disappointing. The latter include some of the best-known deposits, such as the famous Sheba Mine; the deposits do not show definite walls, and the auriferous rock does not differ from the surrounding country except by its impregnation with iron pyrites and with gold, often very finely disseminated, so that the workable limits of the deposits can be established only by continual assays. It is pointed out that the zone of contact between the granite and the adjoining stratified rocks is the area within which most of the important gold-bearing deposits are situated, and it is suggested that "gold occurrences are far more likely to be expected within the sphere of influence of the intrusive granite," this forming a belt of country averaging about three miles in width. Furthermore, in prospecting, it should not be forgotten that many of the payable deposits of the Barberton district take the form, not of the well-defined quartz reef, with which most prospectors are familiar, but of "mineralised zones of impregnation, sometimes almost indistinguishable from country rock."

THE SPINNING-TOP IN HARNESS.[1]

THE gyroscopic theory of the lecture and its applications was illustrated by experiments with apparatus designed to show the chief principles of gyroscopic motion on a large scale, so as to be visible to an audience; some bicycle-wheels and a Maxwell dynamical top were used.

The lecture began with a quotation of the initial sentence of Maxwell's own description of his top, as given to the Royal Society of Edinburgh, April, 1857, and the phrase "the perplexities of men who had successfully threaded the mazes of the planetary motions" was interpreted as a sly, malicious dig at Newton and his struggle in the "Principia" with the gyroscopic theory of precession.

Twirled by the left hand, the dynamical top gives the appropriate precession in direction; called precession because the seasons come up in consequence of it twenty minutes earlier each year than otherwise, and twenty minutes a year gives the twenty-six thousand years required for a complete revolution among the stars.

Two large 52-in. bicycle-wheels were employed as spinning-tops on the floor, made originally by Prof. C. V. Boys for his Otto bicycle. A hub was fitted with ball-bearings, carrying a spike and a long stalk. Spun by hand, with the spike resting in a small cup raised about 3 ft. from the floor, the evolutions of the wheel could be watched as they became more violent, and finally extinguished when the rim reached the floor.

When the stalk was grasped and raised horizontal and the wheel spun, the gyroscopic effect was very marked if the wheel was allowed to drop or the stalk was brandished. Letting the spike rest in the hand, the wheel moved round in precession, and Kelvin's rule could be shown off in the alteration of the inclination of the axle.

According to this rule, "Hurry the precession, and the axle rises against gravity." This is observed instinctively in riding a bicycle on the road. To avoid an object the bicycle must be steered towards it in a smaller circle, so as to rise and swerve away. A bicycle cannot run straight.

The stability of the axle was shown by hammering the wheel-rim with a stick, causing it to flinch only slightly, but hurrying the precession.

The mathematical theory was too complicated to be undertaken in the course of an hour's lecture, even when stated in Poinsot's concise manner, "which has brought the subject under the power of a more searching analysis than the calculus, in which ideas take the place of symbols and intelligible propositions supersede equations."

The elliptic function theory arises in all its complexity, and appears as if created to speak the language of gyroscopic theory.

Two special cases of motion were suggested to interest the mathematicians in the audience, where the equations are quasi-algebraical, and may be employed as typical illustrations in the wilderness of general theory:—

(1) Project the axle of the gyroscope horizontally with no spin of the wheel; this gives a spherical pendulum motion, as of the bob of a simple pendulum projected so as to move in a spherical curve, and not in plane oscillation.

(2) Spin the wheel and hold the axle up at an angle above the level, such that when let drop the axle reaches the horizontal and rises again, and so on to a series of cusps.

This motion was illustrated on the gyroscopic apparatus exhibited, an ordinary 28-in. bicycle-wheel and hub screwed to a stalk, a short length of steel rifle-barrel, suspended in altazimuth freedom from a vertical spindle, another bicycle hub, fastened to an iron bracket, bolted to the underside of a wooden sleeper supported on brackets—not a thin lath, as I found them trying in Rome with the specimen I had sent to the Mathematical Congress in 1908. All details to be bought cheap or easily constructed.

The three angles, θ, ψ, ϕ, introduced into the treatment by Euler (1750), were shown in the altazimuth suspension: θ is the angle of the axle with the nadir downward vertical; ψ is the azimuth; while ϕ measures the rubbing angular displacement of the wheel over the axle.

The exact dynamical interpretation of ϕ is rather delicate in its relation to the rotation of the wheel about a moving axle. Thus, starting with the wheel at rest on the axle, we cannot turn it by twirling the axle. But move the axle round in a conical way back to rest at its original start, and we find the wheel has turned round on the axle through an angle ϕ proportional to the conical angle described by the axle. So here is an answer to the challenge of Aristotle: to turn a sphere round that is perfectly smooth, or spitted along a perfectly smooth diametrical axle.

In showing the θ and ψ displacement in altitude and azimuth, the wheel must be held to the axle by the thumb; as, if free, the angle ϕ will come into existence.

Anyone can show this off with a pencil or pen-holder held between finger and thumb.

The small bicycle-wheel is dismounted by removing the supporting pin, and can then be spun by hand as another top alongside the large wheel, or else superposed, as in Maxwell's experiment of the "top on the top of a top," thus forming two links of a gyrostatic chain, standing up like a *will o' the wisp*, which may be supposed in imagination to reach up to the ceiling, as a mechanical model of the electromagnetic rotary polarisation of light.

Sir William Thomson gave an elaborate mathematical investigation of the vibration and wave propagation, but this can be simplified and brought under elementary treatment by considering the gyrostatic chain as a uniform helical polygon rotating uniformly about the vertical, as I have explained in my Report on Gyroscopic Theory (1914).

Any similar discussion of a double pendulum, as of a bell and clapper, or a chain of links, is simplified in this manner by comparing the oscillation with a

[1] Abstract of a discourse delivered at the Royal Institution on May 3 by Sir George Greenhill, F.R.S.

steady revolving motion, throwing a shadow moving to and fro in plane vibration on the wall.

The bicycle-wheel forms a compound pendulum, with the axle held fixed, and put out of balance with an iron rod between the spokes; and then the wheel can show off oscillation of any finite extent, beating the elliptic function, or it can make complete revolutions, say from I to XI, or all round the clock.

For this experiment an ordinary bicycle complete will serve, laid on its back, using the front wheel, and then the hind wheel, to show off the effect of the inertia of the chain and crank-axle. The writhing of the frame on a smooth floor will illustrate the stress of reaction of the frame to the motion.

Prof. Perry has written a popular book on the "Spinning Top" in his most stimulating kindergarten style, but it is doubtful if he has ever seen a top of the size of these bicycle-wheels; and I wonder if he has ever seen this gyroscope apparatus, although I made him a present of one many years ago.

As in skating over thin ice the novice can progress swiftly, never stopping to look down at the black water underneath, whereas if he paused to consider the depth below he would break through and go down; so in the theory of the top the analytical difficulties would drown the beginner if not kept out of sight as long as possible.

The kindergarten explanation of the spinning-top is eloquent in answer to the beginner's question of the how and why. But in mathematical treatment it is the "how much?" That is the question.

Crabtree's "Gyroscopic Motion" goes more deeply into the mathematics of the subject in elegant treatment; and here is a Report on Gyroscopic Theory (1914) intended to serve for reference on the complete theory, where no analytical difficulty is avoided when any practical problem arises for solution. And the simple apparatus shown here is intended to be applied at once to a practical test of any new suggestion of harnessing a top or gyroscope.

Attention was directed to the deformable Henrici hyperboloid passing through the shape of a confocal system. This was employed by Darboux for the material representation of a state of top-motion by geometrical constants. Calculation was thereby replaced by measurement on a drawing.

Then there is Kirchhoff's kinetic analogue of the bent and twisted wire, to associate in making a mental picture of the top-motion in all its complexity.

This analogue states that if an elastic round wire, rod, or shaft is bent and twisted into its most general tortuous curve under the action of an equal opposing wrench at each end, the shape of the curve is such that if a point moves along the curve with constant velocity, the hodograph of its motion is a spherical curve, which can be identified as the curve described by a point fixed in the axle of a symmetrical top spinning about a fixed point, as in this small cup, and in the same period by a proper choice of the constant velocity.

In most practical applications the nutation is small and imperceptible, though never absent entirely, and the motion is apparently steady, with the axle at a constant inclination and moving round with uniform precession; in the Kirchhoff analogue the shaft is sprung slightly.

The curious property of a spinning body in rising erect in opposition to gravity, or of running along like a hoop or bicycle without falling over, has directed attention to the distinction between balance and stability according as it is statical or dynamical.

It was mentioned that Lord Kelvin, just twenty-five years ago, lectured at the Royal Institution on "Isoperimetrical Problems—Dido, or Making Things Spin," on a sheet of plate-glass fenced with a frame.

Since Newton compared himself with a child gathering pebbles on the shore, he set the fashion for his rivals of making them spin. But Newton took it for granted his audience knew he was quoting against himself the lines from "Paradise Regained":—

> Many books
> Wise men have said are wearisome.
> Who reads incessantly and to his reading brings not
> A spirit and a judgment equal or superior
> (And what he brings, what needs he elsewhere seek ?)
> Uncertain and unsettled still remains,
> Deep versed in books, and shallow in himself;
> Crude or intoxicate, collecting toys
> And trifles for choice matters, worth a sponge,
> As children gathering pebbles on the shore.

In the contrast of balance, statical and dynamical, the C.G. in statical equilibrium seeks the lowest position it can find, but it rises as high as it is able in dynamical stability of balance, as of a sleeping top or bicycle. A top is said to sleep when spinning steadily upright; man or an animal sleeps lying down, with the C.G. low. But for ease of progression a man assumes the noble upright attitude of a biped, not on all fours, or rides upright on the back of a horse or high up on a bicycle. Any burden, rifle or knapsack, he carries as high as possible. Mounted still higher on stilts, his progress is not more difficult with the confidence of experience.

Confusion between statical and dynamical stability of balance has led to serious mistakes and misapprehension of theory, as of lowering the soldier's knapsack, or ballasting a ship too low and so making it uneasy among waves, as recommended by Euler; or spreading the railway gauge to lower the boiler and carriage-body between the rails, in Brunel's idea.

The modern locomotive is seen to-day high up over the wheels, as high as it can go under the old cramping limitation of the loading gauge of our bridges and tunnels.

A literary friend has directed attention to De Quincey's account of a wonderful brother, who claimed the power of rising against gravity to walk like a fly on the ceiling, provided with spin enough, but that he would require the flagellation of a whip-top in harness, emblem of fortitude in adversity.

> Tu ne cede malis, sed contra audentior ito.

Without attaining so far as the positive levity of De Quincey's brother, we have seen how a top can be made to climb a pole in the model described to the Royal Society by Mr. Tournay Hinde in their Proceedings. And Brennan can make it run along the tight-rope or on a single rail, concealed in harness inside a carriage, to which it gives the upright stability, acting automatically as the brain in riding a bicycle.

In the description of the American poet—

> Are you the Mr. Brennan makes gyroscopic tops
> To keep a car in balance when it runs, or if it stops,
> On single rail or wire rope that's stretched across a chasm ?
> Pray write and tell me, Mr. Brennan, if you're the man that has 'em.

Axial stability of motion of an elongated body through the air, an arrow, bullet, or shell, is maintained by the gyroscopic action of the spin imparted by the rifling, and the calculation of the least amount required is a delicate question of dynamics. No more spin should be given than absolutely necessary, or the shell or bullet will be uneasy in flight, as a ship is uneasy among waves if bottom-heavy, as recommended by Euler, the weights stowed too low.

Passing from small to large applications, the Parsons turbine in the steamship requires to be treated on gyroscopic theory for motion among waves. Rolling does not affect them, but the internal stress due to pitching becomes important, and must receive investigation.

So, too, if electric dynamos are mounted with axle across the ship, they are very sensitive to the rolling, and are heard squealing and complaining as the ship rolls.

When a vessel proved a heavy roller, a cure could be made by fitting bilge-keels, but at a permanent loss of speed in all weather, rough or smooth, of a knot or two. Schlick's sea gyroscope will cure the rolling with no sacrifice of speed; it need not be put in action until wanted, and requires little power to keep it going.

The gyroscope consists of a heavy horizontal flywheel harnessed in gimbals, and controlled by a hydraulic buffer in the line of the keel. The damping action of the buffer can be regulated by a valve to suit the period of the waves, and it makes the flywheel react against the rolling and kill it out.

The inventor is said to have been offended when his apparatus was found more useful still in increasing the rolling and maintaining it, in the case of an ice-breaker, to worry a way easier through the pack or even in working off a sandbank. A different setting of the buffer valve was all required.

A spinning-top stands up vertical in a smooth cup even when the cup is moved about, as on a rolling ship, as we can show here with the Maxwell top; so that if the top carries a polished mirror across the axle, it can serve as the mercurial horizon does on *terra firma*, and so give an altitude when the sea horizon is obscured.

The idea was suggested by Serson in 1744, and the enterprising Admiralty of the day did not crab the idea straight off with the usual "won't work," but sent him to sea in the *Victory* to make a practical test; unfortunately the ship was lost with all hands on the Casquets, near Alderney.

A specimen from the King's collection is preserved in King's College, Strand. The idea has been revived of late years by French navigators as the Fleuriais gyroscopic horizon; it is claimed to give good results in skilful hands where an ordinary observation would be impracticable through fog.

But the most important service to navigation in recent times of the top in harness is the gyroscopic compass. The idea was suggested by Sir William Thomson, but the high spin requisite could not be realised in his day until the great improvement arrived in modern mechanical skill of an Anschutz or Sperry, as a steel flywheel was required, some 4 in. in diameter, spun at 20,000 revolutions a minute. The axle, mounted freely, is always striving after the position as close as it can get to the direction of the polar axis, and so carries the compass-card with it pointing due north, with no magnetic variation requiring constant correction.

Because in modern swift steamship navigation across the Atlantic, where the great circle course must be maintained, practically the only nautical observation required is for azimuth, in its correction of magnetic variation; and there is no variation in the gyro-compass. A specimen would be too complicated and delicate to show off in this room. And if any young researcher should take it into his head to test the action by pushing the card away from its course, it would take an hour or more to swing back into place again.

But the greatest spinning-top we know is this Earth itself, spinning round once a day, with the axis pointing near to the Pole Star. Ancient observation reveals a precession (as in the Maxwell top here, twirled with the left hand), so that the pole is making a circuit among the stars, which will be completed in 26,000 years. Since Homer's day the pole has made more than one-tenth of the way round, and the constellations have changed from one sign of the zodiac well back through the next, and beyond.

We are able thence to assign a date to Homer and Hesiod from their astronomical allusions. Thus the nymph Calypso gives Ulysses his final instructions how to keep off Africa before he sets sail on his raft from Gibraltar: "Never to let the Bear take a bath. He alone should be unsharing of the baths of Ocean," not setting below the horizon any star of the constellation. To-day these instructions would land Ulysses well ashore, some six hundred miles on Africa.

Ulysses could take his latitude with a piece of string, one end held up to the pole, and sliding the other finger to cover some well-known star, then sweeping the hand round to see if the star would graze the horizon, in which case the polar distance of the star is equal to the latitude.

Two such observations on different stars would fix his position, on Sumner's method, provided he had a chart; and Lord Kelvin amused himself on his yacht in testing the primitive methods of Ulysses and the old Greek navigators against the most modern instruments of observation, sextant and chronometer, with Nautical Almanac.

In the ancient tradition there was formerly no obliquity of the ecliptic, and the year was one perpetual spring. But after the Fall of Man, in the Greek legendary astronomical theory Milton has thrown into verse in "Paradise Lost"—

> Some say he bid his angels turn askance
> The poles of Earth, twice ten degrees and more,
> From the Sun's axle. They with labour pushed
> Oblique the centric globe.

No particular labour would be required, as we see with the Maxwell top, if only the polar axis projected, as the angel could move the poles by holding his finger against the axle and letting it run up. A reverse action at the Millennium will restore eternal spring.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

LONDON.—A generous offer made by Sir Basil Zaharoff, G.B.E., through the Air Ministry, to provide a sum of 25,000*l*. for the establishment of a chair of aviation has been accepted by the Senate with cordial thanks, and steps have been taken to secure a speedy appointment to the post.

New regulations have been adopted by the Senate under which extended facilities are offered to graduates of other universities, especially to students from overseas with suitable qualifications, to register as internal students and as candidates for higher degrees (except in medicine and surgery).

The following doctorates have been conferred:—*D.Sc. in Biochemistry:* Mrs. M. T. Ellis, an internal student, of the Physiological Laboratory and the South-Western Polytechnic Institute, for a thesis entitled "A Contribution to our Knowledge of the Plant Sterols." *D.Sc. in Chemistry:* Mr. L. H. Parker, an internal student, of the Imperial College, Royal College of Science, for a thesis entitled "(i) Reactions between Solid Substances, and (ii) The Interaction of Sodium Amalgam and Water." Mr. O. C. M. Davis, an external student, for a group of papers dealing with steric influence and other subjects. *D.Sc. in Statistics:* Mr. Alexander Ritchie-Scott, an internal student, of University College, for a thesis entitled "(i) The Correlation Coefficient of a Polychoric Table, and (ii) A First Study of Polychoric Functions and the Incomplete Moments of a Normal Correlation Surface." *D.Sc. (Engineering):* Mr. James Montgomerie, an internal student, of the West Ham Municipal Technical Insti-