On the Use of Bare Wire for Resistance-coils

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DISCUSSION.

Mr. BLAKESLEY said that the author's arrangement could only be used for measuring the *current* in the primary. Only if the self-induction of the primary is large and its resistance small, the secondary circuit being open or of large resistance, can the voltmeter of the secondary coil give indications proportional to the P.D. of the primary. The reading will then be the P.D. of the primary multiplied by fraction representing the ratio of the coefficient of mutual induction to that of self-induction in the primary. This will be true independently of the period. But if the frequency is to be kept constant as well as all the other properties of the circuits, of course all effects in both circuits will simply be proportional to the P.D. of the primary, but in that case there is no necessity to make the self-induction of the secondary great, so that the advantage of doing so is not obvious.

XXV. *On the Use of Bare Wire for Resistance-coils.* By F. W. BURSTALL, M.A., formerly Scholar of St. John's College, Cambridge*.

I. *Introduction.*

It is perhaps somewhat surprising that the form of resistance-coils as used in the ordinary box has, during the last twenty years, changed less than any other kind of electrical instrument. The most serious defects of the present form of resistance-box are, firstly, the difficulty of ascertaining the temperature of the wire forming the resistance, and, secondly, that the method of short-circuiting any required number of coils by means of divided brass blocks and taper plugs leads to contact-resistances which are often of very variable amount. A resistance-coil, the wire of which is covered with silk wound very closely and then covered with paraffin, of necessity conducts heat very badly, and therefore the temperature, as shown by a thermometer placed in the box, gives but little information as to the temperature of the resistance-wire. I have endeavoured to overcome the temperature difficulty by using manganin

* Read June 26, 1896.

wire, but the uncertain nature of this material has forced me to abandon its use. The suggestion for the employment of a bare wire immersed in oil is due to Mr. E. H. Griffiths, and it is with the developments of this suggestion that the present paper deals. There can be no doubt that with a bare wire immersed in oil the heating by the testing current is much less than with covered wire, and further, the temperature of the wire can be accurately measured; but perhaps one of the most important advantages in the use of a bare wire lies in the fact that the wire can be annealed in a most perfect manner by the passage of a sufficiently large current to heat it to a red-heat for a few seconds. It has long been known that well-annealed coils are much less liable to change than coils which have not been so treated. Dr. Lindeck, of the Reichsanstalt, has, in his various papers, laid great stress upon the necessity for annealing standard coils, which is effected by heating the coil in an air-bath to about 140° , the highest temperature a silk-covered coil can bear without material injury. The heating of the wire to a red-heat is, of course, much more efficient than the method adopted by Dr. Lindeck for freeing the wire from undue stress.

The wire which I have employed for the whole of the resistance-box was drawn from one cast of platinum-silver, a material which experience has shown to be the most perfect for resistance-measurement.

The two forms of resistance-box usually employed are the series form and the dial form. In the former a number of coils are placed in series, and any required number can be short-circuited. This form, though it requires comparatively few coils, has the disadvantage that any fluctuation in one plug causes an error in the final measurement, and if any considerable number be used, it is almost impossible to prevent variation in the sum of the contact-resistances. For these reasons it seemed advisable to adopt the second form of box, the dial pattern, in which the number of plugs employed is a minimum, and remains the same whatever resistance is being measured.

It is not essential to make standard resistances in order to calibrate a resistance-box, as each dial can be measured in terms of the preceding dial. This method, however, perpetuates any errors that may have been made in the measure-

ment of any of the smaller coils, and it is not possible to measure the coils in the box with the same accuracy that can be attained in the determination of the standard coils. I have therefore constructed standard coils for every dial, and their values have been obtained from a 1 ohm coil independently of the resistance-box.

II. *Construction of the Resistance-box and Standards.*

The resistance-box has five dials, each consisting of nine coils, ranging from $\frac{1}{10}$ of an ohm to 1000 ohms, and four pairs of proportional arms ranging from 1 to 1000 ohms.

The $\frac{1}{10}$ ohm coils have a length of 96 millim., the wire having a diameter of .63 millim. Being so short, there is no difficulty in supporting the coils.

The wire of the 1 ohm coils has the same diameter and a length of 960 millim. These coils were at first wound into short spirals, and were allowed to hang freely from their terminals. It soon, however, became apparent that the convolutions of the spiral required to be fixed rigidly to the ebonite top. The method that has been finally adopted is to screw the spiral into holes pierced in a mica plate; this plate being screwed top and bottom to a brass bar which is attached to the ebonite top.

In the coils of from 10 to 1000 ohms it is not easy to find a form of bobbin on which to wind the great lengths of bare wire required in such a manner as to avoid short circuits, and to bring the wire in contact as little as possible with the insulator. The form I have ultimately adopted is as follows (fig. 1):—To a central brass rod are attached, for the 10 ohm and 100 ohm coils, two small brass crosses at a distance of about 150 millim. apart; to the ends of the arms of these crosses are screwed serrated strips of mica, the pitch of the serrations being about 1 millim. The resistance-wire is then bifilarly wound into these serrations. The 1000 ohm coils are of the same form, but from their greater length, 250 millim., it is necessary to employ a third cross in order to strengthen the mica, and even then difficulty has been experienced owing to the mica bending under the coil-tension, culminating in several cases in the breakage of the wire.

For the 10 ohm coils wire having a diameter of .30 millim. and a length of 2400 millim. has been used. For the 100

ohm coils, a diameter of $\cdot 15$ millim. and a length of 6200 millim. For the 1000 ohm coils, a diameter of $\cdot 075$ millim. and a length of 14500 millim.

The top is of ebonite, 86 centimetres long, 28 centim. wide, and 19 millim. thick.

Instead of using divided blocks for the dials, conical plugs, having a maximum diameter of 9 millim., and a taper of 1 in 12, fitting into conical sockets have been employed*. The plugs are connected with the zero socket of the previous dial by means of heavy flexible leads, having a copper core, 5 millim. in diameter, composed of copper wires of diameter $\cdot 2$ of a millim. It was found necessary to use comparatively large wire, as the first set of connecting leads, built up of wire $\cdot 07$ millim. in diameter, parted with the constant turning and gave rise to a variable plug-resistance. The use of the conical plug in a solid conical socket is completely free from errors caused by the change of shape of the insulating material; further, such forms can be easily and accurately machined, a matter of no small importance to those who make their own apparatus.

The terminals are of large diameter (25 millim.), and are arranged with the screw in the moveable part, so that the top of the fixed part can be readily cleaned.

The proportional arms are fitted with the usual divided blocks.

The whole of the metallic part is made of phosphor-bronze, a material which is harder and less liable to oxidation than ordinary brass.

The containing box is lined with copper for the reception of the oil.

The form of bobbin and the wire for the standard resistance-coils are the same in the 1 and 10 ohm standards; but in the 100 and 1000 ohm standards the mica is stiffened by being slipped into a brass back, like the back of an ordinary tenon saw, which quite prevents any tendency to bend. The temperature is measured by means of a thermometer placed in a pierced tube which lies inside the coil. The coils are inclosed in an outer brass case and fitted with the usual copper terminals for use with mercury-cup connexions.

* This method of constructing the plugs is due to Mr. R. W. Paul, Proceedings of the Physical Society, 1892.

Fig. 1.

The $\frac{1}{10}$ ohm standard is of manganin, of the usual British-Association pattern.

The oil employed is a pure heavy hydrocarbon oil, obtained from Messrs. Price's Patent Candle Company; it is free from any trace of alkali or acid, and experiments conducted by Messrs. Price prove that it has no action on the wire.

III. *Construction of Bridge and Galvanometer.*

The bridge employed was of the usual equal-armed pattern, having a straight wire of platino-iridium 1.5 millim. in diameter and 500 millim. long. The wire is stretched immediately over the scale by means of two brass split chucks, these chucks terminating in circular brass rods, having a diameter of 6 millim. The rods slide in heavy brass blocks, and the wire can be tightened by nuts on the ends of the rods. Thus the wire is not soldered to the terminals, and can be removed for repair. The scale is divided into 1000 parts, and the divisions are then divided into 10 by estimation; this is easily done with the aid of a good magnifier. The slider moves on the scale itself, and is provided with a fine adjustment. The connexion to the galvanometer is made by a platinum-tipped spring, resting on a platinum wire which is laid parallel to the main wire. The equal coils are made of manganin, and have a resistance of about 10 ohms. They have several times been adjusted to exact equality, but have never preserved that equality for a long period. This inequality, however, is unimportant, since it is eliminated by double balancing, which has been done at least once during each set of determinations. The actual amount of inequality at the present time is shown by the facts that, with 1 ohm in each of the outer arms, the bridge centre (*i. e.* the mean of the readings when the coils are interchanged) is 500.25, whilst with 1 ohm in each arm it is 500.4, and with 10 ohms in each arm it is 500.5.

The wire is mounted on a stout marble base. To protect the wire as much as possible from heat radiated from the observer's body two blocks of wood have been hollowed in such a manner that they can be slid over the wire; the slider itself being wrapped in cotton-wool. These precautions reduce

the effect of the thermo-currents to a few scale-divisions on the galvanometer. The effect of thermo-currents on the galvanometer was eliminated by the galvanometer-circuit being kept closed, the battery-circuit being made and broken as required. In order to connect the box-coils and the standards to the bridge, three pairs of heavy flexible copper leads have been constructed; one pair has mercury-cups, intended for the reception of the standard coils, at one extremity; a second pair has conical plugs, so that any particular coil in the box can be measured alone; the third pair and the other six extremities of the leads are provided with heavy copper spades, by means of which connexion can be made with the terminals of the box and the bridge. The three pairs of leads are adjusted to exact equality one with another, and each has a resistance of $\cdot 00966$ ohms at a temperature of $11^{\circ} \cdot 8$. The values of these resistances do not enter into any determination as the leads were always in pairs, one in each arm of the bridge.

The galvanometer is a four-coil astatic instrument, the resistance of each coil being 60 ohms. The magnet system is supported by a fine quartz fibre 260 millim. long. In order to diminish as far as possible the effects of the vibration caused by London traffic, thick rubber blocks are placed on the pier supporting the galvanometer; this precaution has made it possible to work at any time except when large masses of iron are being moved in the neighbouring goods station. The scale is placed 3 metres from the mirror. The motion of the mirror is observed by means of a small electric lamp which projects the image of a fine wire on to the mirror, thence it is reflected on to a ground-glass scale. The observer is at a considerable distance from the galvanometer, a matter of some convenience since the zero is thus not so liable to be changed. The galvanometer gives a distinct movement for an alteration of $\cdot 00001$ of an ohm, with 10 ohms in every arm, the battery being one Helleisen cell, together with an added resistance in series with it of 10 ohms. The galvanometer is connected to the bridge by 20 gauge rubber-covered high insulation wires; the rubber covering is necessary as I have found serious errors introduced unless the insulation of the galvanometer connexion is extremely good.

IV. *Determination of Standards.*

The temperature difficulties which are most liable to cause inaccuracy in resistance measurements have been greatly simplified by the remarkable uniformity of temperature of the room in which the measurements have been made. The room is almost entirely underground, and is protected on all sides by other portions of the building from the heat of the sun. It is lighted by one small electric lamp, which gives rise to no appreciable change of temperature. The presence of one experimenter causes the temperature of the air to rise about $\cdot 2$ of a degree during the first half hour, and then it becomes constant; but the temperature of the resistance-box and standards, the latter being placed in earthenware vessels and surrounded by sawdust, takes several hours to rise as much as $\cdot 03$ of a degree.

The bridge-wire was calibrated by a method due, I believe, to Mr. Griffiths. In one of the outer arms is placed, by means of mercury-cups, a coil of low resistance, called the gauge-coil; on the other hand, the gap can be short-circuited by means of a thick copper bar. In the opposite outer arms are placed three resistance-boxes in parallel. The object of this arrangement is to secure the necessary fine adjustment. Commencing with the slider at one end of the wire, the gauge-coil being in place, a balance is obtained by adjusting the resistance in the boxes, the slider remaining fixed. The gauge-coil is then removed and the copper bar substituted; the slider is then moved until a new balance is obtained. Proceeding thus, the whole wire is divided into a number of parts the resistances of which are equal. From these observations a chart can be prepared showing the deviation in resistance of the wire from a wire of uniform resistance per unit of length. One of the great advantages of this method is that, when an abnormal value has been obtained, it is a simple matter to come back to that particular portion of the wire for a check measurement. The gauge-coil was equal to the resistance of 22.293 mean scale-divisions (each 0.5 millim.), and the greatest error at any point of the wire amounted to $\cdot 4$ of a scale-division. Throughout the whole of the comparison of the coils this calibration of the wire has been

employed, and several apparently discrepant observations have been thus brought into line.

The temperature-coefficient of the bridge-wire has been found by raising the temperature of the room from $10^{\circ}\cdot4$ to $18^{\circ}\cdot1$, the bridge having in one arm a coil of known temperature-coefficient, and was found to be $\cdot071$ per cent. per degree.

The thermometer employed, which is of hard Jena glass, is divided into tenths of a degree, each tenth being approximately $\cdot5$ millim. in length. By means of a small reading telescope it can with ease be read to $\cdot01$ of a degree. It was tested at the Reichsanstalt and, over the range employed, was accurate to at least $\cdot05$ of a degree.

The temperature-coefficient of the platinum-silver wire, over a range from 10° to 25° , was determined by immersing a coil of about 1 ohm in paraffin-oil at 25° , and allowing it to cool very slowly. It was found to be $\cdot000274$ per ohm per degree.

The 1 ohm coil from which the standards have been built up is of manganin, and when tested in June 1894 by Mr. Glazebrook had a resistance of $1\cdot00026$ ohms at $13^{\circ}\cdot4$. I was, however, so doubtful of the constancy of this standard that in December 1895 I constructed a bare platinum-silver 1 ohm coil. This was compared with the manganin standard, and the mean of eleven determinations gave its value as

$$1\cdot00000 + \cdot000274 (t - 14\cdot96).$$

No doubt the manganin coil had changed its value in the eighteen months that had elapsed since it was tested, so that the above figures were not true ohms.

The 10 ohm standard was obtained by the use of three approximate 3 ohm coils*, first placed in parallel and balanced against a 1 ohm coil, and then in series with the 1 ohm coil and balanced against the 10 ohm coil. Instead of connecting the legs of the coils by mercury-cups, as is usually done, the fusible metal made by Mr. F. Thomas, of Cambridge, was used. This metal, which melts at 60° , gives very constant contact resistances, and does not seem to injure

* This method is described in the B. A. Reports, 1883.

in any way the amalgamated terminals of the coils. I first determined the value of a manganin 10 ohm coil, which had been made for nearly a year. The value obtained on December 20, 1895, was 9.9987 at $9^{\circ}3$. This coil was used as a standard to which to adjust the platinum-silver 10 ohm coil. The value thus obtained for the latter was 9.9895 at $10^{\circ}3$. On stepping up to the platinum-silver 10 ohm coil, the value found on December 30 was 9.9905 at $10^{\circ}6$. Taking into account the known temperature-coefficient, the latter at $10^{\circ}3$ would be 9.9897, which differs by only two parts in 100,000 from its former value.

To obtain the value of the $\frac{1}{10}$ ohm coil, which was of manganin, a bridge was formed of two 1 ohm coils, a 10 ohm coil, and the $\frac{1}{10}$ ohm coil, and a balance obtained by shunting one of the 1 ohm coils*.

On January 12th, a value of .099934 at $11^{\circ}2$ was obtained.

„ „ 13th, „ „ .099932 „ $10^{\circ}2$ „ „

The temperature-coefficient of the wire was known to be .000004 per degree. Between these two determinations the bridge had been dismantled. This coil was again tested on April 8th, and had then a value of .099944 at $12^{\circ}1$, whereas, if it had remained unaltered, its value at that temperature should have been .099938. This change is, however, too small to cause any error in the box-coils.

For testing coils which are very nearly in the proportion of 1 to any power of 10 this method is extremely sensitive, and certainly more accurate than making the comparison by means of the wire bridge, provided that the resistances of three out of the four coils forming the bridge are accurately known.

In obtaining the values of the 1 ohm and 10 ohm standard coils, not more than 50 scale-divisions of the wire had been employed, hence a small error in the total resistance of the bridge-wire would not cause any inaccuracy in the values so obtained. The resistance of the bridge-wire was determined in the first instance by placing the standard 1 ohm coil in parallel with a coil of slightly smaller resistance than the

* This method is described by Mr. Glazebrook, B. A. Reports, 1894.

bridge-wire. This gave the resistance per scale-division of the wire as $\cdot 00087$ at $10^{\circ}1$. After the value of the $\frac{1}{10}$ ohm coil had been found, the resistance of the bridge-wire was determined by balancing the $\frac{1}{10}$ ohm coil against a coil of slightly smaller resistance than the bridge-wire; the $\frac{1}{10}$ ohm coil was then removed, and the gap short-circuited. The actual figures are of interest as showing the value of a calibrated wire.

$\cdot 1$ ohm in A. Gauge in D. Temperature $10^{\circ}8$.

Reading $394\cdot 0$.

Correction for calibration $\sim \cdot 3$.

Short circuit in A. Gauge in D. Reading $967\cdot 9$.

Correction for calibration, $-\cdot 2$.

Hence, if ρ be the resistance per scale-division,

$$\cdot 1 \text{ ohm coil} = 2 \times 574 \rho = 1148 \rho.$$

On interchanging the coils,—

$\cdot 1$ ohm in D. Gauge in A.

Reading $32\cdot 9$. Correction for calibration, 0 .

Short circuit in D. Gauge in A.

Reading $607\cdot 0$. Correction for calibration, $-\cdot 1$.

This also gives

$$\cdot 1 \text{ ohm coil} = 1148 \rho.$$

Whence $\rho = \cdot 00008705$ at $10^{\circ}8$.

A and D being the two outer gaps of the bridge.

The 100 and 1000 ohm standard coils were determined on similar bridges. The 100 ohm coil,—

On April 14, had a value $99\cdot 913$, at $10^{\circ}8$.

„ „ 17, „ „ $99\cdot 964$, „ $12^{\circ}5$.

Whereas it should have been $99\cdot 960$, according to the observation on the earlier date. This discrepancy is, I believe, due to the fact that the shunt required on one of the 10 ohm coils forming the bridge was greater than 12,000 ohms, which was the largest resistance at my disposal: in

order to obtain a balance one of the 10 ohm coils had to be warmed, by means of a water-bath, about 2° above the temperature of the room, which led to some uncertainty as to the actual temperature.

The 1000 ohm standard coil was obtained by forming a bridge with the 1, 10, 100, and 1000 ohm coils, and had a value, on April 28, of 1000.24 ohms at $12^{\circ}.8$. No other determination has, as yet, been made. The coils were adjusted so as to be right at 15° .

V. Calibration of the Resistance-box.

For the first three of the dials the coils were balanced against standard coils (fig. 2), and the differences obtained

Fig. 2.

by means of the wire bridge. In order to connect the conical plugs to the arms of the wire bridge, the flexible leads with conical ends were used; the standard in the opposite arm being connected by means of the leads with mercury-cup ends.

For the 1 and 100 ohms in the proportional arms spade-

ended leads were used, and attached to the terminals at the ends of the proportional arms (see diagram).

For the sake of convenience of comparison, I have reduced the resistances to their values at 11° C.

The values of the $\frac{1}{10}$ ohm dial are as follows :—

No. of Coil.	Jan. 12.	Jan. 20.	Jan. 22.	Jan. 24.	Jan. 25.	Jan. 26.	Mar. 11.	Mar. 14.	Mean.
1 ...	·10067	·10071	.....	.....	·10065	·10065	·10073	·10073	·10073
2 ...	·10012	·10012	·10009	·10008	·10008	.....	·10012	.....	·10010
3 ...	·10067	·10069	·10063	·10061	·10063	.....	·10050	.....	·10050
4 ...	·10008	·10014	.....	.....	.....	·10011	·10010	.....	·10011
5 ...	·09976	·09974	·09975	.....	·09973	·09972	·09975	.....	·09974
6 ...	·09982	·09987	.....	.....	·09985	·09985	.....	.....	·09985
7 ...	·10046	·10046	.....	.....	·10042	.....	.....	.....	·10045
8 ...	·10003	·10004	.....	.....	.....	·10003	.....	.....	·10003
9 ...	·10055	·10061	.....	.....	.....	·10066	.....	.....	·10061

It will be noticed that, in coils 1 and 3, I have rejected certain values determined on dates before March 11; the reason being that, when the new flexible leads were attached in February, these two coils were touched and slightly bent, and had in consequence to be re-annealed.

The values of the 1 ohm coils are—

No. of Coil.	Jan. 8.	Jan. 11.	Jan. 26.	Feb. 12.	Feb. 16.	Mean.
1	·99929	·99929	.....	.....	·99931	·99930
2	·99956	·99956	.....	.....	.....	·99956
3	·99569	·99568	.....	.....	.....	·99568
4	·99964	·99969	·99970	.....	.....	·99968
5	·99776	·99774	.....	.....	.....	·99975
6 .....	.....	1·00007	1·00007	.....	1·00008	1·00007
7 .....	.....	·99976	·99979	·99978	·99980	·99978
8 .....	.....	·99878	·99875	·99875	·99878	·99877
9 .....	.....	1·00053	1·00051	.....	1·00053	1·00054

Values of the proportional arms are—

	April 3.	Mar. 8.	Mar. 16.	Mean.
1 in X	·99863	·99860	·99860	·99861
1 in Y	·99645	·99641	·99642	·99643

Considerable trouble was experienced in the determination of the 1 ohm coils in the proportional arms, owing mainly to variations in the resistance of the plugs, which were fitted into the usual divided blocks. The amount of this error is of

little moment when compared with the 10 ohm coil. The 1 ohm coils have not been employed in the determination of the larger resistances.

The values of the 10 ohm coils are :—

No. of Coil.	March 8.	April 3.	April 4.	Mean.
1	9·9765	9·9764	.....	9·9764
2	9·9926	9·9925	.....	9·9925
3 .....	.....	10·0033	10·0033	10·0033
4	9·9976	.....	9·9973	9·9974
5	9·9999	10·0000	10·0001	10·0000
6	9·9574	9·9573	.....	9·9573
7	9·9558	9·9555	.....	9·9556
8	9·9863	9·9858	9·9864	9·9862
9	9·9748	9·9753	9·9758	9·9753

The values of the proportional arms are :—

	Mar. 8.	Mar. 16.	Mar. 17.	April 3.	April 4.	Mean.
10 in X	9·9513	9·9506	9·9513	9·9507	9·9509	9·9509
10 in Y	10·0106	10·0099	10·0103	10·0098	10·0101	10·0101

Desiring to obtain a check measurement, I balanced the nine ·1 ohm coils against the 1 and 10 ohm standards in parallel, and obtained the value ·90224 at 13°, while the first five coils of the dial, when balanced against the two 1 ohm coils in parallel, gave ·50125 at 13°·2. The actual values for the sums of the nine and five respectively, as found by the separate determinations, were ·90259 and ·50147. Of course any contact-error due to the plugs would appear when the values of the coils are added up. When the separate values of the nine coils are added up, the contact-error will have entered 18 times into the result, and for five coils 10 times ; on the other hand, when the coils are measured in series, the contact-error will only enter twice in each case, and the differences between the two sets of values in both cases are explained by the ascertained result that the contact-resistance of each plug is ·00002.

It is somewhat bold to assert that an error of ·00004 ohms has not entered into the determination of each of the $\frac{1}{10}$ ohm coils. The standard itself is certainly correct, as will be seen by reference to its values on the various dates ; the only possible explanation would be that the connecting leads of

the two arms had not equal resistances. A subsequent test, however, proved that they were equal. I was, therefore, driven to the conclusion that the contact-resistance as above found was real, and not due to an experimental error.

The resistance of the box from terminal to terminal with each plug in zero was obtained in three ways. Firstly, by short-circuiting the mercury-cups in one of the arms of the bridge, and measuring the resistance of the leads and plugs on the bridge-wire. This gave a value of $\cdot 00967$ ohm at $12^{\circ}8$. Secondly, the first coil of the $\frac{1}{10}$ ohm dial, together with the leads, was balanced against the $\frac{1}{10}$ ohm standard; subtracting from this resistance the known resistance of the box-coil, we get a value of $\cdot 00964$ ohm for the resistance of the leads, at $12^{\circ}4$. Thirdly, a similar method was employed to measure the first coil in the 1 ohm dial, and this determination gave the resistance of the leads as $\cdot 00954$ ohm at $10^{\circ}3$. In order that these three observations may agree it is necessary to assume that the temperature-coefficient of the copper leads is about $\cdot 00005$ ohm per degree. This is rather high, but the temperature range is too small for an accurate determination.

The values of the coils in the 100 dial were obtained on the box itself. In the gap A (fig. 3) the 1 ohm standard coil

Fig. 3.

was placed; this, together with the first three dials, gave a resistance of about 100.9 ohms; and constituted one arm of a Wheatstone bridge, the two 10 ohm coils in the proportional arms formed two other arms, the fourth arm was any one of

the 100 ohm coils, which was connected to the gap C by means of the two flexible leads with conical ends. The plug from the centre of the 100 dial was in the zero of the 1000 dial so as to complete the circuit from the gap A to the gap C. The smallest resistance in the box was $\frac{1}{10}$ of an ohm, so that the last two figures of the resistance had to be obtained by interpolation from the swings of the galvanometer. The battery employed was one storage-cell, and the current was commuted for each observation. With the coils of the galvanometer placed in series an alteration of $\frac{1}{10}$ of an ohm in the box caused a total galvanometer swing of about 116 scale-divisions.

The values of the 100 ohm coils are:—

No. of Coil.	April 5.	April 6.
1	100·511	100·510
2	100·967	100·971
3 .....	.....	100·266
4	100·300	100·305
5	100·362	100·365
6	100·671	100·676
7	100·603	100·607
8	100·434	100·435
9	100·845	100·850

The 100 ohm proportional arms were determined by the same method as was used for the 100 ohm standard coils. Their values are :—

	April 17.	April 20.	April 21.	Mean.
100 in X .	100·224	100·219	100·220	100·221
100 in Y .	100·312	100·314	100·309	100·312

The 1000 ohm coils were also measured on the box itself. In the gap A (fig. 4) was placed the 100 ohm standard coil; this, together with the first four dials, formed one arm of a Wheatstone bridge; the two other arms were the 100 ohm coils in the proportional arms. A single flexible lead connected the last coil of the 100 dial with any required coil on the 1000 dial. Another lead connected the other terminal of the

coil to be measured to the terminal of the proportional arm Y. The current was provided by two storage-cells.

Fig. 4.

The values of the 1000 ohm coils are :—

	April 25.
1	1023.35
2	1027.30
3	942.05
4	1022.04
5	1017.21
6	1032.04
7	1007.44
8	1003.45
9	1026.42

The values of the proportional arms are :—

	April 27.
1000 in X	947.92
1000 in Y	994.21

My object in giving the whole of the figures relating to the resistance-coils is to show to what an extent bare wire coils are to be trusted. Whether the coils retain their values as well as the resistance standards of the British Association, time alone can decide. There is no reason to suppose that, if the coils are kept continuously in an oil-bath, and the oil kept free from water, any considerable alteration can take place.