

A CONVENIENT FORM OF GALVANOMETER WITH
MAGNETIC SHIELDING.¹

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THE progress toward increased sensitiveness of galvanometers of the Thomson type which has been made by Paschen,² Mendenhall and Waidner,³ Abbott,⁴ and others has realized nearly all that can reasonably be expected from galvanometers of this pattern. The art of shielding such instruments against magnetic disturbances from without has not, however, advanced beyond the stage where very considerable improvement is likely.

The problem of magnetic shielding presents many difficulties from the mathematical side, and yields only approximate solutions. If, however, the shielded space be given, together with the room occupied by the shielding device, Wills⁵ has shown the best conditions for three concentric hollow spheres or cylinders will be obtained when the inner and outer radii of the successive shells, and the air spaces separating them, advance outward in the same geometric progression. Spherical shells without holes or joints would give the highest shielding ratios, but as this condition cannot be fulfilled in construction and long hollow cylinders prove at once effective and workable, this latter form of shielding has been adopted.

In designing the magnetic shields to be described, the following general considerations have been kept in mind:

1. The shields should be symmetrically disposed about the center of the needle systems which should be brought as near together as conveniently possible.
2. The shields should be uniform and free from flaws, borings or lateral openings.

¹ This galvanometer was described and exhibited to the Physical Society, December 29, 1906.

² F. Paschen, *Zeitschriften für Instrumentenkunde*, 13, 13, 1893.

³ Mendenhall and Waidner, *Am. Jour. Sci.* (4), 12, 259, 1901.

⁴ C. G. Abbott, *Astrophys. Jour.*, 18, 1903.

⁵ A. P. Wills, *PHYS. REV.*, XXIV., 243, 1907.

3. If long unbroken shields were to be used, either some complicated system of prisms or mirrors must be devised to get the light from the scale in and out of the top of the shields, which seemed difficult, or the scale reading mirror must be placed well above or below the needles on the end of a much elongated rotation axis. For sensitiveness combined with short period the needles should be very light. Hence, if the rotation axis is other than a very fine and absolutely straight rod, the increase of the moment of inertia due to its mass and wandering shape will more than neutralize all the advantage gained by light needles.

After many trials we abandoned hope of drawing a whip of glass at once sufficiently fine and straight for the purpose. We found it possible, however, to straighten a fine quartz rod by setting the top of it firmly in a clamp, attaching a small weight to the bottom, and stroking it up and down with a yellow gas flame. The rod was thus at once softened, stretched straight, and annealed. Rods after this treatment were apparently perfectly straight.

THE GALVANOMETER FRAME.

The details of construction of the galvanometer are shown in the diagrams, Figs. 1, 2 and 3. The upright *A* was made from a solid round brass rod, sawed through the axis, and the surfaces carefully faced, leaving elevations and depressions *ed* for hinges. A slot *mn* along the axis was cut out to receive the suspension *abc*. The halves were then firmly fastened together and turned down to a diameter of 3.8 centimeters, and a screw-thread turned on the lower end to attach it to the circular hard rubber base *B*. Just above this screw one of the halves was sawed through in a plane normal to the axis. This half of the rod was hinged to the other and served as a door. The rounded surfaces of both halves were milled out at *f*, as shown in Fig. 2, and transverse taper borings at *g* were made to receive the coils *c*₁, *c*₂, *c*₃ and *c*₄ which were set into place with beeswax *h*.

With the door closed the space between the coils facing each other was two and one half millimeters, just sufficient to allow the needle-system room to turn round.

¹ This method has since been used by Coblentz and is described by him in the Bulletin of the Bureau of Standards, Vol. 4, No. 3, 1907.

The door was also bored at i , and a mica window k , with its plane inclined to the vertical set into a recess, as shown in Fig. 2. When the door was closed a hard rubber disk B , bored out at the center to fit the gently tapering upright, could be slid down over

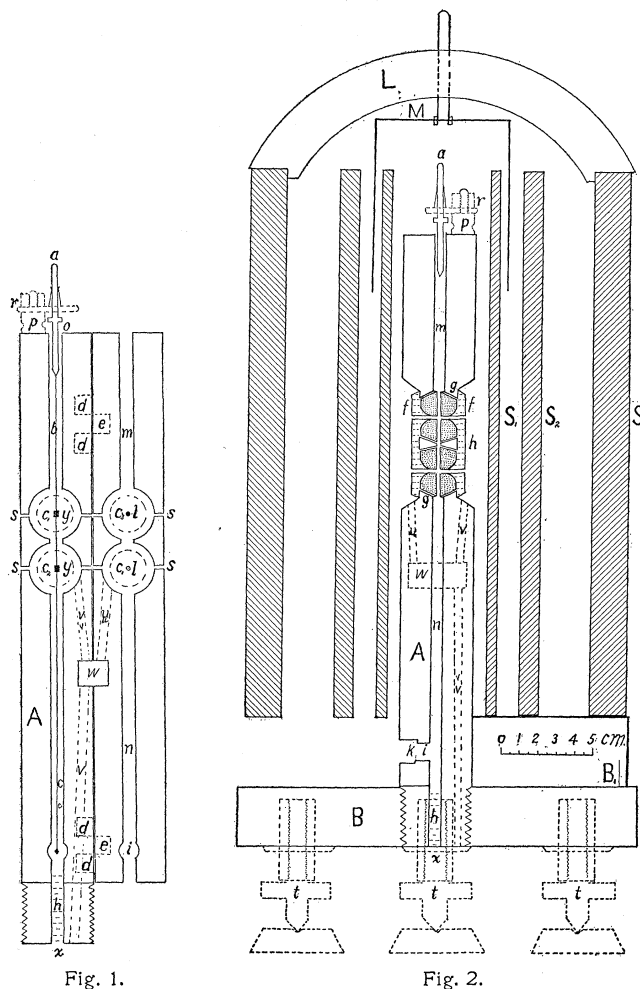


Fig. 1.

Fig. 2.

the upright, which it snugly fitted at the bottom, and thus the door was kept tightly closed. Out of this rubber disk B , which served as a support for the magnetic shields a sector was cut opposite the window k , to permit the observation of deflections. This is shown

by the dotted lines in Fig. 3, which represents a plane of the base. The arch *L*, bored at the top, carried a control magnet *M*, made of bent clock spring, by which the zero point and sensitiveness of the galvanometer could be changed at will.

The upper end of the quartz fiber of the suspension was attached to a rod *O* free to turn in a sheath soldered to a strap of brass. A slot was cut in the brass strip through which the shank of the binding post *p* passed. By these means the suspension could be accurately centered and clamped by the head *r*. By loosening the head when the door was open the suspension could be swung out from the plane of the rear coils for examination. The rod *O*, to which the fiber was attached, could be drawn out or put in from beneath

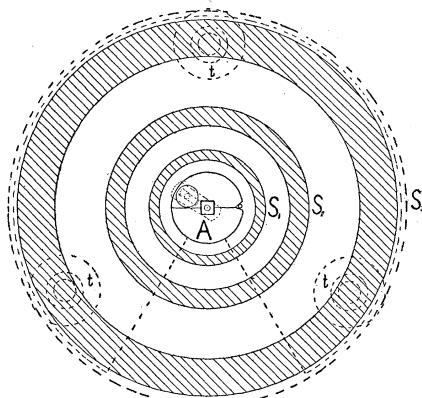


Fig. 3.

and was held in place by friction. These adjustments made it very easy to mount and center the suspension or to quickly exchange one suspension for another.

Small holes *l* through the axis of the two coil pairs facing each other and small slots *s* in the halves of the uprights at the heights of coil centers made inspection of the centering of the needle systems possible with the door closed, and the final adjustments of the needles might be made with the levelling screws *t* on the base.

THE COILS.

The dimensions and form of the coils and method of winding them were taken from data given by Abbott.¹ From his tabulated

¹ C. G. Abbott, l. c.

list of coils the size which gave a coil rated at five ohms resistance was chosen. Each coil was wound in three sections, the innermost consisting of 81 cm. of No. 38 wire, the middle section of 328 cm. of No. 32, and the outside section of 1,318 cm. of No. 26. The finished coils gave each a resistance of 5.6 ohms approximately.

The plane faces of the coils were covered with tinfoil to guard against static charges, and the terminal wires of each coil were twisted together and carried down through channels bored in the upright. The terminals of the two coils in the door were carried down the channel *u* to a space *w*, cut away from standard and door in the axis of the hinges. From this point all the wires passed down through the channel *v* to an outlet beneath the hard rubber base and were distributed thence to the eight binding posts lying in a semicircle on the underside of the base. The coils connected in multiple gave a total resistance of 1.4 ohms, in series 22.4 ohms.

NEEDLE-SYSTEM AND MIRRORS.

The needle-system *y* consisted of two groups of seven needles each. The needles were cut 2 mm. long from tungsten steel wire, 0.165 mm. diameter. They were attached to the thin quartz rod *bc*, 20 cm. long, and then magnetized in place. No special pains were taken to make the system astatic. At the bottom of the quartz rod a mirror of thinnest microscope cover-glass 1 by 0.9 mm. was fastened.

THE SHIELDS.

The shields, three in number, S_1 , S_2 , S_3 of " $x-1$ " silica steel were obtained from the General Electric Company through the kindness of Dr. Elihu Thomson. They were cast from patterns made in the laboratory shops. As the castings were not wholly free from flaws, the thicknesses planned for the separate shields could not be rigorously carried out.

The dimensions and weight of the shields appear in Table I.

TABLE I.
Length of Shields, 29.3 cm.

Shields.	Inner Radius.	Outer Radius.	Weight.
1	2.55 cms.	3.55 cms.	1,875 gms.
2	4.40 "	5.45 "	7,500 "
3	8.25 "	10.45 "	26,860 "

The shielding ratio was measured by using a single magnetized needle as a magnetometer. The deflecting field was generated by sending a current through a solenoid (L , Fig. 4) 41 cm. long, the axis of which was normal to the magnetic meridian. Measurements were made with current in solenoid direct and reversed for two symmetrical positions, R and L , one on each side of the needle as shown in Fig. 4. The period of the unshielded needle was observed,

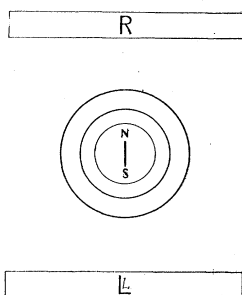


Fig. 4.

and the deflection due to a given current in the solenoid noted. The first shield was next put in place, the period of the needle again taken, and the deflection due to a larger known current in the solenoid observed. The shielding ratio for the first shield would then be

$$s_1 = \frac{\partial_1 i_2 t_2^2}{\partial_2 i_1 t_1^2},$$

where t_1 , ∂_1 , i_1 are the time of vibration and deflection for a current i_1 in the solenoid for the unshielded needle, and t_2 , ∂_2 , i_2 , the corresponding quantities for the shielded needle.

In this way the shielding ratio s_1 for the inner shield, $s_1 + s_2$, the shielding ratio for the inner and middle shield together, and $s_1 + s_2 + s_3$, the same ratio for the total shielding due to all three shields, was measured. This was done for the shields as they came direct from the lathe and repeated after the shields had been subjected by Dr. Wm. Campbell to a special annealing process by which the iron was subjected to several cycles of high temperatures followed by slow cooling. It is a pleasure here to acknowledge the

extent of our indebtedness to Dr. Campbell's skill, an indebtedness the extent of which the figures given below show plainly enough.

TABLE II.

Shielding Ratios.	Unannealed.	Annealed.
s_1	18.62	20.57
$s_1 + s_2$	240.44	317.60
$s_1 + s_2 + s_3$	2,903.33	4,273.50

A similar set of observations was made with five shields cut from soft iron water pipe. Dimensions and weight of shields are given in Table III., while Table IV. gives the shielding ratios.

TABLE III.

Length of Shields, 30.7 cm.

Shields.	Inner Radius.	Outer Radius.	Weight.
1	2.65 cms.	3.00 cms.	1,530 gms.
2	3.90 "	4.45 "	3,120 "
3	5.20 "	5.70 "	4,260 "
4	6.45 "	7.05 "	6,130 "
5	8.95 "	9.70 "	9,650 "

TABLE IV.

Shielding Ratios.	Annealed.
s_1	19.30
$s_1 + s_2$	104.09
$s_1 + s_2 + s_3$	252.00
$s_1 + s_2 + s_3 + s_4$	723.08
$s_1 + s_2 + s_3 + s_4 + s_5$	2,724.79

The galvanometer described, with coils in multiple and a full period of six seconds (three seconds swing), gave a sensitiveness of 4×10^{-10} volt for 1 mm. deflection on a scale 1 meter distant. When shielded with the three "x-1" iron shields the galvanometer on open circuit kept to a zero well within two divisions of the scale during the heaviest hours of traffic on the Amsterdam Avenue electric cars which pass within less than 25 meters of the instrument.

Greater sensitiveness is of course attainable with longer period, but as Abbott¹ has already pointed out the air damping for such suspensions is so great that there is little gain in increasing the time of a deflection unless the instrument is enclosed in an exhausted space. The form of galvanometer here presented is so compact that it could easily be put under a bell-jar and exhausted to any required vacuum.

Recently a second galvanometer of this same type has been built by our mechanician Mr. Cooley for Mr. L. E. Woodman with six annealed shields of commercial water pipe. A shielding ratio of over 9,000 was obtained. The dimensions of these shields are given in Table V.

TABLE V.
Length of Shields, 30.5 cm.

Shields.	Inner Radius.	Outer Radius.	Weight.
1	1.897 cms.	2.413 cms.	1,650 gms.
2	2.940 "	3.646 "	3,480 "
3	4.264 "	5.080 "	5,660 "
4	5.435 "	6.350 "	8,280 "
5	7.302 "	8.413 "	12,990 "
6	9.683 "	10.953 "	19,540 "

This galvanometer was placed directly beside the best form of shielded two coil Siemens and Halske galvanometer designed by duBois and Rubens. When the two were on open circuit and working at comparable sensibilities the new galvanometer showed a shielding against outside disturbances over forty times as great as the other.

In none of the above sets of shields was the geometrical relation of shield thickness to air space fulfilled, hence better shielding than we have reached could doubtless be obtained. The advantage of Mr. Woodman's shields over the others is probably due in considerable part to the smaller radius of the inner shield in his set.

PHENIX PHYSICAL LABORATORIES, COLUMBIA UNIVERSITY,
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¹C. G. Abbott, l. c.