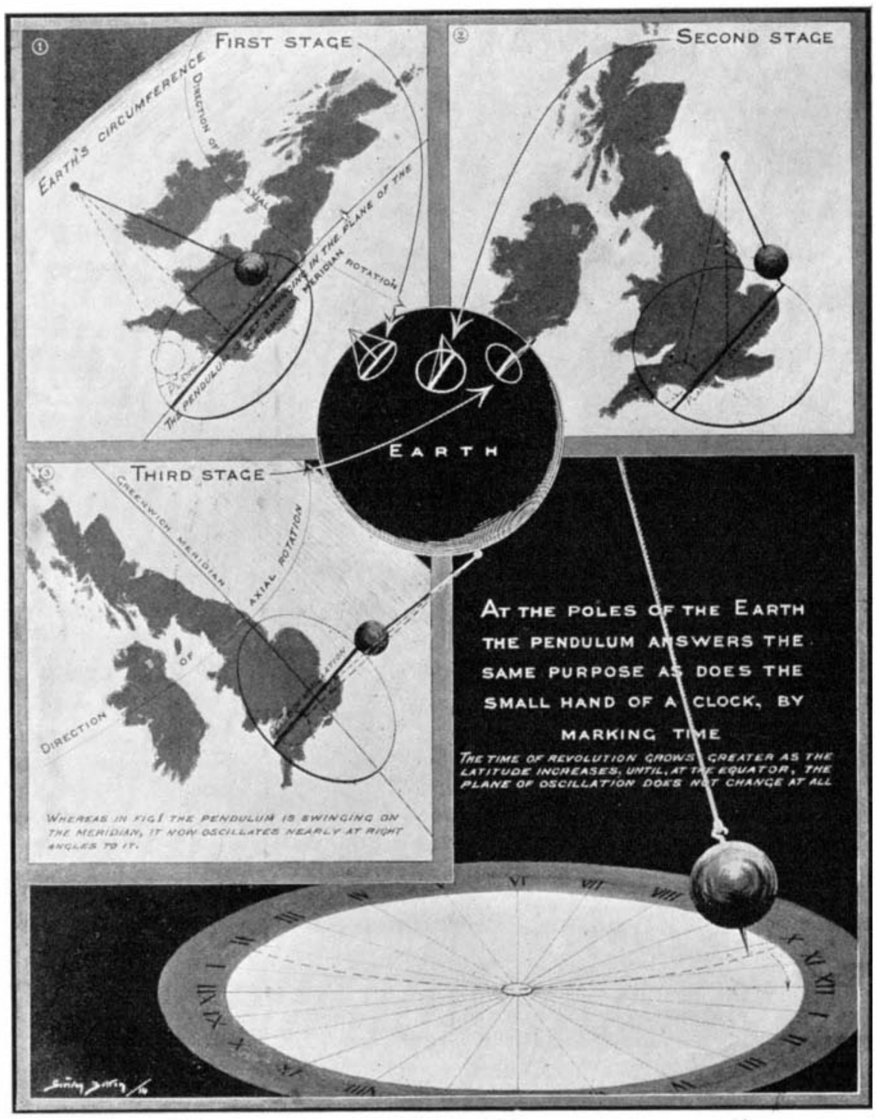
Watching the Earth Revolve

An Apparatus That Enables the Movements of the Earth to be Directly Studied

By Arthur H. Compton

For most people the fact that the sun rises in the morning, travels slowly across the sky and sets in the evening is sufficient evidence that the earth goes around. Our ancestors, however, believed for the same reason that the sun and moon and stars all actually move across the sky while the earth itself stands still. Indeed, the attempt of Copernicus and Galileo to dispel this idea, which seemed so evident as to be almost axiomatic, was the cause of their bitter persecution. It is really impossible to prove definitely by means of observations on the heavenly bodies whether the earth really revolves while the stars remain fixed or whether it is the stars which revolve about the earth. Even though we may show that these bodies are millions or trillions of miles from us, we can still explain their apparent daily motion by keeping the earth at rest if we suppose that the stars are traveling through the heavens with a sufficiently great speed. In fact, this is the assumption on which Ptolemy based his theory of the universe.



By courtesy of the *Illustrated London News.*

Fig. 1.—Foucault's pendulum, which was the first satisfactory means of showing that the earth actually revolves.

It was not until the middle of the last century that Foucault performed his famous pendulum experiment in the Pantheon at Paris (Fig. 1), which was the first good proof that the earth is actually revolving.[1] Even his experiment, however, did not show that all the apparent motion of the stars across the heavens is due to the turning of the earth. Since a pendulum swings in a vertical plane, it is only the part of the earth's rotation about a vertical axis which Foucault's apparatus was able to measure. Suppose that the pendulum is set up at the point *O* (Fig. 2) on the earth's surface. It is evident that there will be some rotation about the vertical axis *OZ*, but this will be less rapid than the rotation about an axis *OP*, parallel to the earth's axis. If the earth turns around the axis *O'P'* once in 24 hours, there ought to be a rotation about a vertical axis at Paris, whose latitude is 49 degrees, at the rate of once in about 32 hours; and by means of his enormous pendulum Foucault showed that such a rotation actually exists. But the fact that there is such a rotation about the vertical axis does not show what the real angular velocity of the earth is nor the direction of the axis about which the earth turns. For example, a comparatively small rotation about such an axis as *O'M* would give the same effect on Foucault's pendulum as a much more rapid rotation about the axis *O'P'*. In order to show that all the apparent motion of the stars across the sky is due to the earth's rotation, it is necessary to determine, without observations on the stars, how fast the earth is revolving, and where its axis is located. This requires more data than are given by Foucault's experiment.

If we can measure the rotation about two horizontal axes, *OX* and *OY*, as well as about the vertical axis *OZ*, the earth's rotation will be completely determined. For by combining the rotation about the *OX* and the *OY* axes, the rotation about a north and south axis *ON* can be found, and combining this rotation with that about the vertical axis the true rate of the earth's rotation about *OP* can be calculated. It is evident that by comparing the relative magnitudes of the rotation about the *OX* and the *OY* axes the angle ψ, or the azimuth of the *X* axis can be obtained, and from the ratio of the rotations about *ON* and *OP* the angle ϕ, which is the latitude of the observer, can be determined. Thus, if the rotation about these three axes is measured, not only the length of the day, but also the position of the true north and the latitude can be calculated, and this wholly independent of astronomical observations.

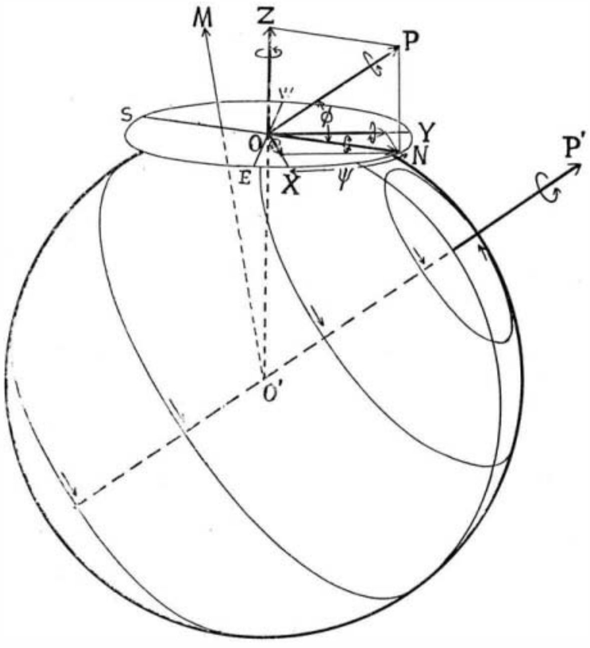


Fig. 2.—Foucault's pendulum was able to measure the earth's rotation only about a vertical axis OZ, while the earth rotation ring measures the rotation about the three axes OX, OY and OZ. The actual length of the day can then be calculated, which was impossible from Foucault's experiment, and the latitude and the position of the true north can also be determined.

The earth rotation ring shown in the photographs was made for the purpose of measuring these three components of the earth's rotation. The principle on which this apparatus works is comparatively simple. The instrument consists essentially of a circular tube filled with water and mounted on an axis in its own plane, as in Fig. 3. This apparatus is set in a plane perpendicular to the axis *OC*, about which the earth's rotation is to be measured. If the rotation is in the direction indicated by the solid arrows, it will be seen that the side *A* of the ring is moving toward the left relative to the other side, and after the ring has been standing a few minutes the water within the tube has the same sort of motion. Now let the ring be quickly turned half way around about its axis, so that the part *A* comes to the nearer side, as shown by the dotted lines. It is evident that the water in that part of the tube will retain a large part of its original motion toward the left, so that there will be a relative motion between the water and the microscope, which turns with the earth. The speed of this relative motion will of course depend upon how fast the earth is revolving about the

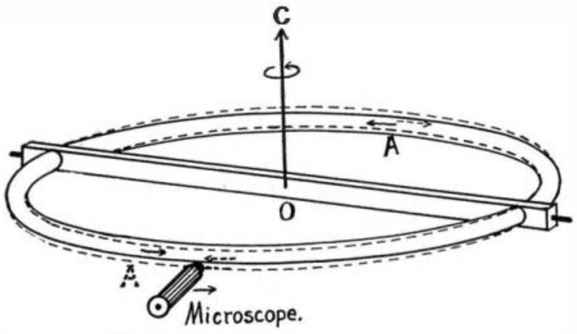


Fig. 3.—If the earth is revolving about the axis OC, when the ring is reversed there is a relative motion between the water and the microscope as shown by the dotted arrows.

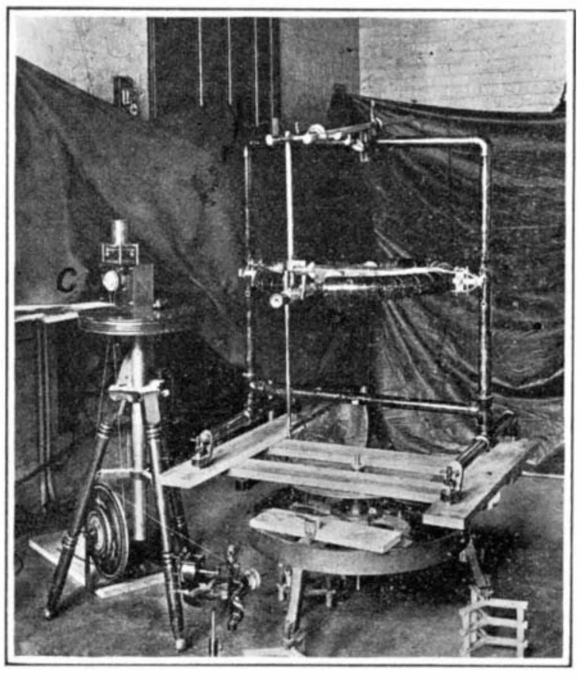


Fig. 6.—Measuring the absolute magnitude of the earth's rotation about a vertical axis.

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[1] This experiment is described in the Scientific American, February 14th, 1914.

axis *OC* as well as upon the dimensions of the ring. With the apparatus here described the motion was usually about as fast as that of the minute hand of a watch, and could easily be seen through the microscope.

The ring used in these experiments was made of 1-inch tubing, bent into a circle a foot and a half in diameter. Where the windows were placed the tube was constricted somewhat so as to increase the velocity of the water which was being watched. The motion of the water which filled the tube was made visible by shaking up with it a mixture of coal oil and carbon tetrachloride of the same density as water, which formed small suspended globules whose motion was easily visible through the observing microscope. In order to avoid spurious motions due to differences in temperature in different portions of the tube, some parts of the experiment had to be performed with the apparatus boxed up in a cold room, as in Fig. 4, but in measuring the effect due to the vertical component of the earth's rotation, as in Figs. 5 and 6, no such particular precautions had to be taken.

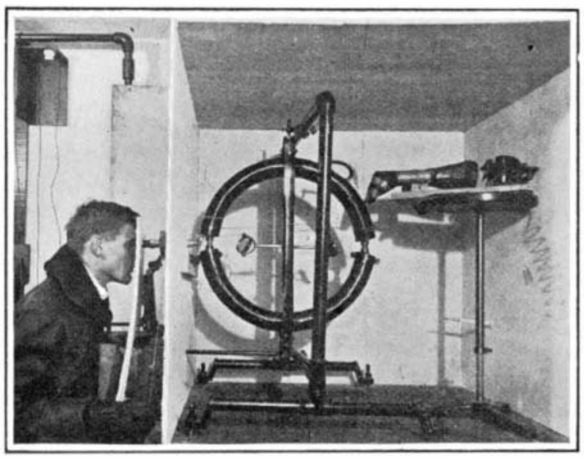

Fig. 4.—Watching the earth revolve. The apparatus is in a constant temperature room just above freezing point to avoid convection currents in the water.

When the ring was held in a vertical plane, as in Fig. 4, the oil globules are always seen to rise on the east side of the tube and go down on the west side, after the ring is reversed. This shows conclusively that the earth is turning over from West to East. Similarly, if the ring is in a horizontal plane, a motion to the left is always observed, which, as we saw above, indicates a motion of the earth in a counter clockwise direction about a vertical axis. It is an interesting experiment to project the motion of the oil globules through the microscopes onto a screen, with the apparatus set up as in Fig. 5. In this manner a room full of people can be shown a moving picture of the earth going around.

As an average of a number of readings, the ratio of the velocity observed about the *OY* axis to that about the *OX* axis indicated that the true north was 61.3 degrees from the *OX* axis, and when the motion about the vertical axis *OX* was determined, the latitude ϕ was found to be 42.8 degrees. In order to find out from these figures how fast the earth is going around, the apparatus was set up as in Fig. 6, keeping the ring in a horizontal position in order to measure the earth's rotation about a vertical axis. The spectrometer table upon which the apparatus was placed could be turned at any desired speed by means of the driving clock *C*. First a set of readings was taken with the clock stopped, and the motion of the globules to the left was measured. Then the clock was started, and was so adjusted that the globules moved just as fast toward the right as they had moved before toward the left. It is evident that the spectrometer table was then turning backward twice as fast, relative to the earth, as the earth itself was turning forward. The spectrometer table was turning at the rate of 1.346 times per day, which means that the earth is turning about a vertical axis at the rate of 0.673 revolutions per day. Since the ratio of the rotation about this axis to that about *OP* was already known, it was easy to calculate that the rate of the earth's rotation about its axis is 0.991 revolutions per day. That is, the length of the day, according to these data is 24 hours and 12 minutes.

It is interesting to compare these values of the azimuth, the latitude and the length of the day with their values as determined astronomically, thus:

	By data from earth rotation ring.	By astronomical data.
Day	24.2 hours	24.0 hours
Latitude	42.8 degrees	40.4 degrees
Azimuth	61.3 degrees	59.9 degrees

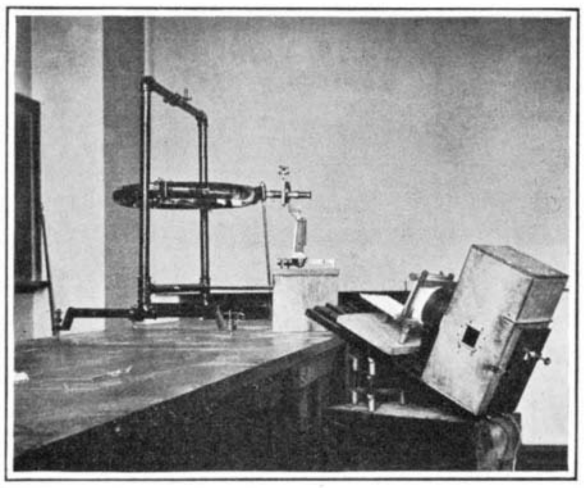

Fig. 5.—The apparatus set up with a projection lantern for showing real moving pictures of the earth's rotation upon a screen.

These figures show conclusively, within the limit of experimental error, that the earth turns about an axis which is identical with its astronomical axis, and that the rate of its rotation is that determined by astronomical observations. Thus it is evident that it is the earth alone which revolves, while the stars remain relatively fixed.

The Koepsel Permeameter*

THE moving coil galvanometer and many other electrical instruments built on the same principle consist essentially of a coil of wire suspended in a magnetic field. This coil experiences a torque which is proportional to the product of the current in the coil and the component of the magnetic field in the plane of the coils. In the instruments just mentioned the magnetic field is constant and the current varies. The deflection due to the torque thus becomes a measure of the current strength.

Instead of using a constant magnetic field, we may maintain a constant electric current through the moving coil and use this system for the measurement of the magnetic field. If this magnetic field is due to an electromagnet, the magnitude of the field depends upon the magnetomotive force applied and the material of the magnetic circuit. An electromagnetic system of this kind may therefore be made the basis of an apparatus for the determination of the magnetic properties of iron and steel.

Robinson[1] in the *Electrical World* of February 24th, 1894, gave a complete description of a permeameter based on this principle. However, he had not actually built the instrument.

Three days later Koepsel[2] described before a German electrotechnical society substantially the same piece of apparatus, which he had built and was actually using. This apparatus, as later improved by Kath,[3] is widely used, both in this country and abroad. It is sometimes called the Siemens and Halske permeameter, from the name of the manufacturer.

Orlich[4] at the Reichsanstalt determined a number of hysteresis loops with the Koepsel instrument and also by the magnetometer method, using ellipsoidal specimens for this latter test. His data show that at inductions of 15,000 gausses the instrument gives values of the magnetizing force which are too high. All values of the coercive force, as obtained by this instrument, are greater than those of the magnetometer. The shearing curves differ for different materials. Rohr[5] compares hysteresis data obtained by the Koepsel permeameter with that obtained by the watt-meter method and finds that the values of the Steinmetz coefficient thus obtained are in substantial agreement.

Much of the data on the magnetic properties of iron and steel have been determined with this apparatus. It seems, therefore, well worth while to give the Koepsel permeameter a careful experimental examination with a view to determining its reliability for use in making magnetic measurements.

As a result of the experiments conducted, the following conclusions were drawn:

The Koepsel permeameter has several valuable characteristics. It gives direct readings of the magnetizing force and the magnetic induction, both for normal induction and for hysteresis data. It is easy of manipulation and does not require greater care than the usual deflection instruments. It repeats its readings as consistently as could be desired. The readings may be very useful in indicating relative values of different materials or the degree of non-uniformity of similar materials. The fact that the observed values of the magnetizing force may differ by as much as 100 per cent from the true values does not destroy the value of this instrument for purposes of comparison.

From the experimental consideration of the different factors which may affect the accuracy of the readings the following detailed conclusions were drawn:

1. Readings on the two sides of the zero of the instrument may differ considerably, but the mean of the two values thus obtained shows satisfactory consistency on repetition.

2. Shearing curves for different grades of material show that the correction to be applied to the observed magnetizing force is not constant for a given induction, but depends upon the nature of the test specimen. This correction is usually subtractive for points below the knee of the induction curve and additive for points above the knee.

3. An increase in the cross-section of the test specimen tends to increase the observed values of the magnetizing force for points below the knee of the induction curve, and to decrease the observed values for points above the knee.

4. The length of the specimen projecting beyond the yokes produces no noticeable effect for points below the knee of the induction curve. For points above the knee the projecting ends increase the observed value of the magnetizing force.

5. If the bushings are not pushed all the way into their proper position, a higher apparent value of the magnetizing force is observed, due to the increased length of the portion of the bar under test.

6. Hysteresis loops obtained by the Koepsel permeameter always show a low observed residual induction and a high observed coercive force.

7. A theoretical and experimental study of the distribution of the magnetic fluxes through different parts of the magnetic circuit shows that shearing curves of the form observed are to be expected.

If the apparatus is to be used for the determination of the absolute values of the magnetic quantities, it is necessary to apply a correction to the readings. Since the apparatus gives consistent results on repetition, the whole error may be charged to errors in the correction or shearing curves. As this shearing curve varies with the dimensions and quality of the specimen, it is essential that shearing curves be prepared for each size and quality of specimen to be tested. With extreme care and the use of proper shearing curves, the apparatus is capable of giving quantitive results within 5 per cent of the true value of the magnetizing force for a given induction.

Uncorrected hysteresis data for hard steels show values of the residual induction that are too small; the error may be as great as 10 per cent. Values obtained of the coercive force are systematically too large; the error may be as much as 40 per cent.

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* A brief summary of Bulletin 228, issued by the Bureau of Standards, describing an investigation made by Charles W. Burrows, Associate Physicist.

[1] L. T. Robinson: "A Modified Instrument for the Determination of B-H Curves," *Electrical World*, 23, p. 236, February 24th, 1894.

[2] A. Koepsel: Apparat zur Bestimmung der magnetischen Eigenschaften des Eisens in absoluten Maas und director Ablesung, E T Z, 15 p. 214, April 12th, 1894.

[3] H. Kath: E T Z, 19, pp. 411-415, 1898.

[4] E. Orlich: E T Z., 19, pp. 291-294, 1898.

[5] W. Rohr: E T Z., 19, p. 713, 1898.

Petroleum Conditions in Russia

THE report of the United States Geological Survey on the Production of Petroleum in 1913 contains the following statement:

The declining condition of the older Russian petroleum localities noted in the previous reports of this series continued in 1913. It was not compensated by increase in the new districts, which include Emba for the first time as a commercial factor. The outlook for the future of Russian production is brightened by the prospecting which has progressed rapidly in the Ural-Caspian region, north of Gurief. The field is reached by steamers to the north shore of the Caspian Sea. About thirty miles from the shore large wells have already been obtained at Dossor, and pipe lines are laid to Gurief, where barges can be loaded and then towed up the Volga without the reloading which is necessary with shipments from Baku. Oil from Baku destined for the Volga River trade arrives at Astrakhan in steamers too deep for the river and is then transferred to barges. Exploration in this Ural-Caspian field has been extended many miles north of the present developments. Prospecting is impracticable in winter, but in summer it can be prosecuted with success in spite of the lack of water, the available supply of which is derived principally from snow scraped up in winter and stored in pits. The inhabitants of the region are nomads living in tents. They are peaceful and disposed to aid exploration.