rectilinear, afford an approximating solution of the problem. They are sometimes adopted in the construction of steam engines.

In the figure S 7′, n m is the crank of an axle n, which receives its circular motion from the first mover, D is a bar attached to the extremity p of the piston rod of a pump, and which will then traverse on the line b b a distance which approximates to twice that of the crank arm n m. The lengths of the arms B and C, and the position of the centre of rotation F, is arbitrary. The bar C is placed in the three positions F t, F q, and F r, which it will occupy at the middle and the extremities of the course described by the point d of the arm D; this will determine q, r, and s for the points of opposition which the other end of the bar B will have at the same time; if a circle be described through these points, its radius will be the length of the arm A, and its centre, the point of rotation. A few repeated trials will be found to afford results sufficiently accurate for practice.

In the figure T 7′ are also given the lengths of the arms E I H, and the point of rotation F; the points n, m, and r are determined as in the last example; and the radius and centre of the circle which passes through them, respectively give the length of the arm L, and the situation of K its centre of rotation.

SECTION. VIII.

To convert a given direct and equable circular motion, or the velocity of which varies by a given law, into direct circular motion, of velocity similar to that of the moving power, either equable, or variable by a given law, and in the same, or in different planes.

A 8.

THE two toothed wheels A and B act on each other in the usual manner; the direct circular motion of the one, is communicated to the other, which is situated in the same plane, but the direction of the communicated motion is of course in this instance, contrary to that of the mover; if a motion be required in the same direction, a third wheel C must be added to the arrangement: the ratio of the velocities will be determined by that of the diameters. If n be supposed to represent the radius of the wheel A, and n′ that of the wheel B, and if n and n′ are whole and prime numbers, the two wheels A and B will after certain revolutions, resume the same relative positions, if the number of revolutions of the wheel A be equal to n′, and those of the wheel B be equal to n. A very ingenious and practical application of this property of circles of unequal radii has been made by M. Breguet, the younger, in the construction of watches, in the following manner:—the fusee is laid aside in this description of watches, and the barrel or cylinder A, (see figure 5, plate 12.) which encloses the spring, has a toothed wheel α β, by which the action of the spring is transmitted to the pinion of the first wheel in the train; the spring is attached by one of its extremities to the axis r d, and by the other to the interior concave surface of the barrel; the length of the spring is such that supposing it entirely released, the axis r d may make twelve revolutions to bring it up to its maximum of tension; in general, the mean tension of the spring is that which is employed, that is to say, the tension produced by four mean revolutions of the axis; the ratchet wheel λ is applied to prevent the arbor from turning in the contrary direction to that in which the barrel is impelled by the spring; and finally, the advantage of suppressing the fusee results from the principle of the escapement itself: the inequality of the action of the spring being compensated by the unequal action exerted on the escapement during its repose. This being understood, the inventor has set a toothed wheel B upon the axis r d, acting on a second wheel C, which is fitted easily upon a cylindrical stud or pin which stands upon the upper face of the barrel, a broad and flat-headed screw is tapped into the upper end of the cylindrical pin, and thus secures the wheel C; the diameters of the wheels B and C, are respectively as five and four, the wheel B must therefore make four revolutions, and the wheel C five revolutions, in order that the same teeth of those wheels shall be in contact and their positions be relatively the same as at the commencement of the movement; if the wheel B does not move, which is the case when the barrel is in action, the wheel C will make four revolutions about the wheel B, in order to arrive at its point of commencement: it will in that course have made five revolutions about its own axis, and the same teeth will again be brought into contact with each other. Now if the spring contained in the barrel is compleatly relaxed, and that we cause the axis d r, and consequently the wheel B to make eight revolutions in the direction indicated by the dart in the figure, we shall then obtain the maximum action of the spring; it will act to impede any farther revolution of the axis r d; we will suppose the lower figure represented in the plate to exhibit in plano, the relative position of the wheels B and C at that moment; if the distance d e be divided into two equal parts in i, and the semicircle d f e be described on that point, it is evident that in order to produce the intended effect to the greatest possible advantage, the stops should fall into contact in some part of the semicircle d f e; but when the motion of the wheel B ceases, the wheel C is made to commence its motion by the action of the barrel, and imagining the diameters of C and B to be respectively represented by n' and n, C cannot return to its first position after n' revolutions about B, because it will previously fall in contact with the stops, in whatever part of the semicircular arc the point of contact may be determined; but it will meet them under different angles: this therefore does not produce the end required. It is a necessary condition that the stops shall fall in contact at right angles before the wheel C shall have compleated the number of revolutions represented by n', about the wheel B. Let f be the required position—it is necessary that the arc a b should be equal to the arc a c, for if the barrel be turned in the contrary direction to that indicated by the dart, the point b will fall in contact with the point C, and when the centre e of the wheel C arrives at g, the angle d e f will equal the angle d g f; and consequently the conditions will be answered: a l is the fourth part of the periphery of B, and a k is the fourth part of the periphery of C; we have therefore

$$a\,h = a\,k = a\,l\,\tfrac{n'}{n},$$

and if we make $a\,h = a\,l\,\tfrac{n}{n}$, and draw through the point h the line d g equal to d e, and from the point d draw the line d f perpendicular to g e, the intersection of that perpendicular gives the position of the point f, in which the stops p and q must be in contact whatever be the ratio of the diameters of the wheels B and C; in this instance we shall have $a\,h = a\,l\,\tfrac{4}{5}$, or the angle g d e = 72 degrees. The position of the point f being thus determined the two stops p and q will be placed as in the figure. The centre of the wheel C will arrive at the point g before it will have completed the number of revolutions represented by n′, and the action of the watch will be stopped: in order to wind it up, the wheel B must be turned in the direction indicated by the dart; the wheel C will revolve on its axis in the contrary direction, and the stop p will be checked by q, as at the commencement of the action.

In watches of this description there is no exterior indication by which the state of the spring may be known, and they are consequently much exposed to the inconvenience of being unexpectedly stopped, as well as improperly wound up. M. Breguet, the elder, has contrived the following method of exhibiting the required indication:—A screw m n is cut upon the axis r d, and the broad nut s t with bevelled edges, is fitted upon it, one or more arms u project from the upper surface of the barrel, passing through the nut s t and allowing it a free vertical motion. Now when the watch is wound up, the screw is turned, but is not at liberty to alter its vertical position, and since the nut s t cannot revolve horizontally on account of the arms u, which pass through and hold it, it will be compelled to rise vertically, that is to say, on the axis r d, as we have already shewn in our explanation of the action of the nut and screw in the article C 3; but while the watch is in action it is the nut which turns, and it then traverses the same space in an opposite direction; from this there results an alternate rectilinear motion, which is then converted into alternate circular motion by the application of a bent lever a′, b′, c′, d′, whose arms are placed at right angles to each other; the smaller arm c′ d′ of this lever rests upon the bevelled edge of the nut s t; and the longer arm a′ b′ carries to the exterior of the watch an accurate indication of the state of tension of the spring; and this is exhibited on the dial plate by an arc of suitable dimensions.

If the three wheels A, B, and C are of the same diameter, during the time in which A makes one revolution in the direction pointed out by the dart, the second wheel B will make one revolution in the opposite direction, and the third wheel C will also make one revolution, but in the same direction.

We will now suppose the wheel A to be fixed, and the wheels B and C to be attached to the wheel A by a bar or arm—it is evident that if the arm be made to turn about the centre of the wheel A, when it has completed one revolution, the two wheels B and C, will also have made one revolution, as in the preceding case with respect to the wheel A; for the relative effect will be the same, whether the first wheel A makes one revolution on its axis, or the second and third wheels make a revolution on that point; but in the second case the wheels B and C will participate in the rotatory motion of the arm, an effect which does not take place in the first case. It follows that the wheel B, whose rotation on its axis takes place in the same direction as that of the arm, will have made two turns or revolutions with respect to the distance, but the rotatory movement of the wheel C about its axis is made in an opposite direction; and consequently by the operation of the moveable arm, it will have traversed the circle which the arm describes in its motion about the axis of the wheel A; but it has no movement of rotation on its own axis, and consequently any lines which may be described on its surface in whatever position or direction, will preserve a constant parallelism among themselves.

This arrangement is often applied to the mechanism by which we illustrate the constant parallelism of the earth's axis in its motion through the annual orbit.

The machinery generally used in the manufactories of porcelain, for the purposes of pounding the materials, and reducing them to the impalpable state in which they are required for the subsequent processes, consists, as is familiarly known, of a large horizontal wheel, which is turned either by the application of animal labour, or the action of water; this wheel drives four or six pinions, the axes of which descend vertically, and each is immersed in a circular trough or vessel A A A A, (see the plan of fig. 6, plate 12, and the elevation No. 1.); at the bottom of each vessel is fitted a slab of stone which exactly fills the space. A second stone D, is placed upon the first—this is also circular, and its diameter is somewhat more than the radius of the lower stone C; the upper stone D performs the action of a muller: it is fixed on or held to the lower end of the pinion by a cramp-iron e d, b c; plates or slabs of porcelain are sometimes substituted for these stones, in which case the upper plate D is surcharged or loaded with some heavier body. The earths and materials which are to be subjected to the operation of the machine are placed in the troughs, which are then filled up