"It discusses the whole subject of Oil-Painting in minute detail, and with a precision and accuracy of definition which cannot fail to make it of universal utility."

CHEEVER'S WORKS, &c.

CHEEVER (REV. GEORGE B.) WANDERINGS OF A PILGRIM IN THE ALPS. Part I.—In the Shadow of Mont Blanc. Part II.—In the Shadow of the Jungfrau Alps. In 1 vol. Cloth 1 00

CHEEVER (REV. GEORGE B.) THE JOURNAL OF THE PILGRIMS AT PLYMOUTH, IN 1620. Reprinted from the Original Volume; with Historical and Local Illustrations of Providences, Principles, and Persons. 1 vol. 12mo., uniform with the above. Cloth 1 0

CHEEVER (REV. GEORGE B.) The same. Cloth gilt 1 50

CHEEVER (REV. GEORGE B.) A DEFENCE OF CAPITAL PUNISHMENT. New edition. 1 vol. 12mo. Cloth, uniform with the above 50

CHEEVER (REV. GEORGE B.) THE HILL DIFFICULTY, and some Experiences of Life in the Plains of Ease. With other Miscellanies. Part 1.—Allegorical and Imaginative. Part 2.—Descriptive and Meditative. Part 3.—Critical and Speculative. 1 vol. 12mo. Cloth, with Steel Portrait of the Author 1 00

CHEEVER (REV. GEORGE B.) The same. Cloth, extra 1 50

CHEEVER (REV. GEORGE B.) WINDINGS OF THE WATERS OF THE RIVER OF LIFE, in the Development, Discipline, and Fruits of Faith 1 00

CHEEVER (REV. GEORGE B.) The same. Cloth, extra 1 50

"There is an exuberance of fancy, a peculiar glow, in the language of Dr. Cheever, which gives a charm to his written productions possessed by few."—*Com. Adv.*

ALEXANDER (PROF. J. A.) ON THE PROPHECIES OF ISAIAH. 2 vols. royal 8vo. Cloth. New and revised edition. (*Shortly*) 4 00

ALEXANDER (PROF. J. A.) ISAIAH ILLUSTRATED AND EXPLAINED. An Abridgment of the Author's Critical Commentary on Isaiah. 2 vols. 12mo. Full cloth 2 50

"A rich contribution of philological exposition for the use of the clergy."—*Presbyterian.*

ATHEISTS—VOLTAIRE AND ROUSSEAU AGAINST THEM; or, Essays and Detached Passages from those writers, in relation to the Being and Attributes of God. Selected and Translated by J. Akerly. 12mo. Cloth 50

BEECHER (REV. EDWARD, D.D.) BAPTISM; with reference to its Import and Modes. 1 vol. 12mo. Cloth 1 25

BIBLIOTHECA SACRA AND THEOLOGICAL REVIEW. Conducted by Profs Park, Taylor, Robinson, etc. Published quarterly. Per annum . . 4 00

BUSH (PROF. GEO.) ANASTASIS ON THE DOCTRINE OF THE BODY NATURAL AND SCRIPTURALLY CONSIDERED. Second edition. 1 vol. 12mo. Cloth 1 00

HEIGHWAY (O. T.) LEILA ADA, THE JEWISH CONVERT. An authentic Memoir. Including also her Diary. By O. T. Heighway. 1 vol. 18mo. Cloth. Second edition 60

"One of the most touching and remarkable portraitures we ever read."—*New York Evangelist.*

HEIGHWAY (O. T.) THE RELATIVES OF LEILA ADA. With some Account of the Present Persecutions of the Jews. 1 vol. small 12mo. Cloth 50

PRINCETON ESSAYS, THEOLOGICAL AND MISCELLANEOUS. Reprinted from the Princeton Review (including the Contributions of the late Rev. Albert B. Dod). Second Series. 8vo. Cloth 2 50

PRINCETON ESSAYS, THEOLOGICAL AND MISCELLANEOUS. First Series. London edition. 8vo. 3 00

ROBINSON (REV. DR.) BIBLIOTHECA SACRA. Tracts and Essays on Topics connected with Biblical Literature and Theology. Complete in 1 vol. 8vo. Cloth . 3 00

ROBINSON (REV DR.) The same. Separate numbers, each 1 00

DOWNING'S WORKS, &c.

DOWNING (A. J.) COTTAGE RESIDENCES; or, a Series of Designs for Rural Cottages and Cottage Villas, and their Gardens and Grounds, adapted to North America. Illustrated by numerous engravings. Third edition. 8vo. Cloth 2 00

"Here are pleasant precepts suited to every scale of fortune among us; and general maxims which may be studied with almost equal profit by the householder in the crowded city, and the man of taste who retires with a full purse, to embody his own ideas of a rural home."

DOWNING (A. J.) LINDLEY'S HORTICULTURE. With additions. 1 vol 12mo. 1 50

DOWNING (A. J.) THE FRUITS AMD FRUIT TREES OF AMERICA; or, the Culture, Propagation, and Management, in the Garden and Orchard, of Fruit Trees generally; with Descriptions of the Finest Varieties of Fruits, Native and Foreign, cultivated in this country. Tenth edition, revised. 12mo. Cloth . . 1 50

DOWNING (A. J.) The same. New edition. 1 vol. 8vo. Uniform with other works. Cloth. In preparation 2 50

DOWNING (A. J.) The same. New edition. With about 80 specimens choice Fruit, most elegantly and accurately colored. 1 vol. 8vo. Half morocco, gilt top. In preparation 15 00

"For clearness and perspicuity, this work is unequalled by any extant, evincing an amount of personal experience and extensive research which nothing but the most careful and close investigation could attain."—*N. E. Far.*

"An invaluable vade-mecum in the fruit department."—*Christ. Intelligencer.*

DOWNING (A. J.) LOUDON'S GARDENING FOR LADIES, and Companion to the Flower Garden. By Mrs. Loudon. 12mo. Cloth 1 25

DOWNING (A. J.) WIGHTWICK'S HINTS TO YOUNG ARCHITECTS. Calculated to facilitate their practical operation; with additional Notes, and Hints to Persons about Building in the Country. 8vo. Cloth 1 50

J. W. also supplies

DOWNING (A. J.) LANDSCAPE GARDENING. 1 vol. 8vo. . . . 3 50

DOWNING (A. J.) COUNTRY HOUSES. 1 vol. 8vo. 4 00

DOWNING (A. J.) RURAL ESSAYS. 1 vol. 8vo. . . 3 00

LIEBIG'S WORKS, &c.

LIEBIG'S AGRICULTURAL CHEMISTRY. CHEMISTRY IN ITS APPLICATIONS TO AGRICULTURE AND PHYSIOLOGY. By Justus Liebig. Edited from his MSS. by Playfair and Gregory. From the 4th London edition. 12mo. Cloth 1 00

LIEBIG'S PRINCIPLES OF AGRICULTURAL CHEMISTRY. With special reference to the late researches made in England. 1 vol. 12mo. Cloth . . 50

LIEBIG'S PRINCIPLES OF AGRICULTURAL CHEMISTRY. ANIMAL CHEMISTRY; or, Chemistry in its Applications to Physiology and Pathology. Edited from the author's Manuscript, by William Gregory, M.D., F.R.S.E., etc. From the 3d London edition. Revised and greatly enlarged. Part I., containing the Chemical Process of Respiration and Nutrition. 12mo. 50

PARSONS. THE ROSE: its History, Poetry, Culture, and Classification, with two large colored Plates, and other engravings. In 1 vol. 12mo. Cloth. New edition with additions . . . .

CLAUSSEN. THE FLAX MOVEMENT—its National Importance and Advantages: with Directions for the Preparation of Flax Cotton and the Cultivation of Flax By the Chevalier Claussen. 12mo. . . . .

SMEE. ELEMENTS OF ELECTRO-METALLURGY. From the Third London edition. Revised, corrected, and considerably enlarged. Illustrated with Electrotypes and numerous woodcuts. 1 vol. 12mo. 1 25

VALUABLE WORKS FOR DISTRICT SCHOOL LIBRARIES, &c

KNIGHT. HALF HOURS WITH THE BEST AUTHORS. Consisting of 365 Selections from the most distinguished Writers of the last three centuries. With short Biographical and Critical Notices by Charles Knight. 4 vols. 12mo., each about 600 pages. Full cloth, extra 4 50

WILLIAMS. THE CHINESE EMPIRE AND ITS INHABITANTS—The Middle Kingdom. A Survey of the Geography, Government, Education, Social Life, Arts, Religion, etc. With a new Map of the Empire, and many illustrations. 2 vols. 12mo. Blue cloth 3 00

LYELL (CHAS., F.R.S.) TRAVELS IN NORTH AMERICA IN THE YEARS 1841-42 With Geological Observations on the United States, Canada, and Nova Scotia. 2 vols 12mo. 1 50