GYROSTATS AND GYROSTATIC ACTION.[1]

I NOW suspend the gyrostat from the horizontal beam by means of this chain terminating in a hook (Fig. 8), which engages, as you see, in a central recess of the rim attachment. The chain, you observe, carries a ball-bearing race. I place the gyrostat with its axis horizontal and leave it to itself. The centre of gravity of the gyrostat lies vertically below the hook, and under those conditions there is no couple tending to tilt the instrument. I transfer the hook to one of the side recesses, set the gyrostat so that its axis is horizontal, and leave it to itself, when instead of falling down it turns its axis in a plane which is nearly horizontal. If I delay the precessional motion the gyrostat descends, if I accelerate the precession the gyrostat ascends. I transfer the hook to the opposite side recess, place the gyrostat so that its axis is horizontal, and again let go. The gyrostat precesses as before, but in the opposite direction. Again I hurry the precession, and again the gyrostat rises; again I delay the motion, and the gyrostat descends.

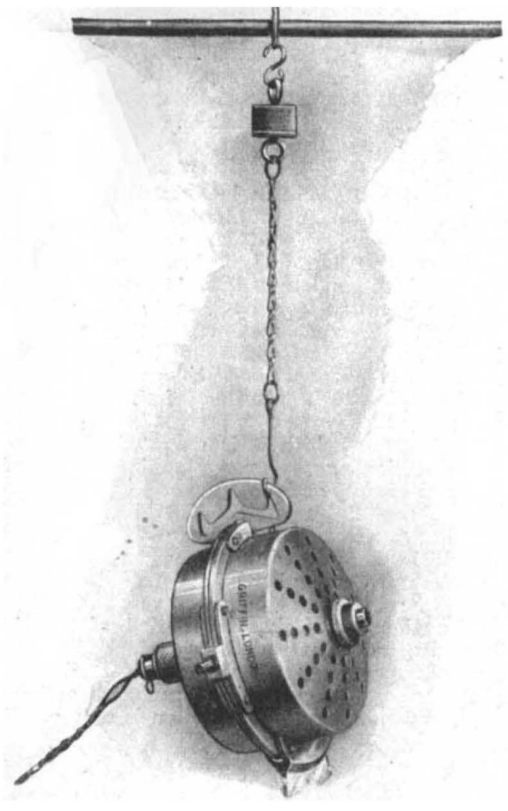

FIG. 8.—Motor-gyrostat precessing on chain support.

In these experiments, when the hook engages in either of the side recesses there is a couple due to gravity tending to produce angular momentum in a vertical plane. The axis of spin-momentum turns towards an instantaneous position of the couple-axis at right angles to it, at angular speed ω say. If μ be the spin-momentum, and the top has been properly started, angular momentum *about the couple-axis* is being produced at rate $\mu\omega$ by this turning, and this is equal to the moment of the couple. The precessional motion remains at the value required to give just the rate of production of angular momentum corresponding to the couple. This is the point generally missed in popular explanations of gyrostatic action.

It is important to notice, however, that, as these experiments are usually carried out, the precession, though apparently steady to the eye, is not, strictly speaking, perfectly steady. There is a very slight alternate rise and fall of the axis. To get quite steady motion the top must not be simply spun and then left to itself; it must be started with the right amount of precession.

I now place the gyrostat within this wooden tray (Fig. 9). The pivots carried by the rim of the gyrostat engage on bearings provided in the tray, and these are on a level with the centre of gravity of the whole. I hold the tray so that its plane is horizontal, and carry it round in a horizontal circle. Nothing happens. Still holding the tray so that its plane is horizontal, I carry it round in a horizontal circle in the reverse direction. The gyrostat immediately turns a somersault, and is thereafter stable. If I reverse the direction of rotation of the tray again the gyrostat turns a somersault, and remains again quiescent.

The gyrostat is stable, with its axis vertical, so long as the direction of spin coincides with that in which the tray is being turned. If this latter direction is reversed the gyrostat turns a somersault so as to render the two directions coincident. It appears as if the arrangement had a will of its own, and refused to be carried round against its direction of spin.

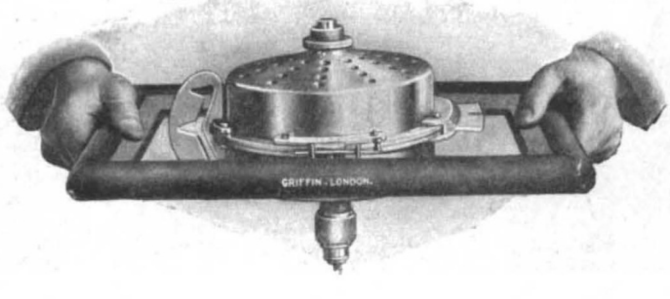

FIG. 9.—Motor-gyrostat mounted to demonstrate the principle of the gyrostatic compass.

The theory of this experiment is very instructive. Both cases are represented by one differential equation, but in one case there is a real period of vibration about the vertical; in the other the period is mathematically unreal, and the gyrostat axis moves further away from the vertical. No better illustration of the two cases of the equation can be found.

The behaviour of the tray-gyrostat is exemplified also in the gyrostatic compass. A heavy and rapidly rotating flywheel is mounted so that its axis is maintained horizontal by means of an elastic support. Under these conditions the equilibrium position of the flywheel under the horizontal component of the turning velocity of the earth (which corresponds to the turning of the tray) is arranged to be that in which the axis of rotation points due north and south. If time permitted, I should be glad to make an experiment with a carefully balanced motor-gyrostat which would not only show the turning of the earth under the gyrostat, but enable the rate of turning to be measured.

[1] Discourse delivered at the Royal Institution on Friday, February 14, by Prof. Andrew Gray, F.R.S. The motor-gyrostats described are the invention of Dr. J. G. Gray and Mr. G. B. Burnside. The gyrostatic tops and combinations used in the latter part of the lecture are due to Dr. Gray. Continued from p. 153.

I would now direct your attention to this motor-gyrostat, which forms the bob of an ordinary compound pendulum (Fig. 10). The tube carrying the gyrostat is attached, by means of a universal joint,

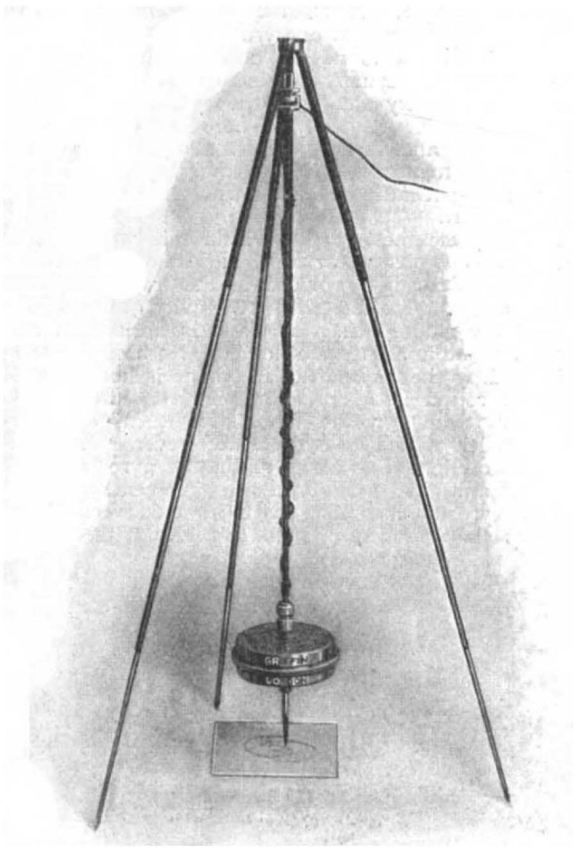

FIG. 10.—Motor-gyrostat fitted up as a gyrostatic pendulum.

to the apex of a triangular stand, made of telescope tubing. The gyrostat is attached to the lower end of its supporting tube by means of a special cap provided with spring contact pieces to allow the current to be led into the motor, and the flywheel is free to rotate about an axis coincident with the rod. Screwed to the lower side of the gyrostat is a pen, which presses lightly on a card placed below.

We have now the pendulum rod in the vertical position. I draw the pendulum to one side and let go, when you see that it vibrates to and fro, and the pen traces out a straight line on the paper. The flywheel has as yet no spin. I start the flywheel revolving, draw the pendulum to one side, and let go, either from rest, or with a certain amount of sidelong motion, when you observe that the pen describes a flower-shaped path (Fig. 11). The path is shown for different amounts of sidelong motion. The peculiar appearance of these curves is due to the rapid falling off of amplitude produced by friction.

When the flywheel is revolving there are, in general, two couples acting on the pendulum, one due to gravity, the other due to gyrostatic action. At an instant at which the axis of the gyrostat is vertical the former couple is zero and the latter one is a maximum, for at that instant the angular velocity with which the axis of the gyrostat is changing direction is greatest. When the pendulum is at one extremity of its swing the former couple is a maximum and the latter one is zero. At that instant the deflection of the bob from the vertical is a maximum, and it is at rest, or is moving sideways, according to the mode of starting, except in so far as the initial conditions have been interfered with by friction. By this relation of the couples the form of the path can be explained.

Another mode of motion is possible which has a very intimate connection with the theory of the vibrations of light-emitting molecules in a magnetic field, as indeed I pointed out here several years ago in a Friday evening discourse (see NATURE, April 13, 1899, and August 24, 1899). The bob can be made to move in a circle about the vertical through the point of support either with or against the direction of rotation of the flywheel. The two periods are different, and the motions correspond to the circularly polarised light of two distinct periods, which molecules, situated in a magnetic field, are found to emit. Thus the gyrostatic pendulum gives a dynamical analogue of the cause of the Zeeman effect.

In 1907 Herr Otto Schlick introduced a method of employing a gyrostat to counteract the rolling of a vessel at sea. The gyrostat is carried on bearings placed athwart the ship. These bearings are in line with the flywheel, and a weight is attached to the frame of the gyrostat in a position in line with the axis. It will be seen that when the ship is on even keel the gyrostat rests with its axis vertical, and with the weight vertically below the centre of gravity of the flywheel. Heeling of the ship in one direction causes the gyrostat to precess in one direction on the bearings on which it is mounted; heeling in the other direction causes precession in the opposite direction, and couples resisting the rolling motion are brought to bear on the ship. The device may be employed in two ways. In the first place, if the bearings on which the frame of the gyrostat is carried within the ship are smooth, the effect of the gyrostat is to resist the rolling force of the waves, and to bring about a lengthening of the free period of the ship, according to a mathematical theory which, when put in the proper way, is really very simple. Excessive rolling of a ship is due to the cumulative action of the waves, and such cumulative action is only possible

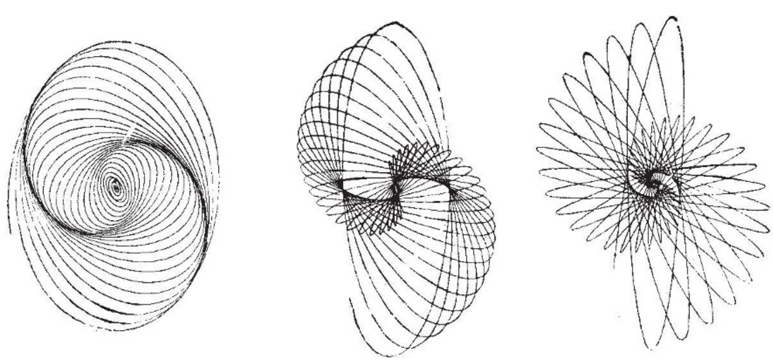

FIG. 11.—Some curves obtained with the gyrostatic pendulum.

where the period of the ship and that of the waves are of about the same order. A large ship has a very long period, and synchronism of the ship and the waves is impossible. The effect of introducing a gyrostatic control, operated in the manner just described, is to endow the small ship with the period of a very large one.

In the second mode of operating the gyrostat, friction is introduced at the bearings on which the frame of the gyrostat is mounted. With this addition the ship is forcibly prevented from excessive rolling. In the trials of the device it was found that with the control in operation the angle of roll of the ship did not exceed 1° in a cross-sea which produced a total swing of 35° when the control was out of action. It is interesting to notice that, contrary to the opinions which were expressed when the device was first suggested, the preventing of the rolling of a ship does not result in the waves breaking over her; a ship controlled by a gyrostat is, I believe, a dry one.

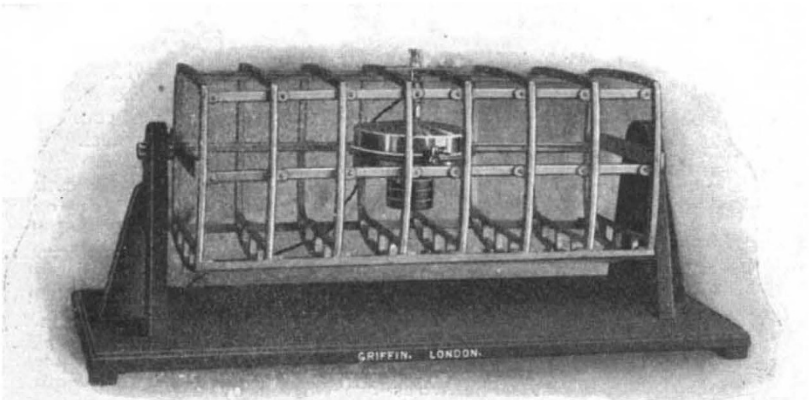

FIG 12.—Motor-gyrostat fitted up to demonstrate Schlick's method of steadying a ship in a cross sea.

I have here a motor-gyrostat fitted within a skeleton frame representing a ship (Fig. 12). The frame is mounted on two bearings arranged on wooden uprights, and may be made to oscillate on these bearings, so as to imitate the rolling of a ship in a cross-sea. The frame of the gyrostat is mounted on two bearings placed athwart the frame, and a weight is attached to the outside of the case in a position in line with the axis of the flywheel. The centre of gravity of the gyrostat is in line with the bearings. A clip-device is provided which allows the gyrostat to be clamped to the skeleton frame, and provision is made whereby a graded amount of friction may be applied at one of the bearings.

I now set the skeleton frame vibrating with the flywheel at rest. You observe the period. I start the motor-gyrostat, and repeat the vibrations, with the gyrostat clipped to the frame. The ship rolls precisely as before. I free the gyrostat from the frame, and again set the ship rolling, when you see that not only is the period vastly increased, but the rolling motion is quickly wiped out.

When the gyrostat is clipped to the frame it produces no effect upon the rolling motion. The couples opposing the rolling motion arise from the precessional motion, and hence the gyrostat must be given freedom to precess. In this connection it is interesting to observe that in 1870 it was proposed by Sir Henry Bessemer to obtain a steady cabin for a cross-channel steamer by placing it on a gyrostat with its axis vertical and supported on fore and aft trunnions. This plan was bound to fail. The dependence of the effect on freedom of the axis to precess in a direction which is not that of rolling was not understood. We now see that the object would have been attained by supporting the cabin on fore-and-aft trunnions and mounting the gyrostat, within the cabin, on trunnions placed athwart the ship.

Here is a monorail top of new design (Fig. 13). The frame on stilts represents the car, and mounted on pivots placed across the frame is a gyrostat. Carried by a rod fixed to the frame of the gyrostat, and in line with the axis of the flywheel, is a weight. When the frame is placed on the table so that the legs and axis of the gyrostat are vertical, with the weight above the flywheel, the arrangement is doubly unstable without rotation; the system of gyrostat and weight is usually mounted on the pivots, and the entire structure is unstable about the line of contact of the feet with the table. When the flywheel is rotating, however, the top balances on the table. The two non-rotational instabilities have been stabilised.

I now place the top on the table with the legs and axis of the flywheel vertical, but with the weight below the gyrostat. You observe that the arrangement is unstable. Here there is only *one* instability without rotation, and the result is instability with or without rotation.

Here is a stilt top similar to the one just shown, but provided with wheels adapted to engage on a stretched wire. You observe the remarkable balancing power of the arrangement.

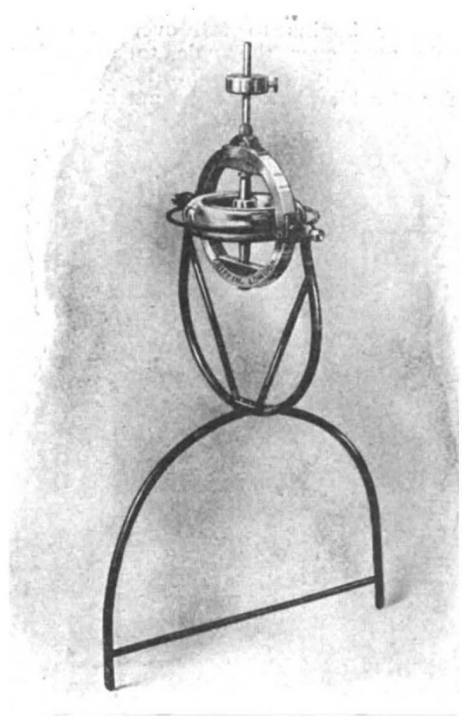

FIG. 13.—New monorail-top.

In this top (Fig. 15) a gyrostat is pivoted within a structure which represents a tight-rope balancer. The structure terminates in wheels adapted to engage on the wire. Attached to the gyrostat are two arms, and carried by these is a light rod weighted at both ends

My assistant spins the flywheel and places the structure upon the wire with the legs vertical and the pole horizontal. The top, as you observe, balances on the wire. If the top tilts over on the wire towards me the gyrostat precesses in the direction which carries

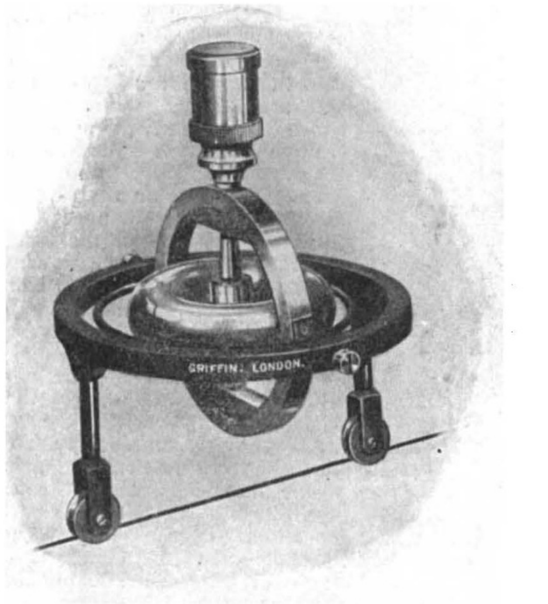

FIG. 14.—Monorail-top on wire.

the pole over towards you, and *vice versâ*. That is, if the balancer begins to fall over to one side it immediately puts over the pole to the other side. The action is exactly that of a tight-rope acrobat.

The rider of a bicycle keeps the machine upright by

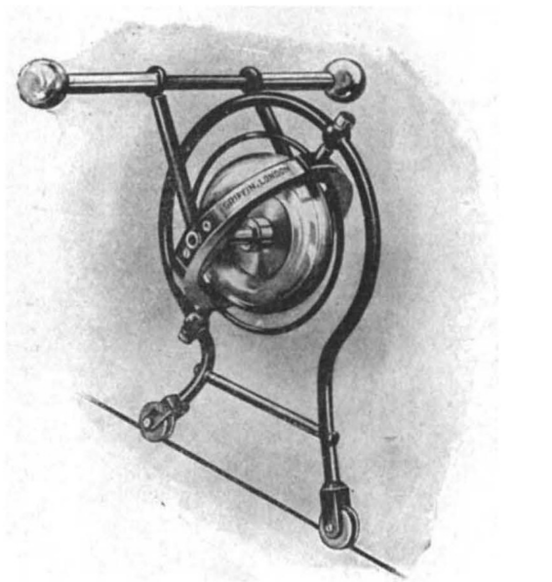

FIG. 15.—Pole-balancing top.

operating the handle-bar. If the machine tilts over to the left the rider turns the handle-bar to the left, and the forward momentum of the bicycle and rider, aided by the gyrostatic action of the wheels (a relatively small factor in this case) results in the erection of the machine. Similarly, if the machine tilts to the right the front handle-bar of the machine is turned to the right.

Here I have a small bicycle of the old-fashioned "high" type provided with a gyrostatic rider. When the gyrostat is spinning rapidly you observe that the top is completely stable. The gyrostat operates the front wheel, just as does the rider on the ordinary bicycle.

Again, here is a small safety bicycle provided with a gyrostatic rider (Fig. 16). In this case the gyrostat is mounted above the back wheel, and is connected by arms to the handle-bar of the front wheel. The action is the same as in the other model.

The tops I have shown you are very interesting from the fact that in each case the gyrostat not only detects but sets about correcting any tendency of the top to fall over. It behaves as if it had both a nervous and a muscular system.

I have also here a gyrostat which can be made to progress in space by a reciprocating motion—in fact, a walking gyrostat (Fig. 17). The gyrostat is suspended by two chains from two horizontally stretched wires. The wires are carried by a wooden frame, which is mounted, as you see, on two trunnions carried

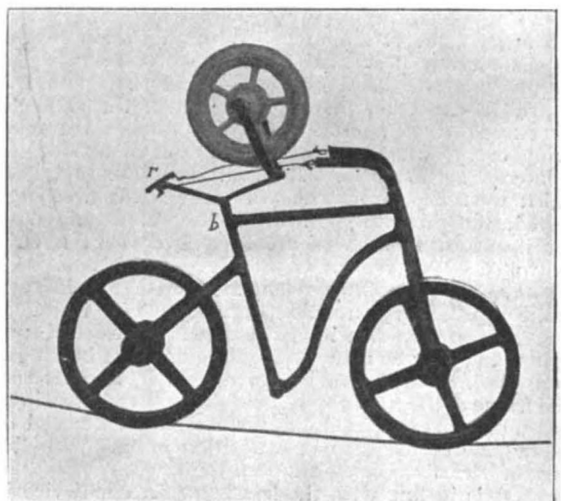

FIG. 16.—Gyrostatic bicycle rider.

by wooden uprights. The chains attached to the arms of the gyrostat terminate in two rings, and these are threaded on the stretched wires.

The gyrostat is spun and replaced on the wires. When the frame is tilted to and fro on the trunnions you notice that the gyrostat walks hand-over-hand along the wires. By the tilting of the frame the weight of the gyrostat is thrown alternately on each of the chains, and in consequence of the precessional motion the gyrostat moves along carrying the chains with it.

At present the spin is great, and therefore the precessional motion is small. The gyrostat proceeds, as you see, with a slow and stately motion. As time goes on the spin falls off, and the rate of walking increases, until finally the gyrostat literally runs along the wires, with considerable loss of dignity. When the gyrostat is enclosed in a box or within an acrobatic figure, the behaviour seems very mysterious.

Here is still another form of acrobatic top, consisting of a large gyrostat, the axis of which is horizontal, and two small ones, with axes vertical, mounted, as you see them, one on each side of the large one, on sleeves threaded on a horizontal bar, as shown in

Fig. 18. My assistant spins the flywheel of the large gyrostat, which is then suspended by means of a string and hook from the upper bar of the frame. At present the centre of gravity of the gyrostat is vertically below the hook, and under these conditions there is no precessional motion. He now spins the two small gyrostats and attaches them to the large one. Each small gyrostat, you will observe, is carried by two sleeves which are threaded on a horizontal bar. The hook is now transferred to one of the side recesses provided in the upper bar of the large gyrostat, and the system is left to itself, when it turns round in azimuth. One of the small gyrostats throws itself up and balances on the bar.

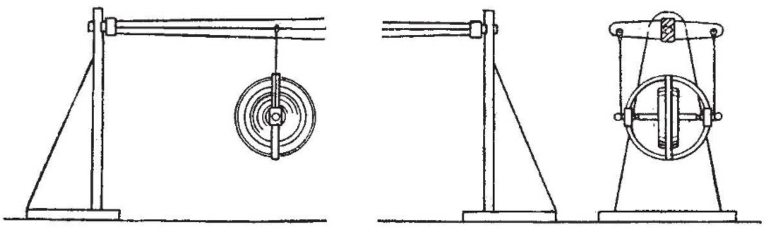

FIG. 17.

The experiment is repeated with the hook engaging in the other side recess, when you observe that the small gyrostat which previously occupied the lower position now rises into the upright one, and the gyrostat which occupied the upright position now occupies the lower one.

This top admits of a large variety of designs. It is easy to imagine a gyrostatic circus rider performing balancing feats on the back of a gyrostatic horse!

I conclude with a gyrostatic model which depends for its action upon an entirely novel and practical method of operating a gyrostat or gyrostats. The method has a very large variety of applications, into which I shall not enter at present. It is here shown applied to a motor-car. The car runs on two wheels in tandem; it can be set to run either in a straight path or a path curved in either direction. You observe that the arrangement includes two parts connected by a vertical or nearly vertical hinge. Each is supported on a single wheel. The front part carries a gyrostat with axis horizontal (in this case), the after-part contains the propelling mechanism. A quasi-gravitational field of force is produced by the propeller behind acting through the hinge.

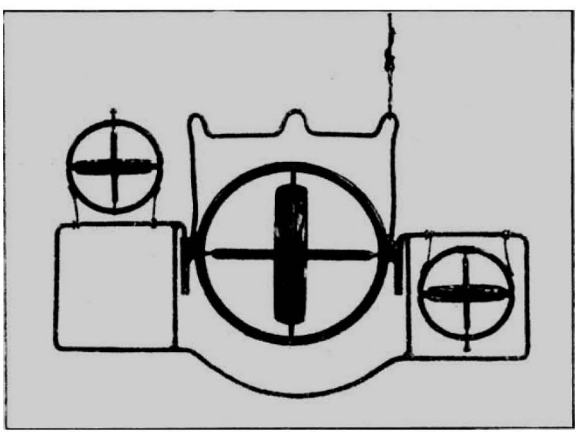

FIG. 18.—Acrobatic top.

The car can be made to go round in any curve by a weight placed on one side, when it will be seen that it leans over to the inside of the curve.

The balancing power is very great; even when a weight comparable with that of the entire car is mounted on a vertical rod carried by the structure, the device does not fall down. In fact, it is dynamically impossible for the car to overturn.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

CAMBRIDGE.—It is proposed to confer the degree of Doctor of Law, *honoris causâ,* upon Admiral Sir Wilmot H. Fawkes, G.C.B., and Mr. J. S. Sargent, R.A.; and the degree of Doctor of Letters, *honoris causâ,* upon his Excellency Adolph H. G. Wagner, professor of political economy in the University of Berlin; Sir Frederic G. Kenyon, K.C.B., director and principal librarian of the British Museum; Sir John Knox Laughton, professor of modern history in the University of London; Sir James A. H. Murray; Prof. C. Bémont, professor of history in the Sorbonne; Mr. Thomas Hardy, O.M.; and Mr. Reginald L. Poole, keeper of the archives of the University of Oxford.

Sir Robert Rede's lecturer for the present year, Earl Curzon of Kedleston, will deliver the lecture in the ensuing Michaelmas term, not, as previously announced, in the present term.

The Linacre lecture, at St. John's College, will be delivered by Dr. Norman Moore, on Tuesday, May 6, at 5 p.m., in the lecture-room of anatomy and physiology, New Museums. The title of the lecture is "The Physician in English History."

MR. W. W. HORNELL, formerly of the Indian Educational Service, and now of the Board of Education, has been appointed Director of Public Instruction in Bengal.

THE council of the South African School of Mines and Technology has made the following appointments to the staff—Dr. G. S. Corstorphine, consulting geologist, of Johannesburg, to be principal of the school and professor of economic geology; Mr. J. S. Cellier, mining engineer, of Johannesburg, to be professor of mining.

MR. PEASE made his annual statement as President of the Board of Education in the House of Commons on April 10. In the course of his remarks he said that the number of pupils in receipt of free tuition in the 885 secondary schools receiving Government grants last year was 52,563, of whom 49,120 came up from the elementary schools. The staffing of the secondary schools is one teacher to every 32·5; of the elementary schools one teacher to every 13·5. There are twenty training colleges, and their total output of trained teachers last year only reached forty men and 195 women. At the continuation schools only 13 per cent. of the total population under seventeen are in attendance. A course of from two to four years will be established in day trade schools. There is room for twenty more in London and 150 in the country. The 2*l*. 17*s*. per head granted by the Government is wholly inadequate, and Mr. Pease has been able to increase the grant to 5*l*. in land schools and 10*l*. to the various training ships. The Science Museum is about to be built on a site in Exhibition Road, South Kensington. It is proposed to erect the