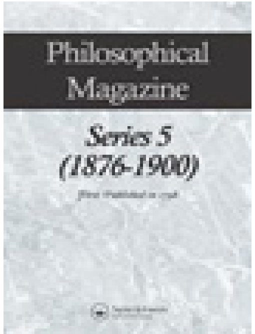

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LXIV. Description of a very sensitive form of Thomson galvanometer, and some methods of galvanometer construction

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LXIV. *Description of a very Sensitive Form of Thomson Galvanometer, and some Methods of Galvanometer Construction.* By F. L. O. Wadsworth*.

[Plate XIV.]

As considerable interest has of late been manifested, particularly in Germany, in the construction of very sensitive galvanometers, a brief description of one, which has recently been constructed for the bolometric work of the Observatory, may not be out of place in connexion with my last article (p. 482). This galvanometer in question is of the Thomson type of construction with four coils wound under my instructions by Messrs. Elliot, Bros.

Fig. 1, Plate XIV., is a section through one of the coils showing the contour of the individual sections, of which there are five, of about 4 ohms each, in each coil. The size of wire, number of turns, and resistance in each section of one of the coils, which is typical of all of them, is given in the following table.

Table I.—*Coil marked* A.

Section.	Size wire.	No. of turns.	Resistance (at 20° C.).
No. I. (inner)	0·0065″(37 B.W.G.).	255	4·48 true ohms.
No. II.	0·012″ (30 „)	410	4·21 „ „
No. III.	0·021″ (25 „)	640	4·13 „ „
No. IV.	0·025″ (23 „)	551	4·25 „ „
No. V. (outer).......	0·030″ (22 „)	540	4·28 „ „

Total number of turns . . 2396.
Total resistance . . . . 21·35 ohms.

The radius of the inner coil is 2 millim., and that of the outer coil 50 millim., and the depth of the coil was about 40 millim. As will be seen from the above table, the diameter of the wire increases somewhat less rapidly than the mean radius of the section, as required by Maxwell's theory, the thickness of the insulating covering, while not constant, being proportionally thicker for the finer than for the larger sizes†. The total number of turns in the four coils is 9593, and the total resistance (in series) 86 ohms at 20° C.

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* Communicated by the Author.

† Maxwell, Elec. and Magnetism, vol. ii. p. 363.

Each coil was cemented by means of melted shellac into an open brass case, which left the windings on the face of the coil exposed, and enabled them to be brought as close to the needle system as possible. These brass cases screwed into L-shaped supports, which rested on three adjustable screws—*a*, *b*, *c*, Plate XIV. (placed at three corners of the foot-plate of the L), the points of which slide in V-grooves planed in the metal plate which forms the base of the galvanometer-case. They are clamped in any desired position by means of a screw, *d*, working in a slot in the plate, as shown. This means of support allows the coils to be accurately centred with respect to each other, and, in conjunction with the levelling-screws on the case, to the needle system, independently of the adjustments of the latter. It also enables the coils to be readily removed whenever it is necessary to get at the needle, and the distance between the coils to be varied to increase or decrease the delicacy, without altering the astaticism of the system by means of a directing magnet.

The needle system itself is shown in fig. 4 (Pl. XIV.). The central staff is about 150 millim. long, drawn from glass tubing, and weighs about 5 mgs. On account of the length and thinness of the staff, special means of drawing it were necessary in order to get a perfectly straight piece.

A good method is to clamp a selected piece of tubing, about 5–10 millim. in diameter, in a retort-stand so it hangs vertical, and attach to the lower end a 4–5 lb. weight, which rests on some simple form of trap 4 or 5 feet above a box filled loosely with waste or shavings. The tube is heated uniformly by two good Bunsen burners until it begins to soften, then the burners are removed, the trap is immediately sprung, and the weight falls into the box placed to receive it, drawing out a thin tube of glass, the diameter of which will depend on the length of tube which has been softened. From a few fibres thus drawn a piece can be selected which will be satisfactory as regards straightness and lightness.

The two members of the system are built up each of ten small magnets, five on each side of the staff, the central one about 3 millim. long, and the upper and lower ones each a little less than 2 millim. They are made from the smallest size sewing-needles broken to the required length, but otherwise untreated*. They were attached to the staff by first

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* This material is unsuited for the purpose, being too soft a grade of steel for retaining a high permanent magnetization. Some bars of special magnet steel were ordered, but have not yet been received, and pending their arrival the above material was used as the best available for the purpose. With steel of proper size, quality, and hardness, the magnetic moment could, I am certain, have been more than doubled, without any increase in weight.

cementing each set of five, in proper position, to a piece of thin tissue-paper, placing two sets face downward in the proper position, and at the proper distance apart, on a glass "flat," laying the glass staff on top of them, and cementing it to each by means of a very small drop of thick shellac. When dry enough to handle, the other two sets were attached to the other side of the staff, opposite the first two, in a similar manner. The mirror was then attached midway between the two members by means of a minute fragment of soft wax ("universal"), which touched the upper edge only of the mirror; a method more satisfactory than any other I have tried for mounting small thin mirrors without distortion.

This mirror was $2\frac{1}{2}$ millim. in diameter and 1 millim. radius of curvature. It had an accurately worked surface (by Brashear) (rendered necessary by the fact that it is used for a photographic record), and had to be therefore quite thick and heavy for its size. The weight of the mirror was about 12 mgs., and the weight of the whole system about 40 mgs. It was magnetized and astaticized after being completed by the method described in my last article. The system was suspended by means of a fine quartz fibre, about 40 centim. long, whose tension was negligible. The method of supporting the fibre is in some respects novel, and has proved very successful in eliminating vibration, which, on account of the lightness of the system, at first proved very troublesome. The glass tube, *f*, of about 1 centim. bore, which carries at its upper end the adjustable head, *h*, to which the fibre is directly attached, is not directly connected with the galvanometer-case, but is supported by two thick rings of soft rubber, *m*, *n*, very slightly compressed between the glass tube and an outer heavy brass tube which is screwed to the top of the galvanometer-case. There is consequently no metallic or solid connexion between the fibre-support and the rest of the instrument, and the vibration which is communicated to the latter from the pier is absorbed by the rubber before it reaches the needle. It is also possible with this arrangement to attach the directing magnet to the outer brass tube without prejudicing the steadiness of the image during adjustment.

The damping of the needle is effected partly by a piece of dragonfly's wing attached to the back of the mirror and partly by four copper rods, which slide into the cores of the coils.

The coils on each side are connected in series, and the terminals brought up and connected to two copper binding-posts on the top of the case. The two sides could therefore be connected either in series (resistance 86 ohms) or in parallel (resistance 21+ ohms); or by changing two connexions inside the case, all four coils could be put in parallel. Total (5 ohms) as desired.

The case was unusually large and heavy, with brass frame and glass sides, with all joints as air-tight as it was possible to make them. It had the usual doors and levelling-screws.

The constant of the galvanometer with the magnet system, already described*, was for all coils in series, $C=4\times 10^{-11}$, where C, as before, is the current in amperes required to produce a deflexion of 1 millim. at a distance of 1 metre for a time of single swing of 10 sec. This is about the degree of delicacy recently attained by Snow †, the constant of whose instrument reduced to the units above used was $C=4\cdot 5\times 10^{-11}$ for a somewhat higher resistance (140 ohms).

More recently, Paschen ‡ has attained a degree of delicacy considerably exceeding this by the use of an excessively light magnetic system, which did not appear to be stable enough to be actually used with a 10 sec. period in measurement.

The question of the influence of the mass of the system on the delicacy is one of importance. It was first pointed out by Boys, and later by Paschen, that if a fixed time of vibration be considered, the sensitiveness of the galvanometer (other things being equal) will increase as the mass of the system decreases. This has been experimentally verified by Du Bois and Rubens, who, by the use of light magnetic systems, have recently produced commercial galvanometers having a sensitiveness nearly equal to that of Snow's instrument §.

But the assumption of a fixed time of vibration is unfair to the heavier systems, for it conditions them to a degree of more and more imperfect astaticism as the weight increases. If, instead of the condition of a fixed time of vibration, we impose that of a fixed degree of astaticism, viz., if we make the residual magnetic moment of the systems as a whole constant, then the sensitiveness of the galvanometer will *increase* with the mass of the magnetic system, supposing always that the coils of the instrument are suitably proportioned to the needle. A better understanding of these points is afforded by their analytical expression. We will suppose

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* As has already been stated in a previous footnote, this system could be very sensibly improved, but as the sensitiveness of the galvanometer even with the present system is greater than necessary, and as my time has been fully occupied with other work, this has not yet been done.

† Wied. *Ann.* vol. xlvii. p. 218 (1892).

‡ *Ibid.* vol. xlviii. p. 284 (1893).

§ Wied. *Ann.* vol. xlviii. p. 236 (1893).

for convenience that each member of the system is equivalent to a circular disk whose diameter, $2r$, is equal to the length of the longest magnet of the system, and whose thickness, w, is such that the mass of the disk is equal to the sum of the masses of the individual magnets*. Then the mass of the disk will be Ar^2w and its moment of inertia Br^4w. The mass and moment of inertia of the mirror will be $A'r_0^2w_0$ and $B'r_0^4w_0$ respectively.

Then, if t denote the time of single swing, M the residual magnetic moment of the system, and H the strength of the field in which the system swings :—

$$t=\pi\sqrt{\frac{I}{MH}}=\pi\sqrt{\frac{Bwr^4+B'w_0r_0^4}{MH}}.$$

The moment of the force required to produce unit deflexion, θ, of the system is FCm; where C is the current flowing in the coils, m the individual magnetic moment of one member of the system, and F a constant involving the constant of the coils, the intensity of magnetization, &c.; and it is also equal to $MH\theta$. Therefore

$$MH=F/\theta\,Cm=F'Cwr^2,$$

since the magnetic moment is, for the same intensity of magnetization in different disks, proportional to the mass of the disk, that is to wr^2.

Therefore, finally,

$$t=\pi\sqrt{B''\frac{r^2}{C}+\frac{B'''}{C}}.$$

Hence, if t is constant, C varies as r^2 plus a constant; that is, the sensitiveness increases somewhat less rapidly than the mass of the system diminishes. But if no limit is imposed on the time of vibration, but only on the final degree of astaticism, then $MH=\text{const.}$, hence $Cm=\text{const.}$, or the sensitiveness varies directly as the magnetic mass. It is true that the conditions of use impose the former rather than the latter limit, but for an average time of single swing of 10 sec., which is not inconveniently long, I believe that a system weighing from 40 to 60 mgs. will be found best, for if very great sensitiveness is required, we can use a time of swing of from three to four times this without as great inconvenience as would result from the use of a system only

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* It is not of importance here to consider the most effective form or arrangement of individual magnets, as we are only considering relations between systems of the same form, but of varying dimensions.

one tenth as heavy with a 10 sec. period. With very light systems the mirror is unduly heavy in proportion to the weight of the magnet systems, and the difficulty of handling, and especially of astaticizing, is much increased. Their principal disadvantage, however, is their extreme sensitiveness to vibration. A system weighing 25 mgs. was first used in the galvanometer described above, but it was found absolutely unfit for photographic work because of the unsteadiness of the image.

Indeed, even with the heavier system, the complete elimination of the effects of vibration proved a troublesome problem, for the Observatory is in close proximity to several traffic-laden streets, and the work had necessarily, because of its nature, to be carried on during the busiest part of the day. Very good results were finally obtained by use of the insulated fibre support, already described, in conjunction with the use of rubber blocks between the slab of stone on which the galvanometer was mounted and the pier which supported the whole. Under very favourable circumstances a somewhat lighter system than the one here recommended could no doubt be used ; but in the great majority of cases I believe that the weight should not be less than 30 to 40 mgs., and may with advantage be considerably more.

Astro-Physical Observatory,
Washington, June 1893.

LXV. *Telephonic Measurement of Electromotive Force.*

By Carl Barus[*].

1. *PURPOSE.*—Notwithstanding the varied use which has been made of the telephone in electrical measurement, I am only aware of isolated efforts[†] to replace the galvanometer by the telephone in the zero methods for electromotive force. Yet, according to the earlier observers, the telephone ought to be more than sufficient for the purpose (§ 2). The problem suggested itself to me in connexion with thermoelectric pyrometry, where an avoidance of the galvanometer would often facilitate the work. Recently I thought of it again in relation to certain meteorological experiments, in which temperatures are made to vary in rapid rhythm by condensation, and the object is to find the thermal amplitude and the character of the oscillation. It thus becomes necessary to vary the electric contacts in like rhythm and to find

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[*] Communicated by the Author.

[†] Ledeboer, *Beiblätter*, ix. p. 357 (1885).

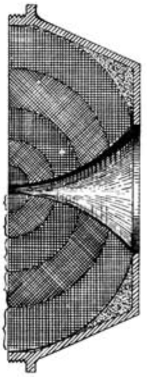

Fig 1

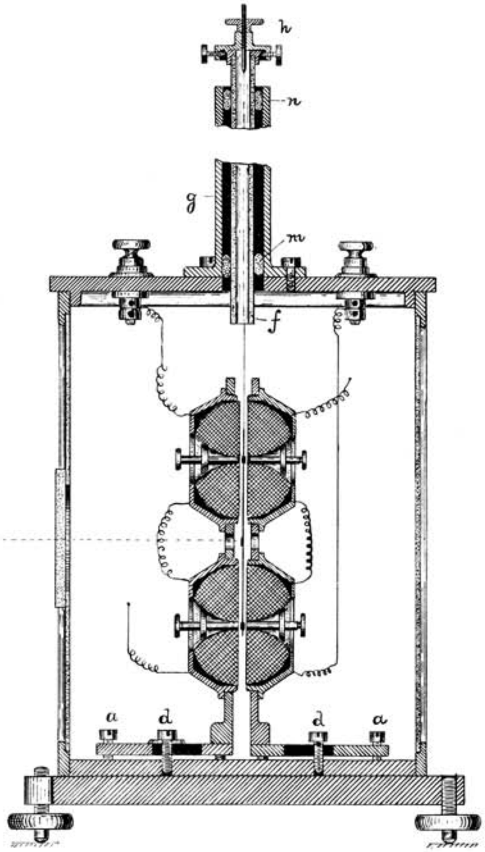

Fig 2

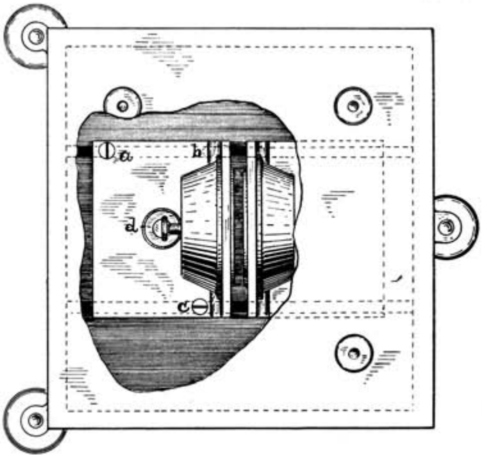

Fig 3

Fig 4