

CHAPTER II.

REST, MOTION, AND FORCE.

A body is said to be at rest when its position is not being changed, but this statement needs some qualification, since any rest known to us is only relative. All bodies with which we are acquainted are continually changing their position either in relation to adjacent objects or along with adjacent objects relatively to distant objects. For example: a boulder is said to be at rest when it maintains its position relative to the earth's surface, but since the earth itself is not at rest, it is evident that whatever is fixed on the face of the earth cannot be at rest.

On the other hand, if the boulder were rolling down a declivity, it would be changing its position relative to the earth's surface as well as to all other objects, and would therefore be said to be in motion; but a body may be apparently in motion while in reality absolutely at rest. If we were to suppose a body projected from the earth into space with a velocity equal to that of the earth, but in a direction opposite that of the earth's motion and uninfluenced by heavenly bodies, the body, although having apparently a high velocity relative to the earth, would be absolutely at rest.

INERTIA.

No body is of itself able to change from a state of rest to a state of motion, neither can a body in motion change its direction or pass unaided to a state of rest. That which causes or tends to cause a body to pass from a state of rest to one of motion, or accelerates or retards the motion of a body, or changes its direction, is known as Force. The incapability of matter to change from rest to motion, or the reverse, is a negative property known as Inertia.

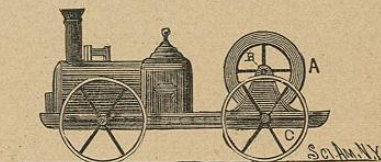
To inertia is due the equalizing effect of flywheels; when

set in motion, they tend to maintain their revolution in opposition to considerable resistance. If sufficient force is applied to the flywheel to counteract the resistance, a practically equable motion is secured, even though the force applied be an intermittent one.

The top is an example of persistent rotation due to inertia. To inertia is due the action of projectiles, hammers, drop-presses, also the hydraulic ram.

The property of inertia, the storage of power, the transfer of power by friction, and the conversion of rotary into rectilinear motion are illustrated by the toy locomotive shown in the annexed engraving. The flywheel, A, is mounted on the shaft, B, which rests on the supporting and driving wheels, C. The wheel, A, is spun by means of a string in the same manner as a top. By virtue of its inertia, the wheel, A, tends to continue its rotary motion. If unaffected by outside influences, it would run on forever; but the friction of its bearings and of the air and other causes combine to bring it to rest.

FIG. 7.



Inertia Locomotive.

The power imparted to and stored in the wheel, A, is given out in turning the wheels, C, overcoming friction, and propelling the machine forward.

FRICTION.

The resistance caused by the moving of one body in contact with another is known as friction. No perfectly smooth surface can be produced, all surfaces having minute projections or roughnesses, so that when the surfaces of any two bodies are moved in contact with each other, the projections of one body engage the projections of the other body, thus offering resistance to the free motion of the bodies. When the surfaces are covered with a lubricant, their inequalities are filled and smoothed over and the friction is lessened.

The friction developed by the sliding of one body upon another is known as "sliding friction," and the kind developed by the rolling of a body upon another is "rolling friction." Rolling friction absorbs much less power than sliding friction. Owing to this fact, the journals and steps

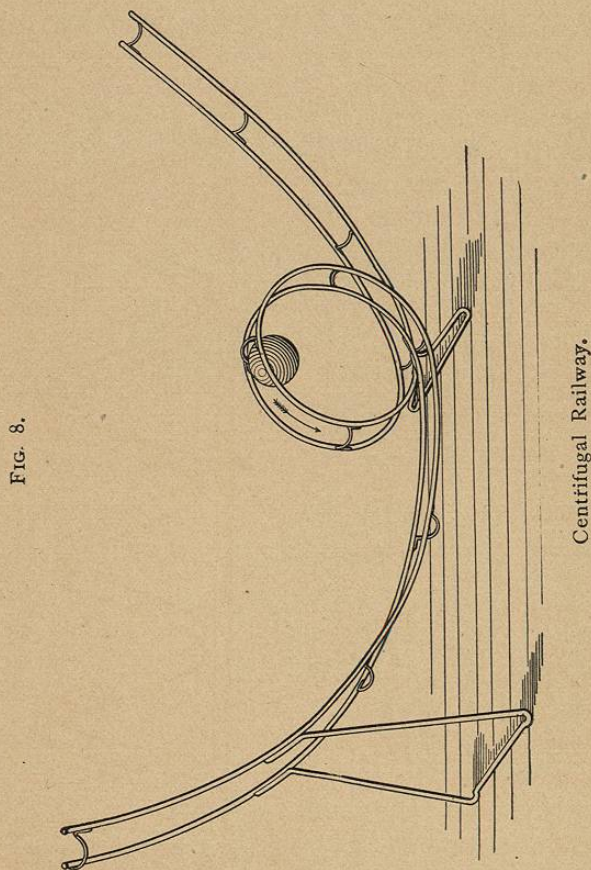


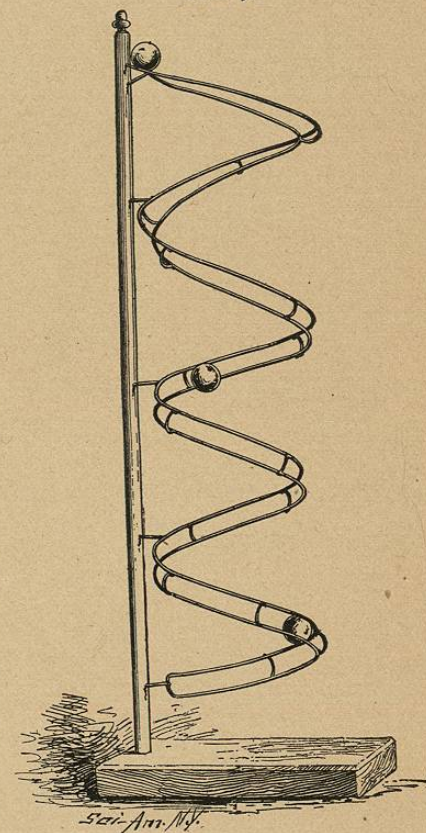
FIG. 8.

of many kinds of machinery are provided with roller or ball bearings, thus substituting rolling for rubbing surfaces. An example of bearings of this kind is found in the pedals and shafts of bicycles and tricycles, which are provided with ball bearings.

CENTRIFUGAL FORCE.

The normal path of any moving body is a straight line; the body can be made to move in a curved path only by restraining it sufficiently to counteract its tendency to leave a circular path and move in a straight line. This tendency is called centrifugal force. When a body moving in a

FIG. 9.



Spiral Railway.

circle path is released, it does not fly off radially, but on a line tangent to the circular path. The fact that a body traveling in a circular path, when released from all restraint, will move in a straight line, proves that the normal path of a moving body is a straight line. The centrifugal railway represented in Fig. 8 shows with what force a restrained body tends to fly from a circular path.

This railway is made in the same manner as the swiftest descent apparatus described on another page. Two wires are bent into spiral loops around a cylinder, and the extremities are curved upwardly as shown. The two curved wires are connected together by curved wire cross pieces fastened by soldering, and two wire feet are attached to complete the apparatus. No particular rule is required for the construction of the centrifugal railway. The only precaution necessary is to see that the

height of the higher end of the railway is to the height of the circular part in a greater ratio than 5 to 4.

A ball started at the higher end of the railway follows the track to the opposite end, and at one point in its travel it is held by centrifugal force against the under side of the track in opposition to the force of gravity.

In Fig. 9 another example of centrifugal action is exhibited by a spiral railway upon which a ball rolls down upon a track consisting of two rails arranged vertically one over the other. The track is formed of two wires bent spirally and connected by curved cross pieces, as in the case of the centrifugal railway already described. The upper convolution of the spiral is twisted so that the ball may start on a

horizontal track. During its descent on the twisted portion of the track, the ball acquires sufficient momentum to cause it to follow the vertical track, being held outwardly against the rails by centrifugal force. The descent of the ball is accelerated. The spiral railway represented in the engraving is two feet high, six inches in diameter, the rails being $\frac{3}{4}$ inch apart.

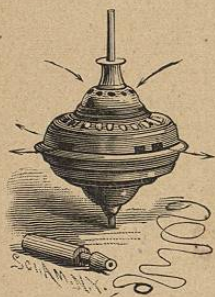
The effect of centrifugal force on air is beautifully exhibited by the ordinary choral top. As the top spins, air, which enters the holes at

the top, is discharged through the holes at the equator by centrifugal force. The air, in going through the top, passes through a series of reeds, setting them in vibration, producing agreeable musical sounds.

The annexed engraving shows a very simple but effective device for exhibiting the effect of centrifugal force on liquids. It is a hollow glass top of spherical form, having a tubular stem, and a point on which to spin.

These tops are filled with various liquids, some of them containing two or more. The one shown at Fig. 11 is filled partly with water and partly with air. When the top is spun, the water flies as far from the center as possible, leav-

FIG. 10.



The Choral Top.

ing in the center of the sphere an air space, which at first is almost perfectly cylindrical, but which gradually assumes the form of a parabola as the velocity of the top diminishes.

At 2 is shown a top having a filling consisting of air,

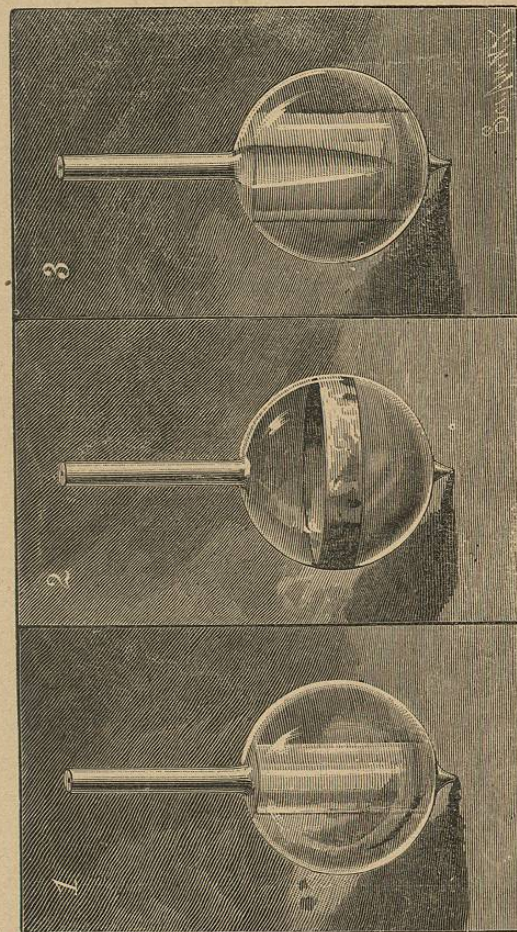


FIG. 11.

Top for Showing the Action of Centrifugal Force on Liquids.

water, and a small quantity of mercury. The water acts as above described, and the mercury forms a bright band at the equator of the sphere.

At 3 is shown a top containing water and oil (kerosene).

The water, being the heavier liquid, takes the outside position, the oil forming a hollow cylinder with a core of air.

The top, after being filled, is corked and sealed. It is spun by the hands alone or with a string and the ordinary handle. The diameter of the top is $1\frac{1}{2}$ inches. It is made of considerable thickness, to give it the required weight and strength.

A SCIENTIFIC TOP.

Every street urchin can spin a top, and get an unending amount of amusement out of it; but it would seriously puzzle the majority of "boys of larger growth" to satisfactorily explain all the phenomena of this simplest of toys.

Why does it continue to revolve after being set in motion? Why does its motion ever cease? Why does it so persistently maintain its plane of rotation? When its axis is inclined to the vertical, why does it revolve slowly around a new axis while turning rapidly upon its own axis? And when so inclined, why does it gradually right itself until it rotates in a horizontal plane? Why does it not revolve proportionately longer when its speed is increased? These and many other questions arise when we begin the examination of the action of the top. They have all been answered so far as it is possible to answer them, still it is difficult to reach far beyond the mere knowledge of the actions themselves.

The top has already risen to some importance as a scientific toy, but it is worthy of being elevated to the dignity of a truly scientific instrument. To give it that eminence, three things are necessary: first, a considerable weight, and in consequence of this an easy and effective method of spinning, and finally it requires a good bearing, having a minimum of friction.

The top illustrated has these three requisities. It weighs $3\frac{1}{2}$ pounds, and its weight might be increased somewhat with advantage. It has a frictional spinning device by which a velocity of 3,000 revolutions per minute may readily be attained. It is provided with a hardened steel pivot which

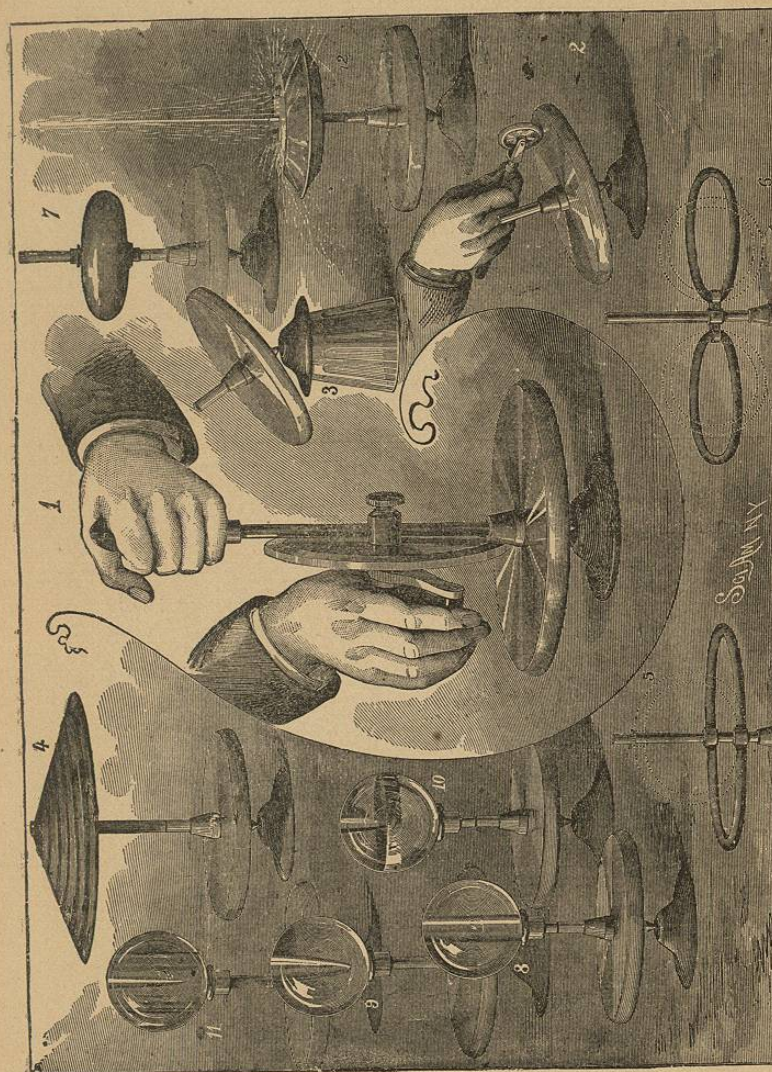


PLATE II.—A SCIENTIFIC TOP.—1. The Top. 2. Persistence in Maintaining Plane of Rotation. 3. Gyroscopic Action. 4, 5, 6. Examples of Centrifugal Action. 7. Formation of Oblate Spheroid. 8, 9, 10, 11. Examples of Centrifugal Action on Liquids. 12. Centrifugal Hero's Fountain.

turns on an agate or steel step.* It is almost perfectly balanced, and the friction of its bearing is very slight. When unencumbered, it will run for over 42 minutes in the open air with once spinning, and its motion may at any time be accelerated without stopping, by a new application of the friction wheel.

The brass body of the top is 6 inches in diameter, and $\frac{5}{8}$ inch thick in the rim. Its steel spindle is $\frac{3}{8}$ inch in diameter and has a tapering longitudinal hole which is $\frac{1}{4}$ inch in diameter at its larger end. To this tapering hole is fitted the tapered end of a rod supporting the stud on which the friction driving wheel turns. The upper end of the rod is provided with a handle, and to the boss of the friction wheel is secured a crank.

A sleeve fixed to the spindle of the top is furnished with an elastic rubber covering which is engaged by the beveled surface of the driving wheel. After imparting the desired speed to the top, by turning the driving wheel, the wheel and the rod by which it is supported may be withdrawn from the top, without interfering in any way with its action.

A large number of interesting experiments may be performed by means of a top of this character. Most demonstrations possible with the whirling table may be adapted to this top, and, besides, many phenomena peculiar to the top itself may be exhibited. A few of the more striking experiments are illustrated.

By suddenly pressing upon one side of the top with a small rubber-covered wheel, as shown in Fig. 2 (Plate II.), it will be found impossible to change its plane of rotation by the application of any ordinary amount of force. In fact, the side of the top to which the pressure is applied will rise rather than yield to the pressure.

By placing the step of the top on an elevated support, such as a tumbler, as shown in Fig. 3 (Plate II.), and gently pressing against one side of the spindle, the axis of the top will be gradually inclined, and a gyroscopic action will be

* An agate mortar of the smallest size, about $1\frac{1}{4}$ inches in diameter, mounted in a wooden base, forms a very good step, but a steel disk, having a concave upper surface, and made as hard as possible, is preferable.

set up. The top will swing around with a very slow, majestic movement, traveling six or eight turns per minute around a vertical axis while revolving rapidly on its own axis, and it will slowly regain its original position.

As the peripheral speed of the top is almost a mile a minute, a little caution is necessary in handling it while in rapid motion, as any treatment that will cause it to leave its bearings will be sure to result in havoc among the surroundings, besides being liable to injure the operator.

Several methods of showing centrifugal action are illustrated, the simplest being that shown in Fig. 4 (Plate II.) A small Japanese umbrella, about 20 inches in diameter, is arranged to be rotated by the top, by applying to its staff a tube which fits over the spindle of the top. In this, as well as the other experiments, the top is set in motion before the object to be revolved is applied. The tube attached to the umbrella having been placed on the revolving spindle, the arms are thrown up by centrifugal action, thus spreading the umbrella.

Fig. 5 (Plate II.) shows a ring formed of two pieces of heavy rubber tubing secured to two metallic sleeves fitted to a rod adapted to the tapering hole of the top spindle. The lower sleeve is fixed, and the upper one is free to slide up or down on the rod. Normally, the rubber forms a ring, as shown in dotted lines, but, when rotated, the centrifugal force reduces it to a flat ellipse. A similar experiment, in which two elastic rings are secured on opposite sides of the rod, is shown in Fig. 6 (Plate II.); the rings being circular when stationary and elliptical when revolved.

In Fig. 7 is shown a device for illustrating the formation of an oblate spheroid. A tube, closed at the lower end and fitted to the hole in the top spindle, is provided near its lower end with a fixed collar and a screw collar, between which the lower wall of a hollow flexible rubber sphere is clamped. The upper wall of the sphere is clamped in a similar way between collars on a sleeve arranged to slide on the tube. The tube is perforated above the lower pair of collars to admit of filling the hollow ball with water. When the ball is filled or partly filled with water, and rotated, it

becomes flattened at the poles and increases in diameter at the equator, perfectly illustrating the manner in which the earth received its present form.

The glass water globe represented in motion in Fig. 8 exhibits a cylindrical air space extending through it parallel with the axis of rotation, the water having been carried as far as possible from the center of rotation by centrifugal action.

When the speed of the globe is reduced, gravity asserts itself and the air space assumes a parabolic form, as shown in Fig. 9 (Plate II.)

In the globe represented in Fig. 10 the filling consists of water and mercury. The rotation of the globe causes the mercury to arrange itself in the form of a narrow band at the equator of the globe.

Fig. 11 shows a globe filled with air, oil, and water, which, when the globe is revolved, arrange themselves in the order named, beginning at the center of the globe.*

A Hero's fountain, operated by centrifugal force instead of gravity, is shown in Fig. 12 (Plate II.) The metallic vessel contains three concentric compartments. The jet tube extends downward into the central compartment and is bent laterally, so that it nearly touches the wall of the compartment. The intermediate compartment communicates with the outer compartment, and the outer and central compartments are connected by an air duct. The central and intermediate compartments are filled with water, and as the vessel is revolved the water in the intermediate compartment is carried by centrifugal action into the outer compartment, and, compressing the air contained in that compartment, drives it through the air duct, with a force due to the centrifugal action, into the central compartment, where it exerts a pressure on the water sufficient to cause it to be discharged through the jet.

* See also chapter on projection.

CHAPTER III.

THE GYROSCOPE.

This instrument has always been a puzzle to physicists. Its phenomena seems to be incapable of explanation in a popular way. In view of the complicated nature of the calculations involved, no attempt will here be made to explain the action of the gyroscope mathematically,* the object of the present article being merely to describe a few modifications of the instrument and to mention peculiarities noticed in the performance of some of these modified forms.

FIG. 12.



Toy Gyroscope.

The difficulty of securing a high speed in a large gyroscope led to the application of a friction driving device, as shown in Figs. 13 and 13a, by means of which an initial velocity of from 4,500 to 5,000 revolutions per minute may readily be attained.

The instrument, after being set in motion, behaves like other gyroscopes not provided with means for maintaining the rotary motion of the wheel, but its size and the facility with which it may be operated render it very satisfactory.

The gyroscope wheel is 6 inches in diameter, $\frac{5}{8}$ inch thick, and, together with its shaft, weighs $3\frac{1}{2}$ pounds. The annular frame weighs $1\frac{3}{4}$ pounds. So that $5\frac{1}{4}$ pounds must be sustained by gyroscopic action when the counterbalance is not applied.

The driving wheel is $7\frac{3}{4}$ inches in diameter. Its face is

* For a mathematical explanation see "Rotary Motion as applied to the Gyroscope," by Gen. J. G. Barnard.