



XIII. On a new form of resistance-balance adapted for comparing standard coils

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of a wire should behave differently; for the slightly heavier loading of its upper parts could hardly, according to the above investigation, explain this anomaly, at least after the state of the wire has become constant.

The present experiments show that the experimental portion of this field of research still needed extension ere it would be possible to arrive at an exhaustive theory of the phenomena of imperfect elasticity, in which, after determining the static (*i. e.* the mean) positions of equilibrium of the molecules executing their thermal vibrations, one might also enter upon the direction of the latter.

I hope shortly to be able to make further communications upon the subject here treated, and especially on its relations to magnetism.

Leipzig, January 1879.

XIII. *On a new Form of Resistance-Balance adapted for comparing Standard Coils.* By J. A. FLEMING, D.Sc. (Univ. Lond.), Scholar of St. John's College, Cambridge*.

[Plate IV.]

1. **T**HE British-Association Committee on electrical standards concluded their valuable labours on the unit of resistance by constructing copies of the selected standard. Certain of these coils, some fourteen in number, are at present preserved in the Cavendish Laboratory, Cambridge. It is important that these coils, which consist of wires of various alloys, should be from time to time carefully compared together in order to determine whether the ratio of their resistances at definite temperatures remains the same†. Observations ought also at the same time to be made of the temperatures at which they agree, and also of their coefficients of variation of resistance with the temperature. In using for the purpose the ordinary form of divided-metre bridge, several objections present themselves which render it a tedious process to determine accurately the difference in the resistance of two coils at different temperatures, and hence to deduce their variation-coefficients. It seemed, on consideration, that

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† A detailed and most careful comparison of these coils was made by Prof. G. Chrystal and Mr. S. A. Saunder in 1875; and their Report is printed *in extenso* in the Report of the British Association at Glasgow in 1876. This is the most recent occasion on which these coils have been examined.

a modification of the usual form of Wheatstone's bridge would render these processes more expeditious and at the same time more accurate. It is the object of the present paper to describe a form of resistance-balance which has been recently constructed for the Cavendish Laboratory, and which experience shows to have several decided advantages over the old form.

2. *Description of the Resistance-balance.*—A circular disk of mahogany 18 inches in diameter and about 1 inch thick (f) (Plate IV. figs. 1 and 2) stands upon three short feet L. Upon this, and concentric with it, is screwed down a disk of ebonite 14 inches in diameter and $\frac{3}{4}$ of an inch thick (e). This ebonite disk has a semicircular groove turned in its circumference. The circular wooden base extends on one side into a narrow rectangle (j) 4 inches wide and of the same thickness as the disk. To this are connected two other rectangular pieces (h, i), which are joined together by slotted brass bars (y , see fig. 2) underneath, in such a manner as to permit the two intervals to be made wider or narrower at pleasure. This promontory is of wood, of the same material and thickness as the disk f , and is supported and levelled by three levelling-screws n, n', n'' . Through the centre of the ebonite disk passes a brass centre-pin $D D'$ (fig. 2), on which is centred a brass arm, $H H'$, capable of revolving round just clear of the disk. Beneath the arm, and soldered to it, is a short brass spring x , which depends vertically downwards. This spring carries at its extremity a small prism of platinum-iridium with one edge vertical and turned inwards. In the groove turned in the disk e is stretched a platinum-iridium wire about $\frac{3}{32}$ of an inch in diameter. The wire extends round about $\frac{2}{3}$ of the circumference, and is about 39 inches long; and the groove is of such a size that the wire lies with exactly half its thickness imbedded in it. This wire is represented by the thick black line $A C A'$ in fig. 1. The ends of this wire are soldered to copper strips k, k . On the wood rectangles j, h, i is fastened an arrangement of longitudinal copper strips, k, k , which connect together eight transverse square copper bars in the manner shown in fig. 1. On the ends of these transverse bars are fixed vertical copper pins $\frac{5}{16}$ of an inch in diameter and $\frac{3}{4}$ of an inch high. On these pins are slipped short lengths of india-rubber tube which extend beyond the pins, so that they form small cups about 1 inch deep, p' (see fig. 3). The top of the copper pin is well amalgamated with mercury, and forms the bottom of the cup. These cups are filled about a quarter full of mercury. On the longitudinal strips of copper are fixed three binding-screws B, B', G ; and a fourth (G') simply goes through

the wood, and is connected by a wire t underneath the base-board with the centre-pin D , and is therefore in metallic connexion with the spring x . The battery is connected with the terminals B , B' , and the galvanometer with the terminals G , G' . To the arm H H' is adapted a trigger, T , of such shape that when the button w , which is of ebonite, is pressed down, the spring x , carrying the platinum-iridium knife-edge, is bent inwards until it touches the wire strained round the circumference of e . The arm carries a vernier N , which travels round sunk in a shallow groove in the face of the ebonite disk; and the ebonite is graduated on the face on the margin of the groove. The graduations are cut into the ebonite, and then rubbed over with powdered chalk mixed with gum and water. This gives a graduation very legible and pleasant to look at. The length of the wire is just one thousand divisions; and the vernier enables these to be divided into tenths. The zero of graduation is so placed that, when the pointer of the vernier reads zero, the knife-edge on the spring x is exactly opposite the extremity of the platinum-iridium wire.

It is thus clear that the revolving arm carrying its knife-edge can be moved round so that, on pressing the trigger-button w , the knife-edge makes contact at any point of this wire, and thus connects this point with the terminal G' .

This part of the arrangement answers to the sliding block and piston-contact piece of the ordinary divided-metre bridge.

3. *Method of using the Balance.*—Let now two resistance-coils of about equal resistance be provided, and let the coil-terminals of one coil be placed in the mercury-cups p and r , and those of the other be placed in q' and s' . And let two more coils be taken of not very unequal resistance which it is desired to compare with each other, let the terminals of one be placed in the mercury-cups a and c , and those of the other in b' and d' . It will then be seen that if a battery be connected with B B' , and a galvanometer with G G' , that we have the usual Wheatstone's bridge arrangements (see fig. 5 on page 113, which gives a diagram of the connexions). Two quart Leclanché cells are best suited for ordinary use. If a more powerful battery is used, there is danger of heating the platinum-iridium wire, and so expanding it that it may slip down out of its groove.

The coils in the intervals between the cups p and r and q' and s' form two branches; and the coil in the interval between a and c , together with the resistance of the platinum-iridium wire round to the place where the spring x touches it, forms the third branch, whilst the coil in the interval b' d' , together with the remainder of the wire, forms the fourth. The

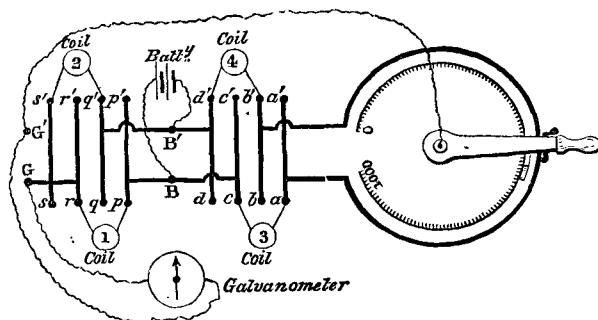
"bridge"-wire consists of the arm $H H'$ and the wire under the base-board together with the galvanometer inserted between G and G' . By moving round the arm $H H'$ and pressing the button w , we can find a position where there is no current through the galvanometer. The copper strips $k k$ are made of copper so thick that their resistance is practically nothing. Having established a balance between the conductors and read the vernier, the next operation is to lift up the legs of the coil which were inserted in the cups a and c and drop them into the cups b and d . Likewise a similar change is effected on the other side; the terminals of the coil inserted in b' and d' are changed to a' and c' . An examination of the connexions as shown in fig. 1 will show that the result of the operation is as if the coils had *changed places* whilst preserving their former connexion. Now let the arm be moved round and a fresh position of equilibrium found by pressing the trigger and reading the vernier. A little consideration will show that the difference of these readings gives the difference between the resistances of the coils in terms of a length of the bridge-wire; for the amount by which one coil exceeds the other in resistance is equal to the resistance of that part of the bridge-wire included between the two readings*. In order to render this method of determining the difference of the two coils practicable, the platinum-iridium wire must be exceedingly uniform in resistance, or else a Table of calibration will have to be made. Great pains were taken to procure a length of wire as uniform in size and resistance as possible; and considerable care was taken, in laying the wire in its groove, not to strain it in any way. It lies evenly in its groove, just sufficient tension being put upon it to keep it in its place. The whole resistance of the wire from end to end is not far from $\frac{1}{20}$ of an ohm at about 15°C .

The wire was carefully calibrated by measuring the difference in the resistance of two pieces of thick brass wire of such lengths that the difference of their resistances was about equal to that of thirty divisions of the bridge-wire; and this difference was measured at about a hundred different equidistant

* This method of obtaining the difference of two resistances in terms of a length of the calibrated bridge wire was suggested by Prof. G. C. Foster, F.R.S., in a paper read before the Society of Telegraphic Engineers, May 8, 1872. In this paper is given an account of the method of calibrating a wire. It is obvious, without any further proof, that if the coil placed in a and c exceeds in resistance that placed in b and d , then on exchanging them, since the united resistance of coils and bridge-wire remains the same, that the contact knife-edge must be moved back along the bridge-wire by a length exactly equal in resistance to the excess of one coil over the other.

positions all along the bridge-wire, and found to be so nearly the same that no Table of calibration was deemed requisite. To protect the bridge-wire from injuries, as well as to preserve it from being heated by radiation from surrounding bodies, a wooden ring, *vv*, is fastened down on the base-board. The ring is $1\frac{1}{4}$ inch wide and $\frac{3}{4}$ inch deep; and its internal diameter is 1 inch greater than that of the ebonite disk. The wire, therefore, lies hidden away on the side of a square-sectioned circular tube; and, furthermore, a shield of cardboard faced with tinfoil lies upon the face of the disk *e*, extending just beyond the ring. An aperture is cut in this shield to permit the passage of the trigger, as well as to allow the vernier to be read. By this means the wire is not only out of sight, but out of reach of all radiation as well as mechanical injury.

Fig. 5.



4. *Method of determining the Variation-coefficients of Coils.*—To determine the variation-coefficient of any given coil we proceed as follows:—Three other coils are provided, two of them nearly equal in resistance, which we will call 1 and 2. A third coil, 3, must be taken whose resistance is nearly equal to that of 4, the coil whose variation-coefficient is desired (see fig. 5). The terminals of 3 are inserted in the mercury-cups *a* and *c*, those of 4 in *b'* and *d'*, those of 1 in *p* and *r*, and those of 2 in *q'* and *s'*. Now the operation to be conducted is to keep the coils 1, 2, and 3 at a fixed temperature, and to keep 4 successively at two known temperatures, differing by about 15° Cent., and to obtain the difference of the resistances of 3 and 4 at these two temperatures. The difference of these differences, divided by the difference of the temperatures, is the mean coefficient of variation of resistance between these temperatures. The chief difficulty to be contended with is that of keeping the temperature of the coils constant during the operation, and of ascertaining what that temperature is;

for, as Prof. Chrystal has remarked in his report (Brit. Assoc. Report, 1876), it is not easy to tell whether the temperature of the water in which the coil rests is identically the same as that of the wire, since the latter is imbedded in a mass of slowly conducting paraffin. To reduce as far as possible the difficulty of keeping the coils at a constant temperature, they are placed in water-vessels made of zinc (see fig. 3, Pl. IV.). These water-boxes are composed of two cylindrical vessels—an outer case 9 inches high and 8 inches in diameter, and an inner one of lesser size; the two are connected at the top, so that they form a sort of jar with hollow sides and double bottom. This interspace forms an air-jacket. Around the inside vessel near the top is a row of small holes; and two tubes communicate at the bottom—one with the inner vessel, and the other with the annular interspace. The top is closed by a wooden lid with apertures for thermometer and stirrer. Water can be made to flow from the supply-pipes into the inner vessel; it rises up and overflows through the holes, and drains away down the interspace and out by the other pipe. The bodies of the four coils are placed in four water-boxes of this description; and water from the town mains being sent in a continuous stream through all four water-boxes, the coils are rapidly brought to and maintained at a known temperature. Any desired temperature can be given to one coil by leading warm water from a cistern into its vessel. The annular air-filled space renders the rate of cooling very slow. Hence the coils, once at the desired temperature, can easily be kept there. Fig. 4, Pl. IV., gives a sketch of the arrangement, two of the water-boxes being removed to show the connexions.

The advantage of the somewhat complicated arrangement of copper bars will now be seen. We can, without withdrawing the coils 3 and 4 from their water-boxes, and without in any way disturbing the other arrangements, *reverse* the position of the coils 3 and 4 on the bridge, by simply lifting up the legs half an inch and changing the mercury-cups into which they dip. Thus the legs of coil 3 are changed from cups *a* and *c* to *b* and *d*, and those of coil 4 from *b'* and *d'* to *a'* and *c'*. This exchange does not occupy more than a few seconds; and hence we can obtain the two readings necessary to give the difference of the resistance of the coils 3 and 4 when they are at different temperatures in a very short time. During this short time the temperatures of the two coils will not change perceptibly, protected as they are by an air-jacket.

In the ordinary form of straight bridge there is considerable trouble in exchanging the coils, because the water-vessels have to be moved and the mercury-cups readjusted; and all this

time the coils are cooling; so that the two readings are never made under the same circumstances as regards temperature. Beginning, then, with all four coils at the same temperature, we take the difference between 3 and 4. To get them all at the same temperature, water from the town mains is allowed to circulate through the system for half an hour. At the end of this time the difference of 3 and 4 is taken; and several readings are taken at small intervals of time to see if the temperatures are constant. This being done, the temperature of coil 4 is raised by the introduction of warm water until it is about 15° above that of coil 3. It is best to raise the temperature about 20° above the other at first, and keep it there for 20 minutes, and then let it fall very slowly. In this way coil and water cool together, and an equilibrium of temperature is established between them. The difference between 3 and 4 is again taken; and from these two readings we have, as seen above, the mean variation-coefficient between the two temperatures. Another method, which would probably be a more accurate one, for obtaining the mean coefficient of variation between 0° C. and 15° C. would be to wait until the temperature of the water in the town mains was about 15° C., and then to keep three of the coils at that temperature, and to cool the fourth by means of ice to zero. If then all four were kept at 15° and the observations repeated, we should have the means of finding the variation-coefficient of the fourth coil between 0° and 15° . Prof. Chrystal, in his report, threw out the suggestion that resistance-coils should have a thermoelectric couple attached to them, one junction being buried in the heart of the paraffin surrounding the wire, and the other outside. This has been tried in some coils recently made, and proves a satisfactory method of ascertaining the equilibrium of temperature between the wire and the water.

Another source of error in the ordinary methods arises from uncertain or variable resistances at the mercury-cups. It is important that the copper legs of the coil-terminals should press very firmly against the tops of the copper pins on which the india-rubber-tube cups are fixed. To ensure this, the plan adopted is to fasten on the coil-legs an ebonite clamp. Along the edge of the wooden promontory, $j h i$ (fig. 1), are put brass pins m ; and by means of steel spiral springs fixed to these and attached to the clamps the coil-legs are pressed down very firmly (see fig. 3). The ends of the pins which carry the india-rubber cups and the ends of the coil-legs being well amalgamated, we get, when they are thus firmly pressed in contact, a very good joint, and one whose resistance is small and constant. If the clamps are not used, then one leg may get lifted

up a little, and thus a short length of mercury interposed, which leads to an error in a reading.

5. *Example of a determination of the Variation-coefficient of a Coil.*—The whole resistance of the platinum-iridium wire is very nearly 0.0512 of an ohm, or not far from $\frac{1}{20}$ of an ohm, at about 15° Cent. As the whole length can be divided by the vernier into 10,000 parts, this gives as the value of $\frac{1}{10}$ of a division $\frac{1}{200000}$ of an ohm.

The unit in the following example is $\frac{1}{10}$ of a division. To secure the greatest accuracy of measurements a low-resistance galvanometer must be used. I am in the habit of using one having a resistance of about half an ohm. The image of a wire strained across a slit is reflected on a scale in the usual way, and read at a distance by means of a telescope. This galvanometer will give an indication, when used with precautions, due to a difference of one tenth of a division when comparing two ohm coils. But as the temperature can hardly be measured with certainty to within less than $\frac{1}{20}$ of a degree, this alone renders such refinement of reading nugatory, in the absence of better methods of ascertaining with certainty the real temperature of the wire.

Two coils were compared. Call them F and K. K is the coil whose variation-coefficient is required.

I. *Difference of Resistance of Coils F and K at 11° Cent.*

	Bridge-readings.		Difference.
Exp. i.	5000	4955	45
Exp. ii.	5000	4954	46
Exp. iii.	5000	4955	45

The first column gives the number of experiment, the second the reading with the coils F and K in one position on the bridge, the third when F and K are reversed or have exchanged places on the balance; and the fourth gives the difference of their resistances at 11° C. in units of the bridge-wire.

II. *Difference of Resistance of Coils F and K at 28°·2 Cent.*

	Bridge-readings.		Difference.
Exp. i.	5439	4492	947
Exp. ii.	5442	4497	945
Exp. iii.	5440	4490	950

As before, the fourth column gives the difference of F and K at 28°·2 C. Taking the mean difference at 28°·2 C. to be 947 units, and that at 11° C. to be 45 units, we have

$$\frac{947-45}{28\cdot2-11} = 52\cdot4 \text{ units}$$

as the mean variation-coefficients between 11° C. and 28° C. in units of bridge-wire. Since the coils F and K are approximately ohm coils, this gives as the variation-coefficient of the coil K ·0262 per cent. This coil is of platinum-silver wire. These three determinations occupied about an hour and a half, during which time many more readings were taken, all closely agreeing with the above. The actual measurement of the differences requires but a few moments to effect, the principal expenditure of time being that required to bring the coils to the same temperature as the water.

In conclusion, I may state that this resistance-balance has been constructed in the workshops of the School of Mechanical Engineering at Cambridge, under the direction of Prof. Stuart. Great care was taken in laying on the wire so as to avoid straining it in any way; and the performance of the instrument is consequently very satisfactory. I should also express the fact that this excellent performance is due to the supervising care of Prof. Stuart, who not only supplied several of the details of the construction, but aided, by his valuable suggestions generally, during the process of carrying out my rough designs into a practical form.

Cavendish Laboratory, Cambridge,
December 1879.

XIV. A Dispersion-Photometer.

By JOHN PERRY and W. E. AYRTON*.

IN measuring what is usually termed the power of a light, it is common to have a screen placed at such a distance from the light that its illumination is equal to that which it or another screen receives from a standard candle. Now, if a standard candle is, say, one foot from a screen, an electric light of, say, 6400 candle-power must be placed at the distance of 80 feet from a screen to give the same illumination. That a great distance like this should be necessary, and in a chamber whose walls are supposed to be blackened, in the laboratories of works where electric lights are usually examined, has placed

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