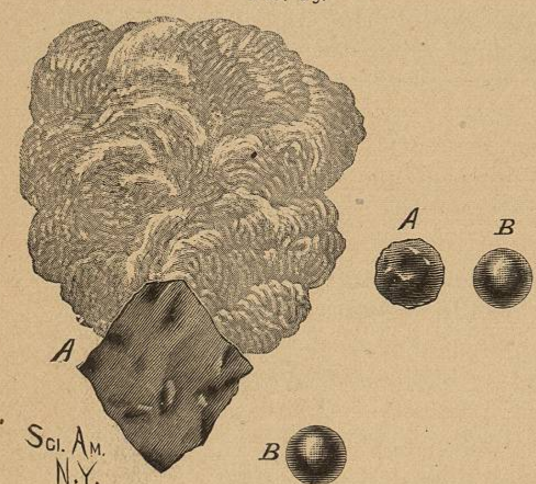
CHAPTER IV.

FALLING BODIES—INCLINED PLANE—THE PENDULUM.

"In a vacuum all bodies fall with equal rapidity." This is the first law of falling bodies. The well known guinea and feather experiment is a demonstration of this law. The

Fig. 25.



Effect of the Resistance of Air on Falling Bodies.

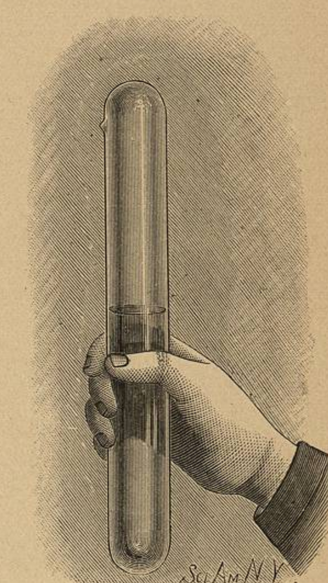
heavy body and the light one being dropped simultaneously in a tube deprived of air, reach the bottom at the same instant.

The converse of this experiment is illustrated in Fig. 25. In this case the retardation caused by the resistance of the air is clearly shown. A bunch of very loose cotton wool is attached to a small piece, A, of tin foil, and the cotton thus arranged is dropped simultaneously with the lead bullet, B. As would be expected, the bullet reaches the ground in about half the time required for the descent of the cotton.

By rolling the cotton into a compact ball and inclosing it in the tinfoil, the surface exposed to the air will be very much diminished, and when the experiment is repeated with the cotton thus diminished in bulk, it is found that the two bodies fall with nearly equal rapidity.

The water hammer shown in Fig. 26 demonstrates that in a vacuum liquids fall like solids, without being broken up or divided. The water hammer consists of a glass tube half filled with water, which is boiled to expel the air, the tube being afterward sealed. When the tube is inverted, the water falls in a body, striking the opposite end of the tube, producing a sharp clink.

Fig. 26.



Water Hammer.

SWIFTEST DESCENT APPARATUS.

The descent of a falling body along an inclined plane is governed by the same law that controls the fall of free, unimpeded bodies, *i.e.*, "the spaces traversed are proportional to the squares of the times of descent." The law does not apply to the descent of a body along any curved path. A body descending a concave path will be accelerated most at the beginning of its fall. A body descending a convex path will start slowly, and will be increasingly accelerated as it approaches the end of its travel.

Three cases are here considered: First, that of a body rolling down an inclined plane; second, that of a body descending a concave circular curve; and third, that of a body descending a cycloidal curve. In the case of the inclined plane, if the body falls two feet in one second, it will fall eight feet in two seconds, eighteen feet in three seconds, and so on. In the case of the concave circular curve, the fall of the body will be accelerated rapidly at the start, and the body will reach the point of stopping quicker than the body on the inclined plane, although it travels over a longer distance. In the case of the cycloidal curve, the body acquires a high velocity at once, as its path at the beginning

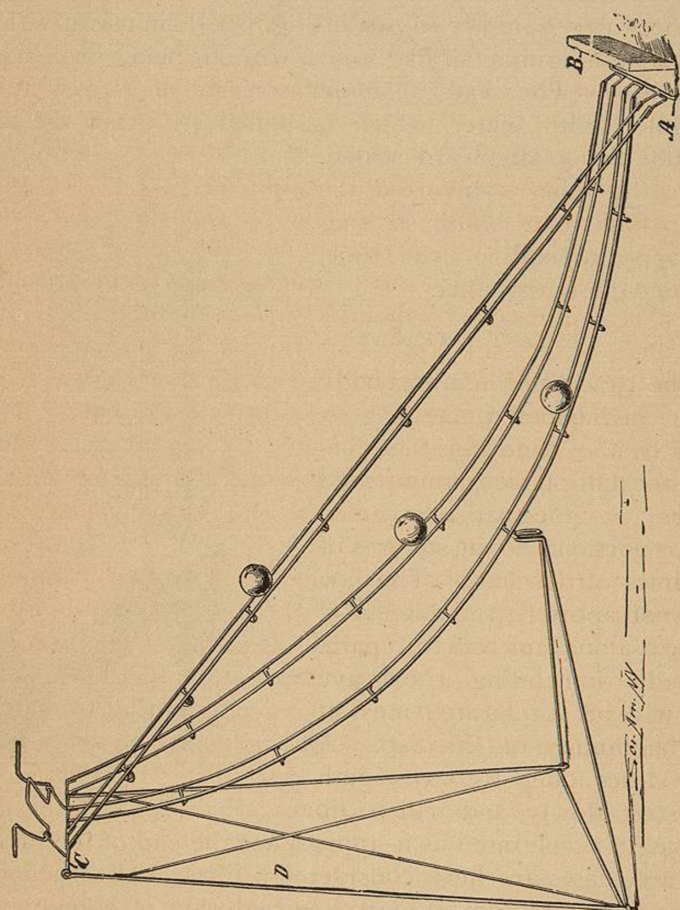


Fig. 27.

Swiftest Descent Apparatus.

is practically vertical. This curve has been called the curve of swiftest descent, as a falling body passes over it from the point of starting to the point of stopping in less time than upon any other path, excepting, of course, the vertical.

The cycloid has another property, in virtue of which it

has been called the isochronal curve. A body will roll down this curve from any point in its length to the point of stopping in exactly the same time, no matter where it is started. For example, if it requires a second of time for a ball to roll from the upper to the lower end of the curve, it will also take one second for a ball to roll from the center of the curve to its lower end.

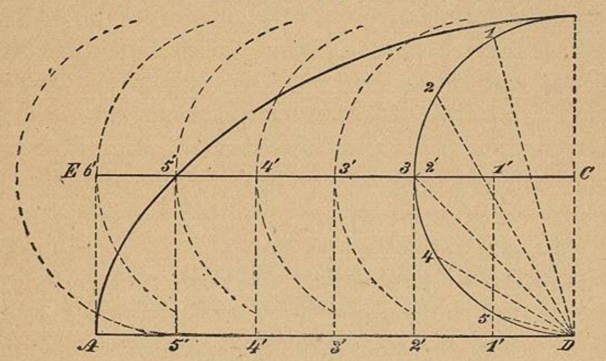
Apparatus for illustrating these principles is shown in Fig. 27. It does not differ much from the ordinary apparatus used for the same purpose. It is, however, made entirely of wire, and is arranged to fold, so that it occupies little space when not in use. The rails of the tracks are formed of one-eighth inch brass wire. These rails are connected by curved cross pieces having ends bent at right angles and soldered to the under surface of the rails. The lower ends of the rails are connected by angled wires with a cross bar, A, which is bent forward, then upward, to receive the board, B, forming the stop for the balls. The upper ends of the rails are connected by angled wires with a cross bar, C, which receives the loops of the wire leg, D. To the leg is jointed a brace which hooks over one of the cross pieces of the middle track.

To the upper cross bar are soldered wire eyes, supporting a wire bent so as to form three cranks for holding the balls, and releasing them all together. The rods of which the tracks are formed are about three feet long. The cycloid track is made first, the others being cut off to match. A method of laying out the cycloid curve is shown in Fig. 28. At the end of the base line, A D, draw the line, C D, perpendicular to A D. Describe a generating semicircle (in this case of nine inch radius) tangent to A D, at D. Through its center draw the line, E C, parallel to the base line. Divide the semicircle into any number of equal parts—six for example—and lay off on A D and E C distances equal to the radius C D $\times$ 3·1416, and divide A D and E C into six equal parts, C $1'$, $1'$, $2'$, etc., equal to the divisions of the semicircle; draw chords, D $1'$, D $2'$, etc. From points $1'$, $2'$, $3'$, etc., on the line, C E, with radii equal to that of the generating semicircle, describe arcs.

From points 1′, 2′, 3′, 4′, 5′, on the line, D A, and with radii equal successively to the chords, D 1, D 2, D 3, D 4, D 5, describe arcs cutting the preceding, and the intersections will be the points of the curve required. Through these points the curve is drawn, and the wires for the cycloid track are bent so as to conform to this curve. The track, when completed, must sustain the same relation to a horizontal line as the curve in the diagram sustains to the base line, A D.

Another method of describing a cycloid is to fix a pencil in the edge of a disk and roll the disk on a level surface, without slipping, with a pencil in contact with a smooth board

Fig. 28.



Method of Describing the Cycloid.

or a piece of paper, the curve being started with the pencil at the lowest point or in contact with the base line.

A ball is supported at the upper end of each track by the cranked wire, and when the three balls are liberated simultaneously by quickly turning up the cranked wire, it will be found that the ball on the cycloid reaches the point of stopping first, the ball on the circular curve coming next, the ball on the inclined plane being slowest of all.

If two cycloidal tracks be placed side by side, it will be found by trial that a ball started from the middle or at any point between the ends of one of the tracks will reach the point of stopping no sooner than the ball started at the top

of the other track. In fact, if the tracks are accurately made, both balls, if started simultaneously, will reach the bottom at the same time.

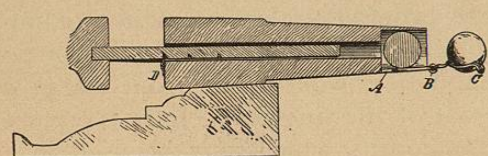
DROPPED AND PROJECTED BALLS.

Although there is no shorter or quicker route for the descent of a falling body than that of a plumb line, it has been shown that a body projected horizontally with whatever force, and describing a long trajectory, will reach the earth in exactly the same time as another similar body simply dropped from the same height. There are many simple and ingenious devices for demonstrating this fact. If the experiment could be brought within convenient compass for observation, nothing would be better for the purpose than an ordinary gun, with powder as the propelling power, but this is of course out of the question. It is therefore necessary to resort to apparatus which may be used in an ordinary room, so that both projected and falling ball may be seen and heard. The apparatus is still a gun, but a very harmless and inexpensive one. It is a modified " Quaker gun," a well known toy used for shooting marbles.

Fig. 29 is a perspective view of the gun, showing it immediately after its discharge, and Fig. 30 is a longitudinal section showing the gun ready to be discharged. The gun consists of a wooden barrel chambered at the muzzle to receive the marble and provided with a rod attached to the breech piece, extending into the barrel and arranged to be propelled forward by a strong elastic rubber cord stretched over the breech piece, with its ends nailed to the sides of the gun barrel.

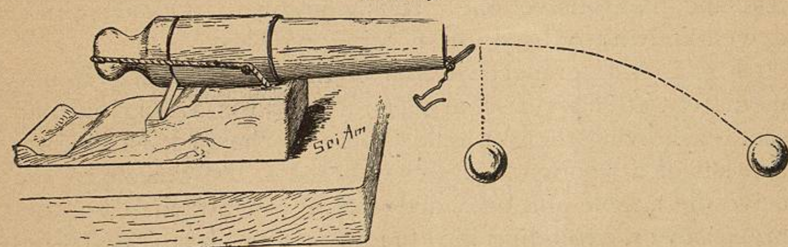
Two changes only are required to adapt the gun to scientific use. First, the notching of the rod passing through the barrel and the application of the trigger, D, for engaging the notches, and second, the support for the falling ball at the muzzle of the gun. The trigger, D, is merely a strip of sheet metal pivoted to the end of the barrel by an ordinary screw. In the muzzle of the gun at the under side is formed a slot, A, and in the end of the gun on opposite sides of the slot are inserted eyes, B. In these eyes is journaled a wire support, C, which holds the ball to be dropped, at one side of the muzzle and out of the path of the projected ball. The wire support, C, forms a lever, one end of which projects into slot in the barrel and is held by the ball in the muzzle. When the rod in the barrel is liberated by pulling the trigger, D, the ball in the muzzle is projected, thereby releasing the wire support, which immediately turns and allows the other ball to drop. It will be noticed that both balls reach the floor at exactly the same time, without regard to the amount of force applied to the projected ball.

Fig. 30.



Longitudinal Section of Gun.

Fig. 29.



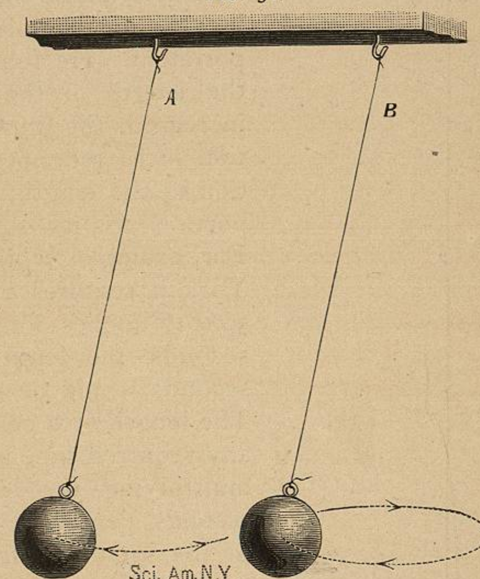
Dropped and Projected Balls.

The falling ball is impelled by the force of gravity only. The projected ball is acted upon by two independent forces—the force of gravity, which draws it toward the earth, and the projecting force, which tends to move it in a horizontal line. The projecting force is concerned only in carrying the ball horizontally forward, and does not in any way interfere with the action of gravity, but gravity brings the ball gradually nearer the earth, until it finally strikes. The gun in this experiment should, of course, be fired over a level plane.

THE PENDULUM.

A simple pendulum, which is a purely theoretical thing, is defined as a heavy particle suspended by a thread having no weight. The nearest possible approach to a simple pendulum is a heavy body suspended by a slender thread, as shown at A in Fig. 31, and although this is known as a compound or physical pendulum, its action corresponds very nearly with that of the simple pendulum. In the present

Fig. 31.



Oscillating and Conical Pendulums.

case the pendulum consists of a heavy bullet or lead ball suspended by a fine silk thread. This pendulum, to beat seconds in the latitude of New York, must be 39·1012 inches long. That is the distance between the point of suspension and the center of oscillation of the weight. This length varies in different places; *e. g.*, at Hammerfest, in Norway, it is 39·1948, and at St. Thomas, one of the West India islands, 39·0207.

A seconds pendulum is one that requires one second for a single swing, or two seconds for a complete to-and-fro