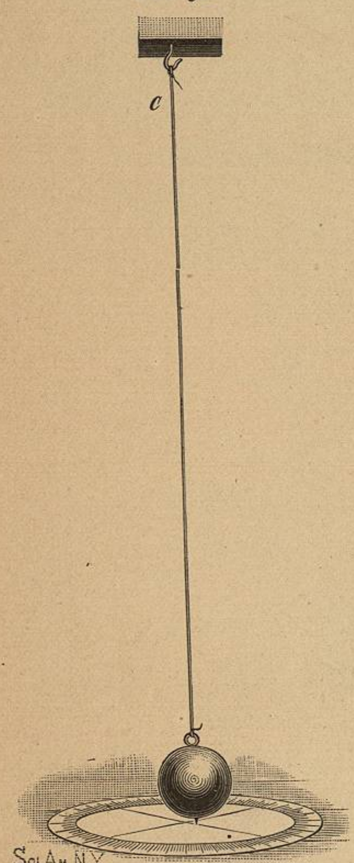
excursion. The distance through which the suspended weight travels in one swing is the amplitude of the pendulum. Galileo's discovery of the law of the pendulum in 1582 is a matter of common knowledge. He observed the regularity of the swinging of a lamp suspended from the roof of the cathedral of Pisa, and noticed that, whatever the arc of vibration, the time of vibration remained the same. He also determined the law of the lengths of pendulums by experiment. He found that, as the length of the pendulum increased, the time of vibration increased, not in proportion to the length, but in proportion to its square root. For example, while in New York it requires a pendulum 39·1012 inches long to beat seconds, the length for two seconds would be 156·4048 in. The length of a pendulum for any required time is found by multiplying the length of a seconds pendulum in inches by the square of the time the pendulum is to measure. In the above example, 39·1012 inches is the length of the seconds pendulum. Two seconds is the time to be measured. $2^2 = 4$. Therefore $39{\cdot}1012 \times 4 = 156{\cdot}4048$, the length of the two seconds pendulum. It is found that, barring the resistance of the air, all materials act alike when used for the weight of a pendulum. This is one proof of the uniformity of the action of gravitation on all substances.

Fig. 32.



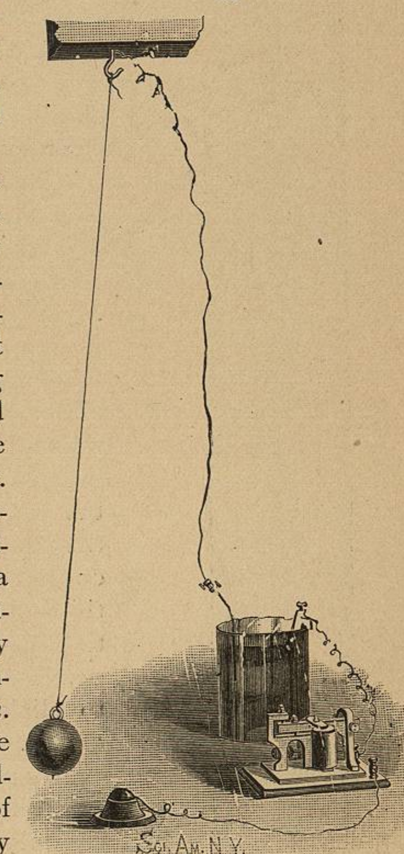
Foucault's Experiment.

In Fig. 31, at B, is shown a conical pendulum. It differs

from the pendulum A only in the manner in which it is used; whereas the pendulum A is made to swing to and fro in a vertical plane, the pendulum B is started in a circle, as indicated by the dotted line. It is found by comparison that the pendulum B completes its circular travel in the same time that pendulum A requires to complete one to-and-fro vibration. The conical pendulum derives its name from the figure it cuts in the air.

The pendulum has been used to determine the figure of the earth, also to show the earth's rotation. Foucault's celebrated experiment at the Pantheon at Paris consisted in vibrating a pendulum having a period of several seconds over the face of a horizontal scale. While the pendulum preserved the plane of its oscillation, the scale indicated a slow rotation. This experiment may be repeated easily on a small scale in the manner illustrated in Fig. 32. The ball, which must be a heavy one, is suspended by a very fine wire of considerable length, say from forty to fifty feet. It must be started very carefully to secure the desired result. To start it, a fine wire is tied around the equator of the ball. To this wire is attached a stout thread, by means of which the ball is drawn one side and held there until the pendulum is perfectly quiescent. The pendulum is then released by burning the thread.

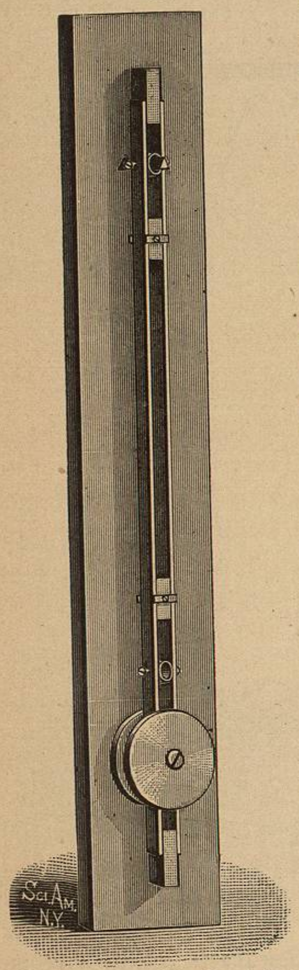
Fig. 33.



Pendulum with Audible Beats.

In the course of a few minutes there will appear to be a slight change of its plane of vibration. The case is like that of the gyroscope already described. The plane of vibration remains really constant, but the rotation of the earth causes an apparent twisting of the plane. If the experiment be performed in the United States, and the plane of vibration be north and south at first, the northern limit will soon swing toward the right, as viewed from the south.

Fig. 34.



Kater's Reversible Pendulum.

A pendulum capable of producing audible beats is often desirable. Fig. 33 shows a simple, well known arrangement for producing audible beats by the aid of a telegraph sounder. The ball, in this case, is suspended by a fine wire. The under side of the ball is provided with a platinum point. A mercury globule is held by an iron cup in the path of the platinum point, and the pendulum, mercury, and sounder are in the battery circuit. By this arrangement an electrical contact is made for each swing of the pendulum, and the sounder is made to click each time the circuit is closed.

By means of Kater's reversible pendulum, the length of a simple pendulum having the same time of oscillation as the compound pendulum may be accurately determined.

In Fig. 34 is shown a slightly modified form of this pendulum, in which the rod is formed of two parallel bars of wood, separated by blocks at the ends and provided with two swiveled cylindric rings, between which are placed two adjustable lead weights, held in place by crossbars secured to the weights by screws, and extending over the edges of the wooden bars. Below the lower swiveled ring are clamped lead weights, one upon either side of the bar, with a screw extending through one weight into the other. These weights are cheaply made by casting lead in small blacking box covers.

This pendulum is suspended upon a knife edge projecting from a suitable support, and the weights between the bars are adjusted until the time of vibration is the same for either position of the pendulum, it being reversed and oscillated first upon one of its rings as a center, then upon the other, until the desired adjustment is secured. Then the distance between the bearing surfaces of the rings will be the length of a simple pendulum which would vibrate in the same time as the compound pendulum.

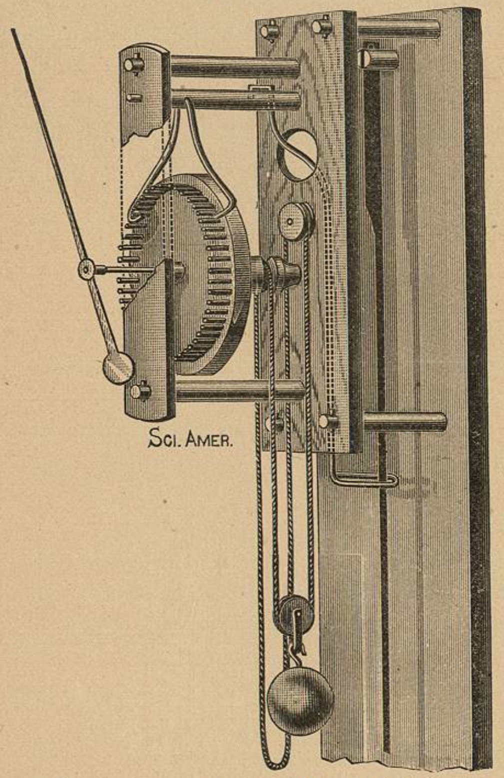
MEASUREMENT OF TIME BY THE PENDULUM.

The application of the pendulum to the measurement of time dates from 1658. In that year Huyghens applied it to clocks. Singularly enough, this has proved to be the only practical use of any importance to which the pendulum could be adapted. The fact that millions of clocks have been made which depend on the pendulum for regulation proves the great value of Huyghens' invention.

A simple model, showing the application of the pendulum to clocks, is illustrated in Fig. 35. It is readily made, and serves to show how the pendulum acts in the regulation of a clock, and is useful for measuring seconds in experimental work. The frame is made entirely of hard wood. The three parallel plates are connected by wooden studs. The wooden arbor of the scape wheel is provided with steel wire pivots, the outer one being prolonged beyond the front plate to receive the second hand. The scape wheel consists of a disk of wood about three inches in diameter, provided with a circular row of steel pins, uniformly spaced and projecting from the face of the disk parallel with the arbor. With a disk of the size given thirty pins will be sufficient, with a larger disk sixty pins may be used.

Above the scape wheel arbor there is a wooden roller furnished with steel wire pivots. In the roller is inserted a steel wire forming the escapement or crutch, the ends of the wire being bent inward to form pallets which engage the scape wheel pins in alternation. The rubbing surfaces of the pallets are flattened and polished and the ends are beveled. In the roller is inserted a wire which extends down-

FIG. 35.



Application of the Pendulum to Clocks.

ward obliquely through a hole in the middle plate, and is finally bent into an oblong loop extending rearward. In a split stud in the back piece is inserted the flattened upper end of the pendulum rod. A small rivet passes through the upper extremity of the rod, and prevents it from slipping through the split stud. The rod passes through the

oblong loop above referred to, and is provided on its lower end with an adjustable weight of $1\frac{1}{2}$ to 2 pounds.

The scape wheel arbor is provided with a circumferential V-shaped groove forming a very small pulley for receiving the driving cord. Upon the middle plate above the arbor is fixed a circular block having a deep V-shaped circumferential groove for receiving and holding the endless driving cord, which passes round the arbor and grooved block as shown, and also passes around the pulley block attached to the weight. It is necessary to have the V-shaped grooves very deep and very narrow to enable them to pinch the driving cord. To insure uniformity in the action of the cord and weight, it is advisable to place in the second loop of the cord a pulley and connect with it a very light weight. When the driving weight has nearly run down, the cord may be pulled upward over the grooved block and fastened. The pendulum rod is made very thin and flexible at the upper end by hammering. The rod is made of wire of sufficient diameter to prevent springing by the action of the escapement, and the pendulum bob is adjustable. The distance between the center of the bob and the split stud is 39·1012 inches.

The motion of the pendulum is a result of the downward pull of gravity and the restraint of the pendulum rod. It is forced by gravity to move until the lowest point of its arc is reached, when the momentum acquired carries it forward and upward, in opposition to the earth's attraction, until its momentum is overcome by gravity, when it stops and is again drawn down by gravity, causing it to return to the lowest part of its arc and repeat the movement just described, but in the opposite direction. But for friction of the air and of its parts, the pendulum would swing on indefinitely without the propelling power.

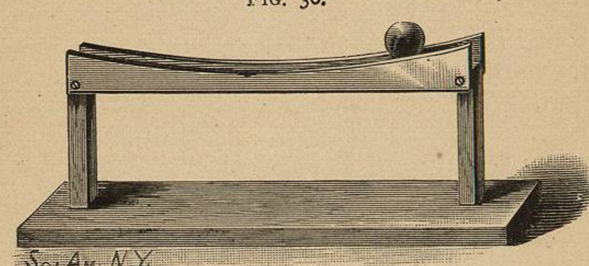
The isochronism of the pendulum is perfect only when its amplitude of vibration remains the same, or when it is arranged to move in a cycloidal path. It is impossible to maintain constantly the same amplitude of vibration, and it is difficult to cause the pendulum to describe a true cycloid. A very close approximation to isochronism is secured by suspending the pendulum by means of a flat spring as above described and by limiting its swing to a very small arc.

The motion of a cycloid pendulum is very well illustrated by the cycloidal track and the ball shown in Fig. 36. The track is formed of steel bars smoothly finished, and the ball is of steel, hardened, ground, and polished, one of the kind used for ball bearings.

The period of oscillation of the ball rolling on the cycloid track is the same for all amplitudes. This may be readily proved by comparing two like instruments with the balls oscillating at different amplitudes.

A torsion pendulum is one that depends for its action upon the twisting and untwisting of an elastic suspension. The simplest pendulum of this class is the toy known as the

FIG. 36.



Cycloid Curve.

return ball. It consists of a wooden ball attached to the end of an elastic rubber cord. By grasping the free end of the cord and swinging the ball so as to cause it to roll in a circular path on the floor, the cord will be rapidly twisted. If, after twisting, the cord be fastened to a support, as shown in Fig. 37, it will be found that the ball will rotate rapidly by the untwisting of the cord. The momentum of the ball acquired during the untwisting will again twist the cord, but in the opposite direction. This pendulum will run more than an hour with a single winding. The period of such a pendulum, taken at random from a pile of return balls, was $1\frac{1}{2}$ minutes, the rubber cord when not extended being about a foot long.

By means of apparatus similar to that shown in Fig. 38,

Coulomb determined the laws of the torsion of wires. The wire by which the weight is suspended is firmly secured to the hook, and the weight is provided with an index. The angle through which the index is turned from the position of rest is the angle of torsion. After turning the weight and releasing it, the elasticity of the wire returns it to the point of rest and the momentum of the weight carries it forward, twisting the wire in the opposite direction, until the weight reaches a point where the momentum of the weight is overbalanced by the resistance of the wire, when the wire again untwists, turning the weight in the opposite direction. These oscillations continue until the force originally applied is exhausted in friction. The oscillations within certain limits are very nearly equal.

FIG. 39. FIG. 37.

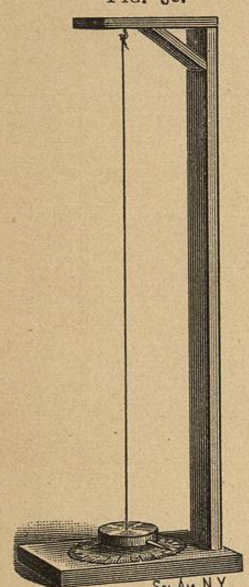
Torsion Pendulums.

A torsion pendulum, with a bifilar suspension, is shown in Fig. 39. The wheel is formed of a disk of metal, with a series of split lead balls pinched down upon its edge. The wheel weighs $1\frac{1}{2}$ pounds. Its diameter is four inches. It has a double loop at the center for receiving the parallel suspending wires, which are $\frac{3}{8}$ inch apart and 5 feet long. No. 30 spring brass wire was used in this experiment. The period of the pendulum was five minutes.

The torsion pendulum has been successfully applied to clocks. Either of two results may be secured by its use. The time of running may be prolonged in proportion as the period of the torsion pendulum is longer than that of an oscillating one, or the number of gear wheels required in the clock may be greatly reduced. Ordinary clocks constructed on this principle run a year with a single winding. Clocks have been made on this plan which would run for one hundred years.

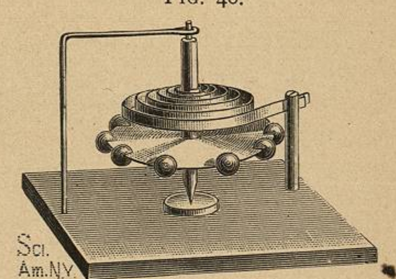
In the same year that Huyghens applied the oscillating pendulum to the clock, Hooke applied the spiral spring to the watch balance, thereby causing it to act as a pendulum.

Fig. 38.



Torsion Pendulum.

Fig. 40.



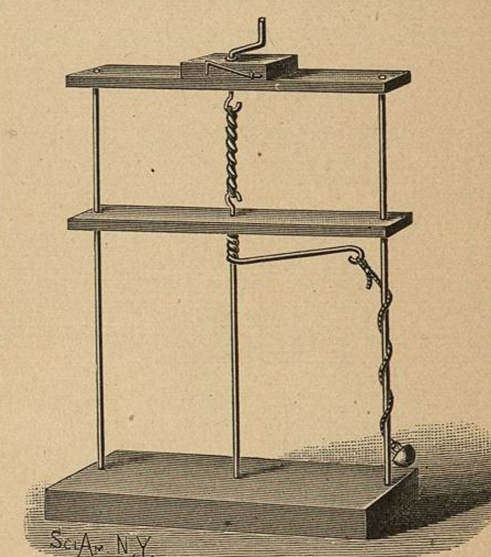
The Balance.

The principle of Hooke's invention is illustrated by Fig. 40. The apparatus here shown has a vibratory period of one second. The staff rests at the bottom in a small porcelain saucer and turns at the top in a wire loop secured to the base board. The disk on the staff is loaded at its periphery with lead balls. A large watch main spring or music-box spring is attached to the staff and to a fixed standard. The oscillation may be quickened by using a stiffer spring or by removing some of the balls.

In Fig. 41 is represented a model of a pendulum of recent invention which has been applied to clocks with some success.

Two cross bars are supported from the base by two wires. In the lower cross bar and in the base is journaled a wire having a hook at the upper end. This vertical wire carries a curved arm, to which is attached a thread having at its extremity a small weight, such as a button. The propelling power in this model consists of an elastic rubber band placed on the hook on the vertical rod, and received in a hook on the little crank shaft in the upper bar. The rubber band is twisted by turning the crank, and the crank is prevented from retrograde movement by the wire catch at the side of the bar.

Fig. 41.



Flying Pendulum.

As the arm is carried around by the power stored in the rubber band, the weight on the thread is thrown outward by centrifugal force. When it reaches one of the side rods, it wraps the thread several times around the rod, thus holding the arm until the thread is unwound by the action of the weight, when the arm describes another half revolution and the operation just described is repeated.