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On the 21st of December, 1871, I delivered a lecture on Magnetism before the American Institute, at the Academy of Music, in the city of New York. It was necessary for the experimental discussion I then made of the earth's magnetism to use a galvanometer, so constructed that the least deflection of its needle would be visible to a very large audience; at the same time the astatic condition of this needle had to be so controlled that it could readily be altered during the progress of the lecture; while finally, the arrangement of the damping magnets had to be such as allowed me instantly to bring the needle into the magnetic meridian when disturbed therefrom, whenever I set in action the huge electro-magnet used on that occasion. Indeed, one of the principal uses to which this galvanometer was applied, in the lecture, was the exploration of the magnetic condition of the space surrounding this electro-magnet. This I accomplished by rotating, around the line of "the dip," as an axis, wire coils at various distances and positions, and leading the induced magneto-electric currents through the galvanometer.

The lantern-galvanometer, which I will now proceed to describe, I devised on the 13th of last November, and as subsequent work with it has convinced me of its value in the lecture-room, I have decided to give it this formal publication.

Referring to the figure; M is a plane mirror inclined 45° to the vertical. In front of this are the back condensing lenses of an oxyhydrogen lantern; while the front lens of the condenser is placed in a horizontal position at *c*, *above* the mirror. The back condensing lenses are of such curvatures that when the calcium light is placed about two inches from the one nearest it, a nearly parallel beam issues from them to fall upon M, thence to be reflected to the upper condensing lens at *c*,* on which rests a disc of glass on whose border is photographed a divided circle. In the center of this disc is a short needle point on which freely rotates a magnetic needle. Above the needle is the projecting lens L, the pencils from which are reflected in any desired direction by means of the plane mirror R, which revolves on a horizontal axis and has also a motion in azimuth around the axis of the lens.†

The horizontal condensing lens is five inches in diameter, and the magnetic needle is four inches long. With this arrangement I have obtained sharp and bright images of the graduated circle 16 feet in diameter.

To deflect this needle by means of an electric current I place as close to the condensing lens as possible the two vertical wire spirals S, S, formed of $\frac{1}{16}$ inch copper wire of *square* section, so as to bring the convolutions as close together as possible. The turns of the spirals are separated with very thin vulcanite ribbon, coated with paraffine, and are wrapped on the faces of vul-

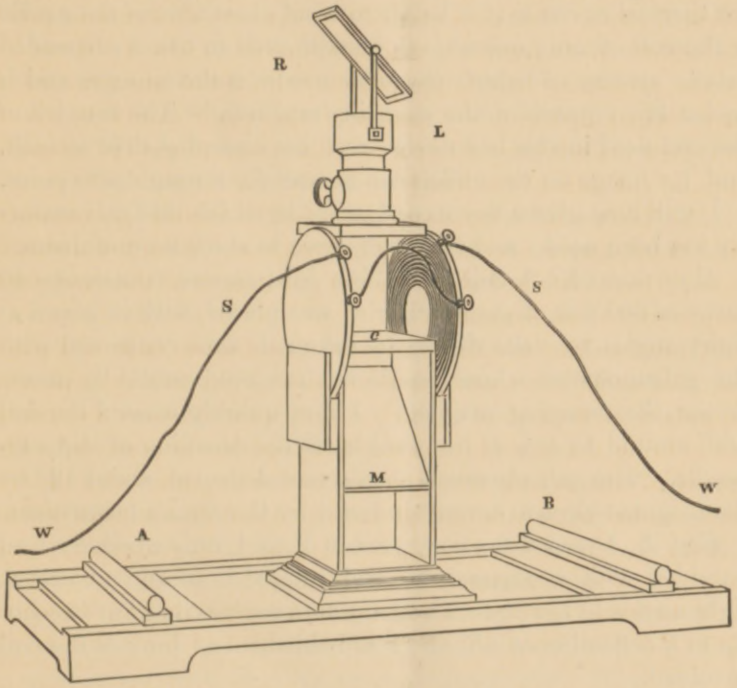
* This arrangement of lenses, which is due to President Morton, gives a bright and uniformly illuminated field free from coloration.

In the *Quarterly Journal of Science*, Oct. 1871, is a report of Prof. Morton's account of this invention ["the vertical lantern"], delivered before the American Institute, as follows: "The original idea and general plan of the instrument shown, was, as the speaker stated, due to Professor J. P. Cooke, of Cambridge; his own work in connection with it being confined to the devising of a convenient mechanical arrangement of parts, the improvement of the combination of condensing lenses with the reflecting lenses [mirror?] so as to secure a white and evenly illuminated field on the screen, and the discovery that an ordinary silvered mirror would serve for the final reflection as efficiently as a metal speculum or glass silvered by Foucault's plan, which are so difficult to obtain and keep in order."

† In a college course of lectures it is sometimes convenient to reflect the image of circle and needle down on a white covered table below the class. The galvanometer can then be placed on the lecture table.

canite discs. The spirals have an internal diameter of four inches and an external diameter of ten inches, and each contains 49 feet of wire in 26 turns. The four terminals of the spirals are connecting screws, two of which serve to connect the spirals so that a current will circulate in the same direction in both. The spirals are so placed that a line joining their centers will pass through the center of the magnetic needle.

The vertical-lantern rests on a base three feet and a half long, with guides on its sides, between which slide boards carrying two bar-magnets, A and B, 15 inches long and one inch in diameter, as shown in the figure. These magnets can-



not only approach to and recede from the lantern, and thus alter their distances from the galvanometer-needle, but they can also rotate around their centers on vertical axes. The like poles of the magnets and of the needle point in the same direction; and by sliding the magnets to or from the lantern-needle we render the latter more or less astatic. Also, in case the needle should not hold to the meridian as you approach the magnets, it can be made to do so by rotating one or both of them in the horizontal plane; and thus, also, can be neutralized any exterior disturbance which may tend to deflect the needle from the magnetic meridian.

The needle may be also rendered astatic, in the usual way, by suspending it by a silk fiber and attaching to this needle a wire which passes through a hole in the condenser and in the inclined mirror and carries beneath the latter another needle with poles reversed.

In working with thermal currents we use a smaller needle and condenser which allows the spirals to approach nearer; but for thermal currents it is better to wind close around the needle a flat coil of only one wire in breadth, and to use a suspended astatic system of which the *lower* needle is the stronger and is under the control of the damping magnets.* The breadth of the coil used in this last device need not exceed $\frac{1}{20}$th of an inch, and its image on the screen can answer for a rough zero point.

I will now give a few experiments in which this galvanometer has been used; and they will serve to show its usefulness.

Experiment 1. A coil of 2½ feet in diameter, containing 40 turns of 300 feet of $\frac{1}{16}$th inch wire, was placed, with its plane, at right angles to "the dip." Its terminals were connected with the galvanometer whose needle was rendered astatic by means of the the damping magnets. I now quickly rotated the coil 180° around an axis at right angles to the direction of dipping-needle. The galvanometer needle was deflected about 12° by the magneto-electric current induced by the earth's magnetism.

Exp. 2. I placed the coil, used in Exp. 1, on a wooden wheel provided with a commutator and rotated it around an axis at right angles to the dip. The galvanometer-needle went steadily up to a deflection of 85° and was held there as long as the coil revolved.

Exp. 3. The two cores of the large electro-magnet of the Stevens Institute of Technology were placed end to end, thus

* The upper needle of this astatic combination swings in the interior of the coil which incloses both the needle and the condenser *c;* the lower needle swings under the inclined mirror M, and is attached to the upper needle by means of a stiff wire which passes through holes in the condenser and to the inclined mirror. In another combination I have placed this lower needle *above* the coil, and have "damped" it by means of a magnet placed above the reflector R.

forming one iron bar, seven feet long and six inches in diameter. This was surrounded by its eight bobbins containing in all 2000 feet of $\frac{1}{5}$ inch copper wire; and through them was sent the electricity developed by the most advantageous combination of 60 plates of zinc and carbon, 10×8 inches.

A coil of 20 inches in diameter formed of one turn of $\frac{1}{20}$ inch wire was rotated 180° around a vertical axis $3\frac{1}{2}$ feet from the end of the magnet. The needle was deflected 3°.

Exp. 4. A coil of 20 inches in diameter having 5 turns of $\frac{1}{20}$ inch wire was rotated 180° around a vertical axis, at a distance of $3\frac{1}{2}$ feet from end of magnet. Deflection of needle was 30°.

Exp. 5. Same as Exp. 4, only coil had 10 turns of wire instead of 5. Galvanometer needle deflected 50° to 60°.

Exp. 6. A coil of 20 inches in diameter formed of 10 turns, $\frac{1}{20}$ inch wire was revolved 180° around a vertical axis $6\frac{1}{2}$ feet from end of magnet. Deflection of 22°.

Exp. 7. The coil used in Exp. 6, was placed three feet eight inches above center of axis of the magnet and revolved 180° around a vertical axis; the needle was deflected 80°.

Exp. 8. A coil of $2\frac{1}{2}$ feet in diameter, formed of 40 turns of 300 feet of $\frac{1}{16}$ inch wire, was placed 28 feet distant from the center of the magnet, and with its plane coinciding with the plane of the magnet's equator. On rotating it around a vertical axis the needle was deflected 20°.

The following experiments will show the excellent proportions (arrived at by a long series of experiments) of the coil used in Exps. 1, 2 and 8, for the evolution and study of the electric currents induced by the earth's magnetism.

Exp. 9. The coil used in Exps. 1, 2 and 8 was laid on a table and its terminals connected with a galvanometer, which is used in connection with Nobili's thermo-electric pile. The needles of this instrument made one oscillation in nine seconds. I lifted the east side of the coil only six inches; the needle was deflected 10°. Lifting the same side nine inches, the needles went to 22°. I now placed the coil in a north and south vertical plane and suddenly tilting its top six inches to the east or to the west the needles went to 60°. Tilting the coil nine inches sent the needles with a blow against the stop at 90°.

The advantages of the new galvanometer may be summed up in a few words. It gives on the screen a bright clear image of only the graduated circle and of the needle. It can readily be rendered more or less astatic to adapt it to the character of the electric currents worked with. The direction of its needle is completely under the control of the damping magnets; and, finally, it is of simple construction and can be rapidly adjusted to the requirements of any special experiment.