

## A NEW FORM OF STANDARD RESISTANCE.

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By Edward B. Rosa.

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### 1. INTRODUCTION.

In an article in this Bulletin nearly a year ago,<sup>1</sup> an account was given of an extended investigation of the effect of atmospheric humidity upon the resistance of coils of manganin wire prepared in the usual way by the use of shellac. It was there shown that the resistance always increases by an appreciable amount when the humidity of the atmosphere surrounding the coil increases, owing to the swelling of the shellac as the latter absorbs moisture from the atmosphere, the wire embedded in the shellac being stretched by an amount depending on the relative humidity of the air and the length of time the coil is exposed. When the atmospheric humidity decreases, the shellac gives up moisture and contracts in volume, the wire shortening at the same time, and the resistance of course decreasing. Although the actual change in volume of the shellac is very small, and the consequent change in the resistance is also small, yet in the case of resistance standards, especially those of relatively fine wire, the change is very serious, and enormous as compared with the errors allowable in measuring such standards.

It was found in this investigation that keeping the coils submerged in oil, using the pure, high-grade petroleum oil, as is usually done in precision resistance measurements, did not prevent this change, although it largely retarded it and apparently reduced the total change. Such oil in a damp atmosphere absorbs moisture and passes it on to the shellac, and in a drier atmosphere gives it up again. The oil, indeed, tends to come

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<sup>1</sup> Rosa and Babcock, this Bulletin, 4, p. 121; 1907.

to a state of equilibrium with the atmosphere as regards its moisture content, and hence if the relative humidity of the atmosphere is constant the resistance of a coil of wire in the oil will tend to become constant; the time required to attain such a steady state is, however, very considerable. In practice the moisture content of the oil is varying day by day as the relative humidity of the atmosphere changes, and if in the resistance measurements the oil is vigorously stirred, to secure uniformity of temperature throughout the oil and equality of temperature between the resistance standard and the oil, the rate of absorption of moisture (or of giving up moisture when the air is drier than the average) will be accelerated. Hence, stirring the oil may greatly increase the rate of change of the resistance, and the same coils when measured in two different baths of oil, one having been stirred more than the other, may differ appreciably.

These variations of resistance may be of importance not only in resistance standards, but also in precision resistance boxes, Wheatstone bridges, potentiometers, and other resistance apparatus, where small changes in the resistances of the coils are serious. In potentiometers it is the relative resistance that should remain constant, so that if all coils change alike no serious harm is done. But all coils do not change alike, the higher resistances generally changing more than the lower ones. Hence the potentiometer will be subject to slight errors that will depend upon the weather or the season of the year. In a recent article in this Bulletin<sup>2</sup> it was shown that several precision resistance boxes which were frequently calibrated showed very marked seasonal changes of resistance, with a maximum in summer and a minimum in winter; and yet most of these resistances were kept submerged in oil. It was this seasonal change which led to the discovery of the effect of atmospheric humidity on shellacked resistances.

In a recent number of the *Zeitschrift für Instrumentenkunde*,<sup>3</sup> Dr. S. Lindeck describes experiments which he has made since the publication of our paper a year ago on the influence of atmospheric humidity upon electrical resistances. His results confirm our experi-

<sup>2</sup>E. B. Rosa and N. E. Dorsey, this Bulletin, 3, p. 553; 1907.

<sup>3</sup>"Über den Einfluss der Luftfeuchtigkeit auf elektrische Widerstände," *Zeitschrift für Instrumentenkunde*, August, 1908.

ments, not only as to the change of resistance in the air but also in oil when the relative humidity of the atmosphere above the oil varies.

Our results have also been confirmed by Mr. F. E. Smith<sup>4</sup> at the English National Physical Laboratory. Mr. Smith subjected some of his resistance standards to extreme conditions, drying them out in an atmosphere freed from moisture by phosphorus pentoxide and then exposing them to an approximately saturated atmosphere. The change in resistance was from 14 to 64 parts in 100,000; but in some other coils leakage due to condensed moisture reduced the resistance so that the resultant change was a decrease instead of an increase. It is impossible to say at just what humidity leakage would begin to appear, and it seemed to us better not to subject coils to so high a humidity. Lindeck used a humidity of 80 per cent as his maximum, and found relatively large increases of resistance. In our experiments at the Bureau of Standards the humidity was seldom carried above 80 per cent, in order to avoid leakage and also to avoid permanent injury to the coils; and to conform as nearly as possible to actual conditions, the humidity was seldom carried below 25 per cent.

Lindeck found two methods of reducing the change produced by humidity. The first was to use a heavy paraffin oil, which absorbs and transmits moisture to a less degree than the petroleum oil commonly used. The second was to use a very thin tube on which to wind the resistances, and to cut slits in it, so that the tube yields readily to external pressure. When the moisture is absorbed and the shellac swelled, the wire is accordingly stretched less, because the yielding of the tube relieves the tension in part. The objection to the first method is that the heavy paraffin oil is less mobile and does not equalize the temperature of the bath as readily as the lighter oil, and is less convenient in use. The second method does not permit as substantial a construction as the usual form of coil, and would not seem to be a satisfactory solution, even if it prevented the change to a greater degree than it does. As, however, neither method, according to Lindeck, prevents the coils entirely from changing, some other method must be employed. The methods which

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<sup>4</sup> Phil. Mag., September 1908, p. 450.

we have employed at the Bureau of Standards will be described below.

As set forth in our articles above referred to, the coils may be dipped in paraffin and the shellac completely protected from the atmosphere, so that whatever moisture is contained will remain constant, and the resistance is then very constant. If, however, the resistances are to be put into oil, either for the purpose of increasing their current carrying capacity or of fixing their temperatures more exactly, paraffin can not be used. Sealing them in air-tight boxes is then an effective protection from the effects of atmospheric humidity. Hence, dipping in paraffin the coils of Wheatstone bridges, potentiometers, etc., gives a satisfactory protection, while resistance standards of the highest precision and resistance boxes which are to carry more current than usual, as in accurate alternating current measurements, can better be protected by sealing in metal boxes which are filled with pure oil.

## 2. DESCRIPTION OF THE NEW SEALED STANDARDS.

Having found that coils which changed greatly when exposed to the air were remarkably constant when kept in an atmosphere at constant humidity, as when sealed in a test tube or preserved in any air-tight inclosure, it was evident that resistance standards ought to be so mounted as to possess this advantage. The design which I adopted more than a year ago, and which experience has since shown to be perfectly satisfactory, is shown in Figs. 1 and 2.

The coil is wound in the usual manner on a brass cylinder 30 mm in diameter and 70 mm long, and is contained within a cylinder 40 mm in diameter and 12.5 cm high. The coil is shellacked, dried, and annealed in the usual manner, as originally specified by the Reichsanstalt. The coil is supported, as shown, by a small tube (closed at the bottom) which serves as a thermometer tube. The hard-rubber top through which the leads pass is threaded, and screws into the outer brass cylinder which forms the case. When the coil is finally adjusted, the case is nearly filled with pure oil that has been freed from moisture, and the top screwed firmly into place. To make the joint perfectly tight, shellac is usually put into the threads before screwing up. Shellac is also put into the joints in

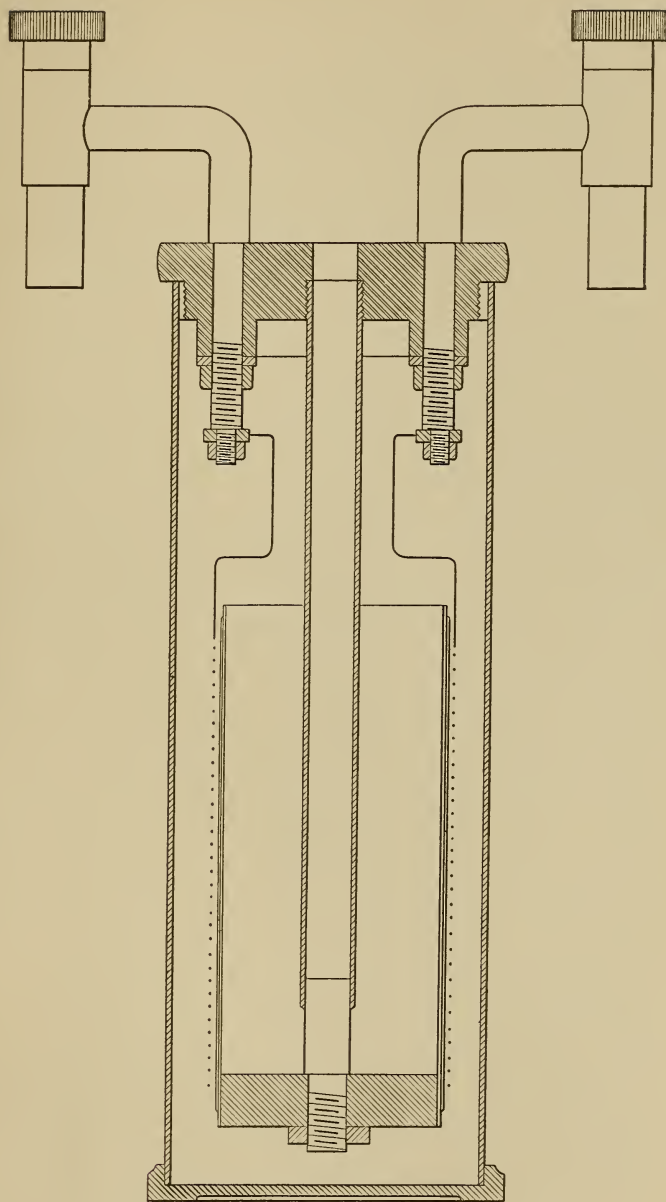


Fig. 1.—Section of Sealed Resistance Standard



the top, where the leads and thermometer tube pass through the ebonite.

The terminals dip into mercury cups, but the upper potential terminals may ordinarily be used as current terminals. Only in low-resistance coils (1 ohm and less) is the difference in resistance appreciable.

Sealing the standards in this way possesses several distinct advantages. First and most important, of course, is the protection against the changes in resistance due to the absorption of moisture by the shellac (or varnish or other protective covering). In the second place, it protects the coils from dirt or mechanical injury, to which they are liable if open. And, finally, if any bare spots exist, due to shellac coming off or being imperfectly applied, the oxidizing effect of moisture in the oil bath and of the atmosphere is far greater than it can be when the coil is sealed air-tight in very pure dry oil. Hence the resistances are not only protected from the serious fluctuations from day to day, and the still greater seasonal changes due to moisture, but also from slower changes due to oxidation of the manganin and the possible sudden changes due to accident.

The new form of resistance standard is much smaller than the Reichsanstalt type, so long and so favorably known throughout the world as a standard of resistance. It weighs only about 400 g filled, and measures only 7.5 cm across the terminals instead of 16 cm. For measurements up to an accuracy of .001 per cent it is measured as it stands, its current capacity being ample when using reasonably sensitive galvanometers, and the small thermometer in the central tube giving its temperature with all needed accuracy. The temperature coefficient is generally not greater than .002 per cent per degree, so that a quarter of 1 degree uncertainty in the temperature would cause an error less than that allowed.

When used as standards of the highest precision, and measured to one part in 1,000,000 or closer, it is necessary to know the temperature of the coil very accurately. The standards are then submerged in an oil bath which can be stirred and kept at constant temperature and the precaution taken not to use current enough to make the temperature of the wire uncertain. The standards when properly prepared and aged are remarkably constant in value, and in

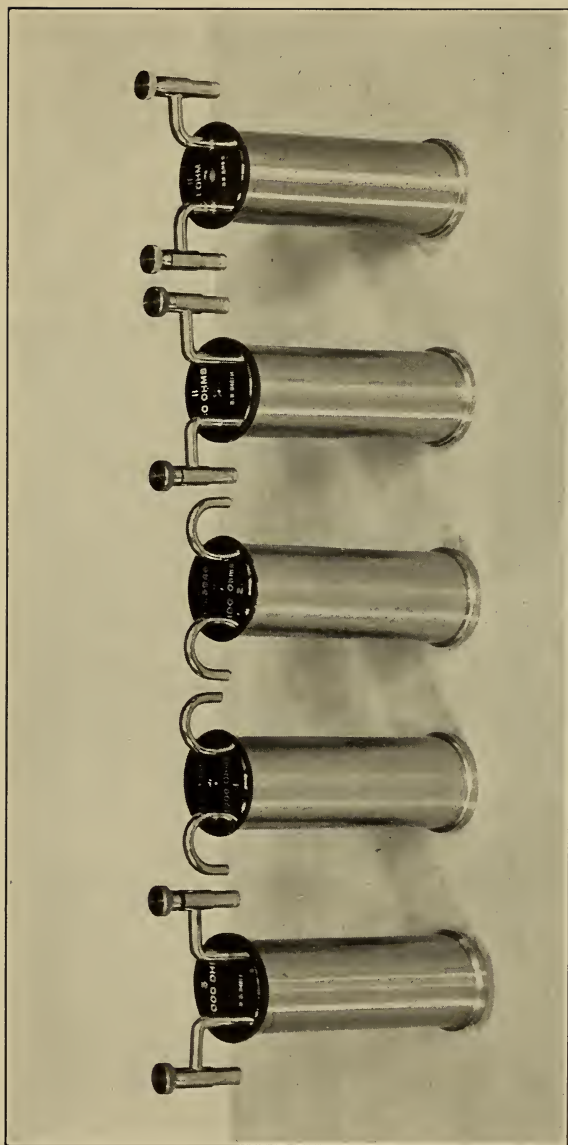
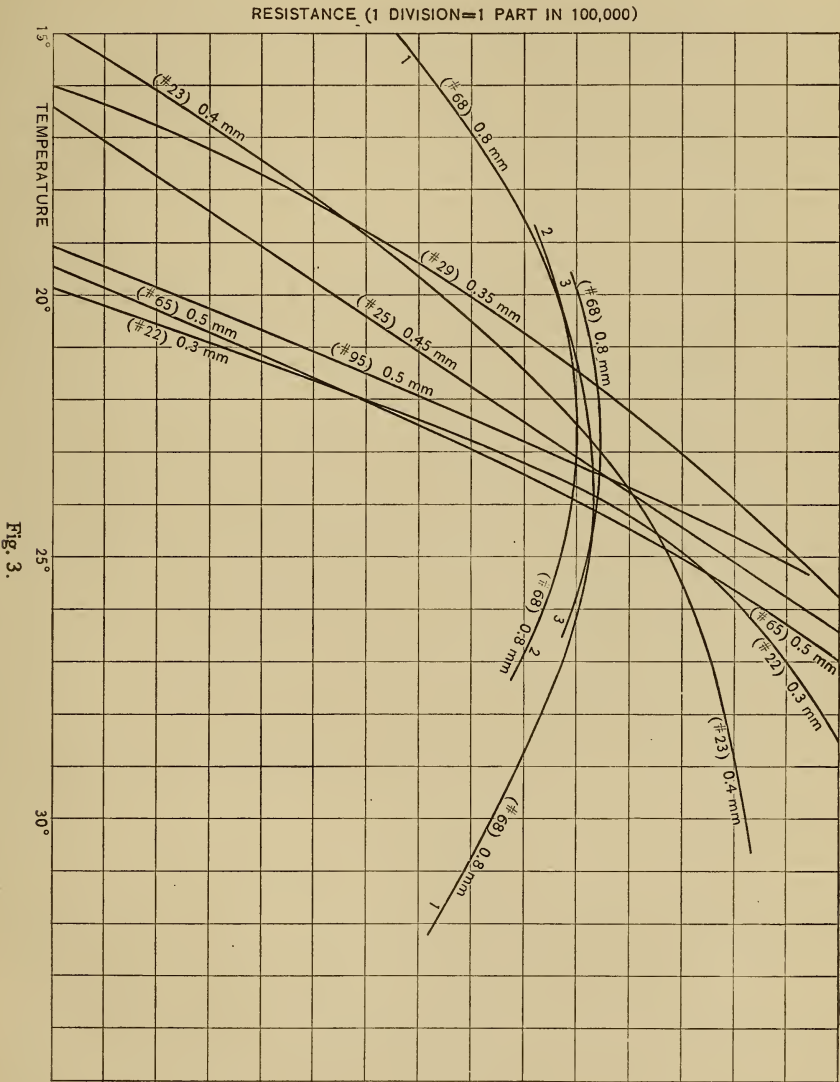


Fig. 2.—Group of Sealed Resistance Standards.

measuring them to test their constancy I have been obliged to take extreme precautions in order not to have their slight variations exaggerated by errors of measurement. The temperature coeffi-



icients of the coils which I have been using vary through wide limits, the average value between 15° and 30° C generally falling between 4 and 20 parts in a million per degree, but sometimes exceeding 20.



Different specimens of manganin wire vary greatly as to temperature coefficient, and hence it must be carefully selected if the coils are to have coefficients as small as these.

### 3. TEMPERATURE COEFFICIENTS OF MANGANIN WIRE.

A series of coils of the style just described was prepared, most of them being made in the instrument shop of the Bureau, but a few were made by the Leeds & Northrup Company. Some of the standards first made consisted merely of coils taken out of a dial

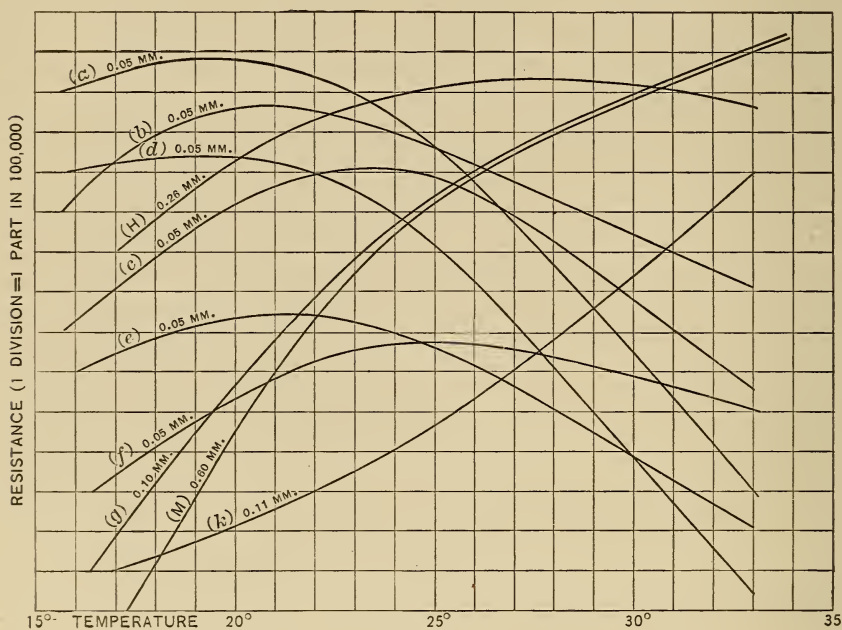


Fig. 4.

rheostat by Otto Wolff and mounted and sealed in our cases. These resistances, being old, were well seasoned, and although their values were not steady in the rheostat they became steady shortly after mounting in the new way. In order to find wire suitable for making new coils of various denominations, we measured the temperature coefficients of a considerable number of specimens, and some of the curves found are shown in Figs. 3, 4, and 5, some of which were determined for me by Dr. G. W. Middlekauff.

The curves are substantially parabolas, and the temperature coefficients (represented by the slopes of the curve) vary greatly through the range  $15^{\circ}$  to  $25^{\circ}$ , which is the important region for laboratory purposes.

It is not generally known that different specimens of manganin vary so widely, and these curves will perhaps serve as a warning to anyone anxious to make good resistance standards not to use manganin wire without first testing it for temperature coefficient. Some of our 1-ohm coils have been made of strips wound on cylindrical forms properly insulated by silk and covered with shellac and

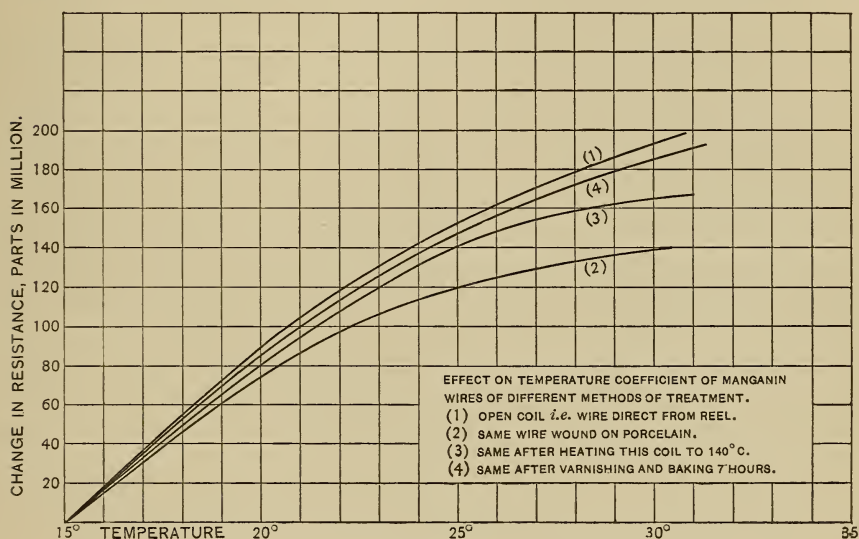


Fig. 5.

annealed, as the wire resistances are treated. It will be noted that the finer wires have generally the smaller temperature coefficients. These specimens of manganin all came from Otto Wolff, the Berlin agent of the German manufacturers. These curves are not intended to show that a large number of specimens of manganin wires would always vary as much as these do, but merely to show the results of our experience on a considerable number of samples. Between  $15^{\circ}$  and  $25^{\circ}$  the mean value of the coefficient varies in the different specimens from 1 to 22 parts in a million per degree. It sometimes goes as high as 40 or 50 per million, or more. In some specimens it

will be noted that the coefficient becomes negative at temperatures as low as  $20^{\circ}\text{C}$ . The finished coils made from these wires would have somewhat different values of the coefficients, generally larger.

It is of great importance in standards for the best service that the temperature coefficients be small. The errors in measurements due to uncertainty in temperature are then smaller, and a larger current

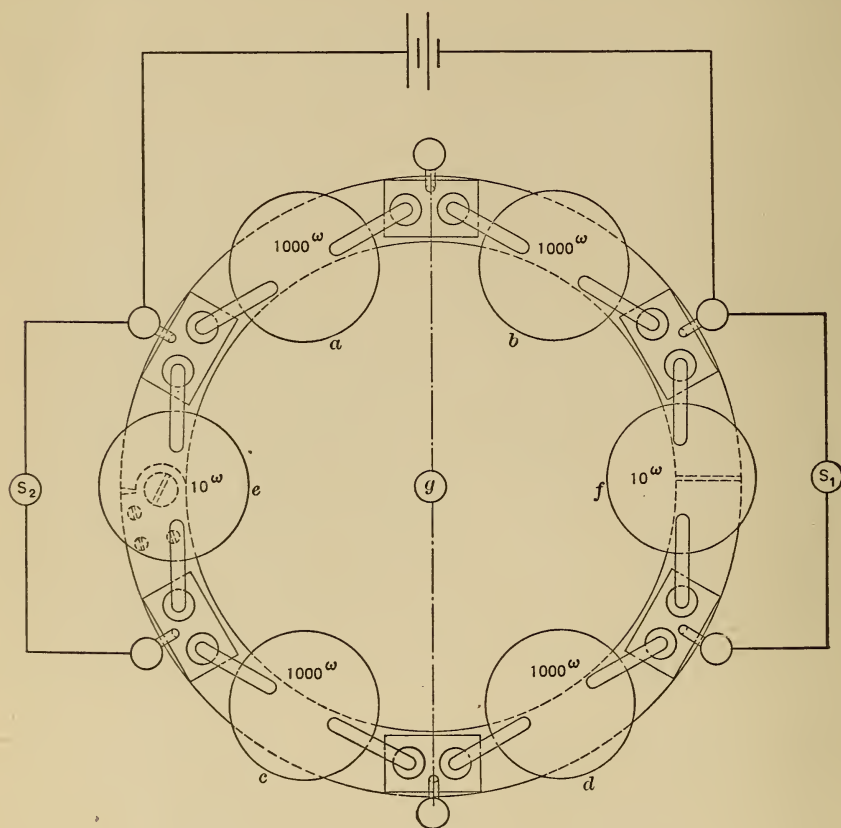


Fig. 6.

can be used in the measurement without appreciable error due to heating. If the coefficient in the working range is below 10 parts per million per degree, an uncertainty of  $0.1$  is only 1 part in a million, and with care the uncertainty can be kept much below this.

In Fig. 3 three curves are given, showing maximum values of the resistance (that is, zero temperature coefficient) at about  $23^{\circ}\text{C}$ . These three curves are for different specimens of wire of  $0.8\text{ mm}$

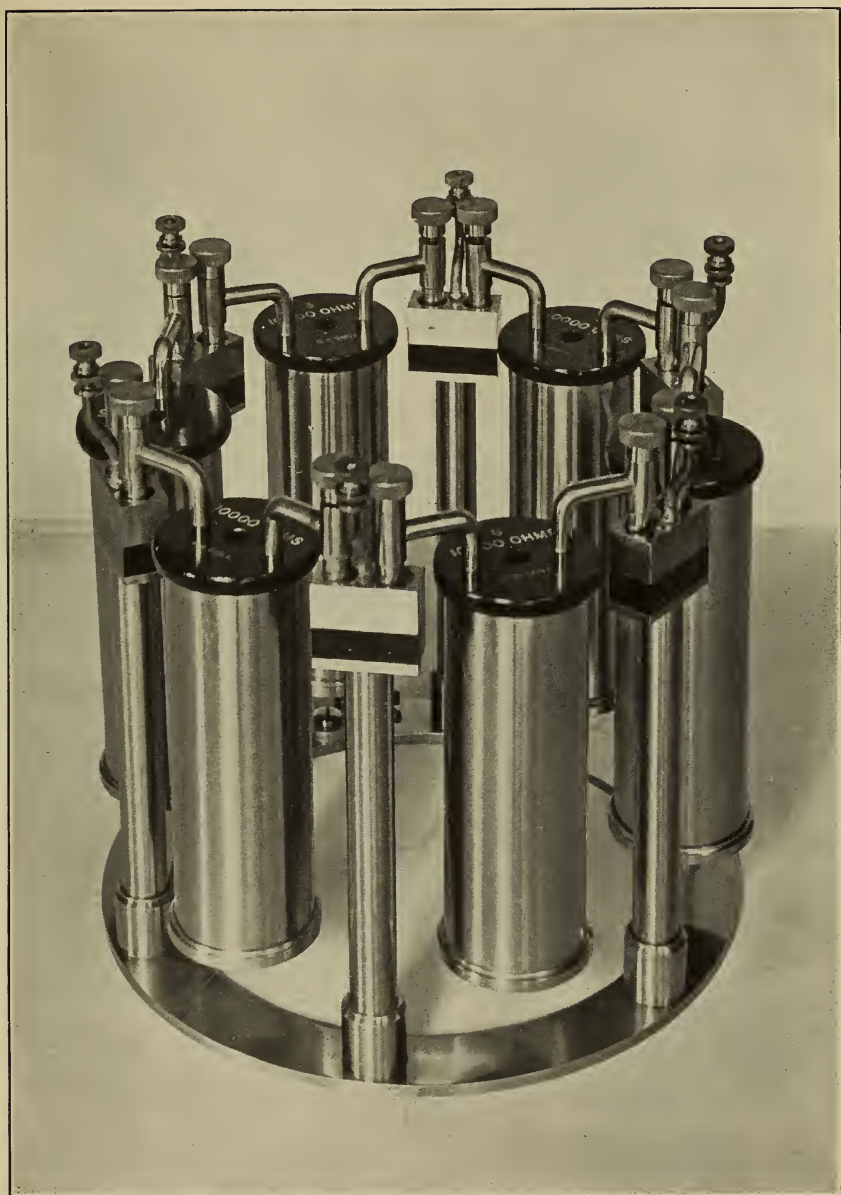


Fig 7.—Bridge for Intercomparing Sealed Resistance Standards.



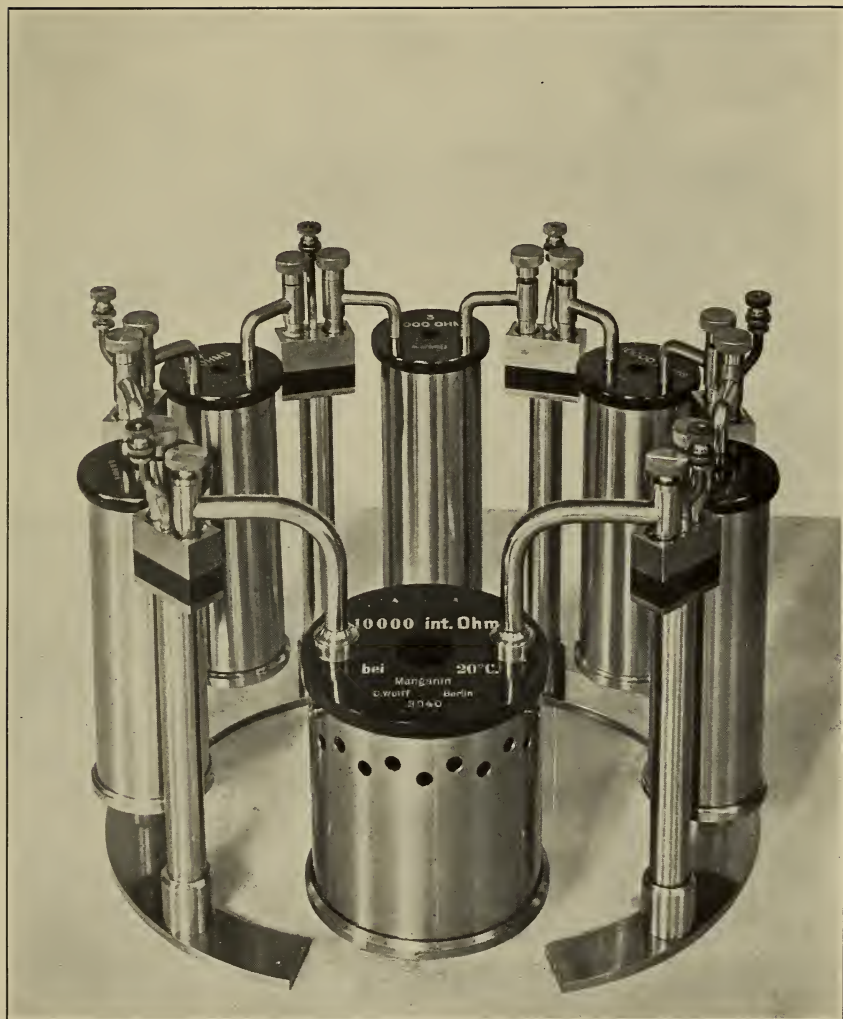


Fig. 8.—Bridge for Intercomparing Resistance Standards Opened to Contain a Larger-sized Coil.



diameter from the same spool, tested before making up into a coil. This is an exceptional specimen of manganin of this size, and when made up gave coils of relatively small temperature coefficient, although the maximum was shifted to a somewhat higher temperature.

#### 4. THE APPARATUS EMPLOYED.

The apparatus employed in comparing the coils of any denomination with one another is shown in Figs. 6, 7, and 8. It is a Wheatstone bridge with the coils arranged in a circle, having two extra coils inserted, on which shunts may be applied for balancing the bridge instead of shunting directly the ratio coils. Or these two openings may be closed by heavy links and the shunts applied directly to the ratio coils. The circular frame is so hinged that it may be opened far enough to admit a larger coil, as for example, one of the Reichsanstalt form, which may thus be directly and conveniently compared with one of the new Bureau of Standards form, Fig. 8. The apparatus is very convenient, is compact, requires a relatively small oil bath, or may be used without an oil bath except in comparisons of extreme precision, and will accommodate any kind of a resistance standard that is provided with terminals for dipping into mercury cups.

For stepping up from one denomination to another I have designed the form of bridge shown in Fig. 9. This is a very compact and convenient apparatus for comparing the sum of five coils of one denomination with two coils in parallel of the next higher denomination. Thus the difference between five 1-ohm coils in series and two 10-ohm coils in parallel is obtained by the method of substitution. Thus the mean of the tens is determined in terms of the mean of the ones. Also five 10's have been thus compared with two 100's, five 100's with two 1000's, and five 1000's with two 10,000's, all by the method of substitution and with extreme precision. If the temperature coefficients of all the coils are known with precision, or the comparisons are made at the standard temperature, the values of all the coils in terms of the mean of the 1-ohm standards are thus determined with very great accuracy.

When the bridge is arranged as shown in Figs. 10 and 11, it consists of four 10-ohm coils, and the balance is obtained by means of the shunts  $S_1 S_2$ ; the five 1-ohm coils are out of circuit, the two cups  $V_1$

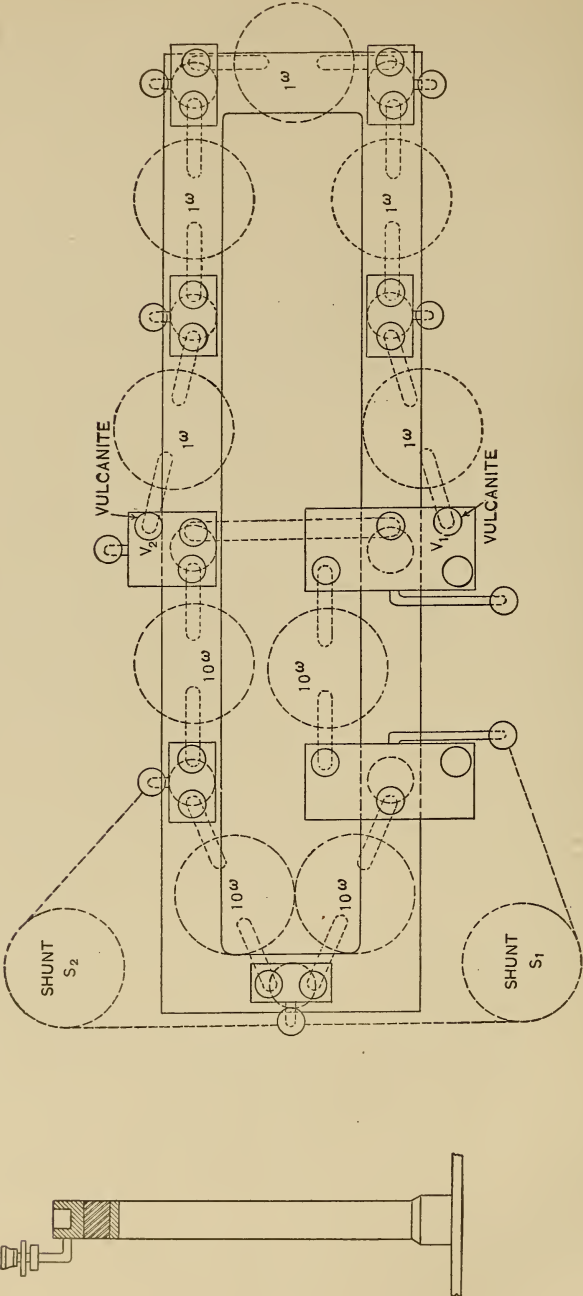


Fig. 9.—Plan of Bridge shown in Fig. 12.

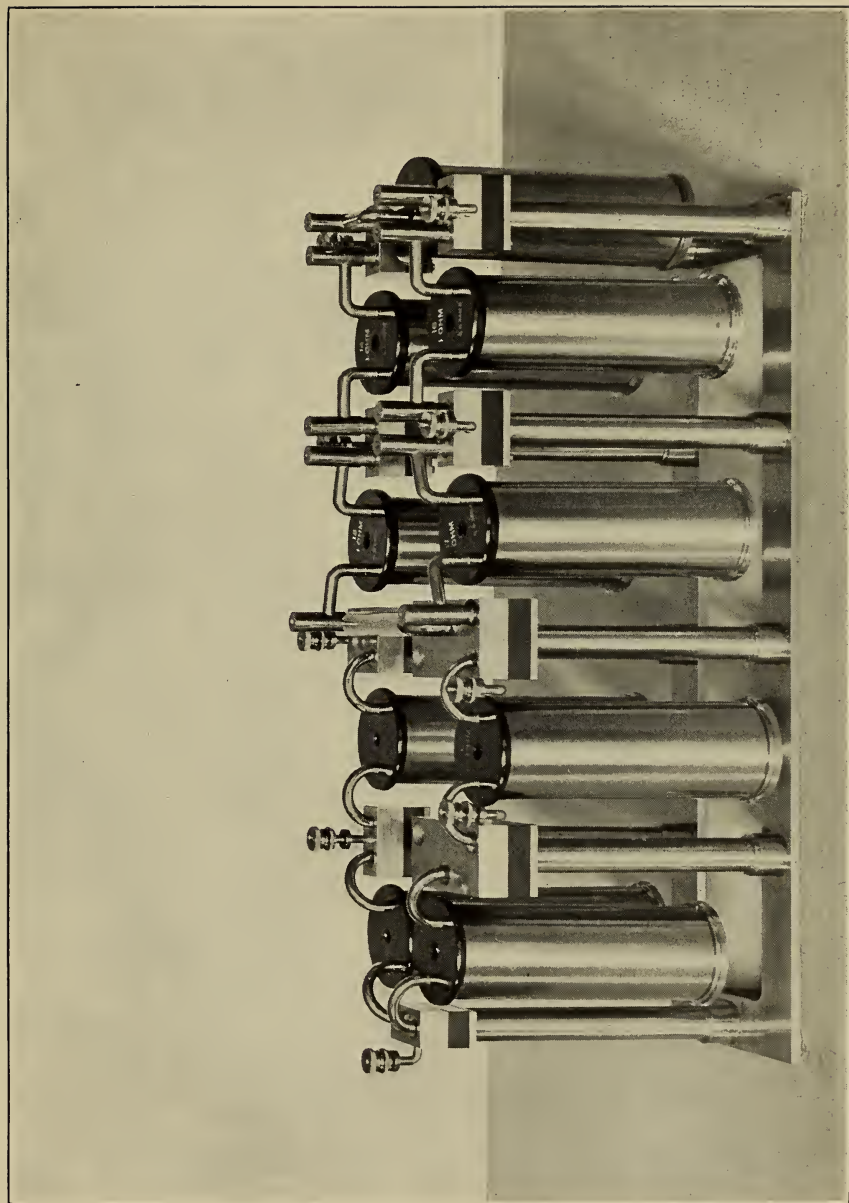


Fig. 10.—Bridge for Intercomparing Coils of Different Denominations. Link in place.

and  $V_2$  being insulated. The coil  $10_A$  may be replaced by  $10_B$  and their difference determined directly. The link  $L$  is then removed and the coils arranged as in Fig. 11. Now the five 1-ohm coils and the two 10's in parallel together make up one arm of the bridge, and the change in the shunt gives the difference between  $10_A$  or  $10_B$  and  $\frac{10_A + 10_B}{4}$  plus the sum of the five 1-ohm coils. Allowance must, of course, be made for the resistance of the link, which amounts to only about 2 parts in a million of a 10-ohm coil. The following measurements made September 29, 1908, show how the method works out in practice:

*Results of stepping up from the units to the tens, September 29, 1908*

Using coil  $10_6$  as a standard of reference, the following relative values were measured:

$$10_2 - 10_1 = -41.3 \quad (1)$$

$$10_3 - 10_1 = -34.0 \quad (2)$$

$$10_4 - 10_1 = +85.0 \quad (3)$$

$$10_5 - 10_1 = +106.4 \quad (4)$$

$$\left[ \begin{matrix} 10_1 \\ 10_2 \end{matrix} \right\} \text{ parallel } + (\Sigma 5 + l_1) - [10_1 + l_2] = -34.9 \quad (5)$$

where the results are expressed in millionths of the nominal value of the 10-ohm coils.

$\Sigma 5$  = sum of the 1-ohm coils Nos. 1, 2, 3, 4, and 5.

$l_1$  = resistance of the connecting blocks between these coils  
 $= 8 \times 10^{-6}$  ohms.

$l_2$  = resistance of the link  $= 23 \times 10^{-6}$  ohms.

$\therefore l_1 - l_2 = -15 \times 10^{-6}$  ohms.

$= -1.5$  millionths of the value of a 10-ohm coil.

For  $\Sigma 5$  we derive from intercomparison of the 1-ohm coils and on the assumption that their mean value is constant and 2.5 millionths less than the nominal value.

Coil	Correction to Nominal Value
$1_1$	- 1.0
$1_2$	- 1.5
$1_3$	0
$1_4$	- 6
$1_5$	- 4.5
Sum = - 13.0	

or  $\Sigma 5 = 5 - 13 \cdot 10^{-6}$  ohms

= 5 ohms - 1.3 millionths of the whole resistance when used in the 10-ohm combination.

Writing

$$10_1 = 10 \text{ ohms} + a$$

$$10_2 = 10 \quad " \quad + \beta$$

$$10_3 = 10 \quad " \quad + \gamma$$

$$10_5 = 10 \quad " \quad + \epsilon$$

we have

$$\left. \begin{matrix} 10_1 \\ 10_2 \end{matrix} \right\} \text{ in parallel} = 5 \text{ ohms} + \frac{a + \beta}{4}$$

and from equations (1) and (5)

$$\frac{a + \beta}{4} - 1.5 - 1.3 - a = -34.9$$

$$\beta - a = -41.3$$

$$a = +43.6$$

$$\beta = +2.3$$

From these follow immediately the corrections (in parts of a million) of the nominal values of the 10-ohm coils.

Coils	By Equations (2)-(5)
10 <sub>1</sub>	+ 43.6
10 <sub>2</sub>	+ 2.3
10 <sub>3</sub>	+ 9.6
10 <sub>4</sub>	+128.6
10 <sub>5</sub>	+150.0

Fig. 13 shows a form of bridge used in measuring temperature coefficients where the two parts, connected by long links, are in baths at different temperatures, one constant and the other variable.

## 5. CONSTANCY OF THE RESISTANCES.

The relative values of a number of 100- and 1000-ohm coils are shown by the curves of Fig. 12, which represent observations extending over a period of six months. The values as plotted are on the assumption that the mean of the 1000-ohm coils numbered 1, 2, 3, 4 is a constant. The first six coils, both of the 100's and 1000's, are



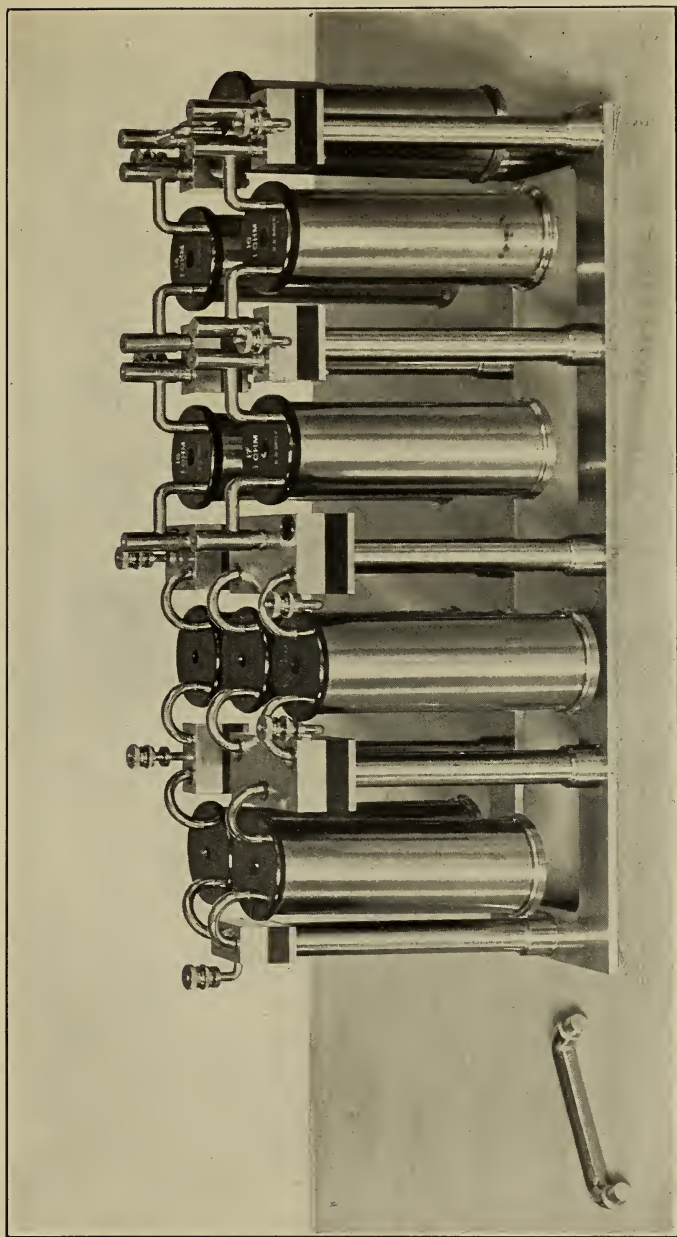


Fig. 11.—Bridge for Intercomparing Coils of Different Denominations. Link Removed

Wolff coils taken from one of his precision rheostats and mounted as sealed standards. Coils 7 and 8, both of the 100's and 1000's, were new, and not at first as constant as the older ones. The two coils, 100-ohm No. 9 and 1000-ohm No. 9, were mounted in precisely the same way, but with several holes in the cases, as shown in the photograph, Fig. 14. Their curves, given in the middle of Fig. 12, show how greatly they varied as compared with the sealed coils. The results of measurements on three Wolff coils of the Reichsanstalt form are also given in Fig. 12. Two of these coils (one of 1000 ohms and one of 10,000 ohms) were mounted as usual, but the third had its case replaced by a case without holes, which was sealed with varnish at the junction of case and top, so as to give the coil an air-tight inclosure. The curves show that the two coils in their own cases varied considerably, the 1000-ohm coil 14 parts in 100,000 and the 10,000-ohm coil 16 parts in 100,000 during this period. Up to November 21 the measurements were made rather infrequently, and the curves therefore appear smooth; but between November 21 and January 8 the open coils were measured eleven times, and their changes up and down as shown in the curves corresponded to varying conditions of the weather. The sudden considerable change between November 21 and November 22 was produced by an unusually damp atmosphere on the evening of November 21, when the windows of the laboratory were open a few hours. The sealed Wolff coil, No. 3057, remained remarkably constant for several months, and the slight upward turn of the curve is possibly due to a slight leak of air.

These and other sealed coils of 10, 100, 1000, and 10,000 ohms have been frequently measured during the past few months, and show a remarkable constancy. Six 10-ohm coils, eight 100-ohm coils, eight 1000-ohm coils, and six 10,000-ohm coils have been under observation. While they are not all constant, there is *only one coil of the above twenty-eight that has changed as much as 2 parts in 100,000 during the past twelve months*. This one coil I regard as defective, but I do not know the reason for its change. Of the other twenty-seven coils, more than half have changed less than 1 in 100,000. The measurements have not been systematic enough to say just how many parts in a million the changes have been, except for a part of the coils.

Fig. 15 shows the results of careful measurements on thirteen 1-ohm coils during the past three months. The dots which represent the individual measurements are plotted on such a scale that one small square is equal to 1 part in a million. For example, the two measurements of July 18 and 20 on coil No. 1 differed by 2 parts in a million. The horizontal lines represent the values of the coils, assuming them all to be constant. The average deviation of the separate measurements from the mean is given for each coil at the right of the figure. In seven coils this is less than 1 part in a million, and for the entire thirteen the mean of these average deviations is exactly 1 part in a million. These comparisons were made at temperatures ranging between 15° and 28° C, some of them thus involving considerable temperature corrections. *These small variations are no more than the probable errors of the measurements, including the uncertainty in the temperature corrections, so that there is no evidence that any one of the thirteen 1-ohm standards has suffered any change whatever during the past three months*, unless possibly the two coils 13 and 14 have increased *very slightly*. On the other hand, open 1-ohm coils exposed to atmospheric influences sometimes change appreciably in a single day,<sup>5</sup> or even in a few hours; and although the average values of the 1-ohm standards at the Reichsanstalt have undoubtedly remained very constant for some years, Dr. Lindeck has recently found<sup>6</sup> a difference of about 13 parts in a million in his 1-ohm coil (A) between April and October. His coils of larger denomination—of 10, 100, 1000, and 10,000 ohms—changed in the same time from 28 to 75 parts in a million.

Fig. 16 is taken from Lindeck's recent paper (p. 234), and shows the changes in resistance of 14 resistance standards with reference to his 1 ohm (A) which was assumed to be constant. The observations extended over a year, and show that the resistances of all the 10, 100, 1000, and 10,000 ohm coils rise to a maximum about the 1st of October and subside to a minimum somewhere between January and April, the observations not being sufficiently numerous to fix the maximum and minimum points closely; and these would, of course, vary from year to year. The 0.1 ohms

<sup>5</sup> F. E. Smith. Phil. Mag. p. 450; Sept., 1908.

<sup>6</sup> Über den Einfluss, etc., p. 234.



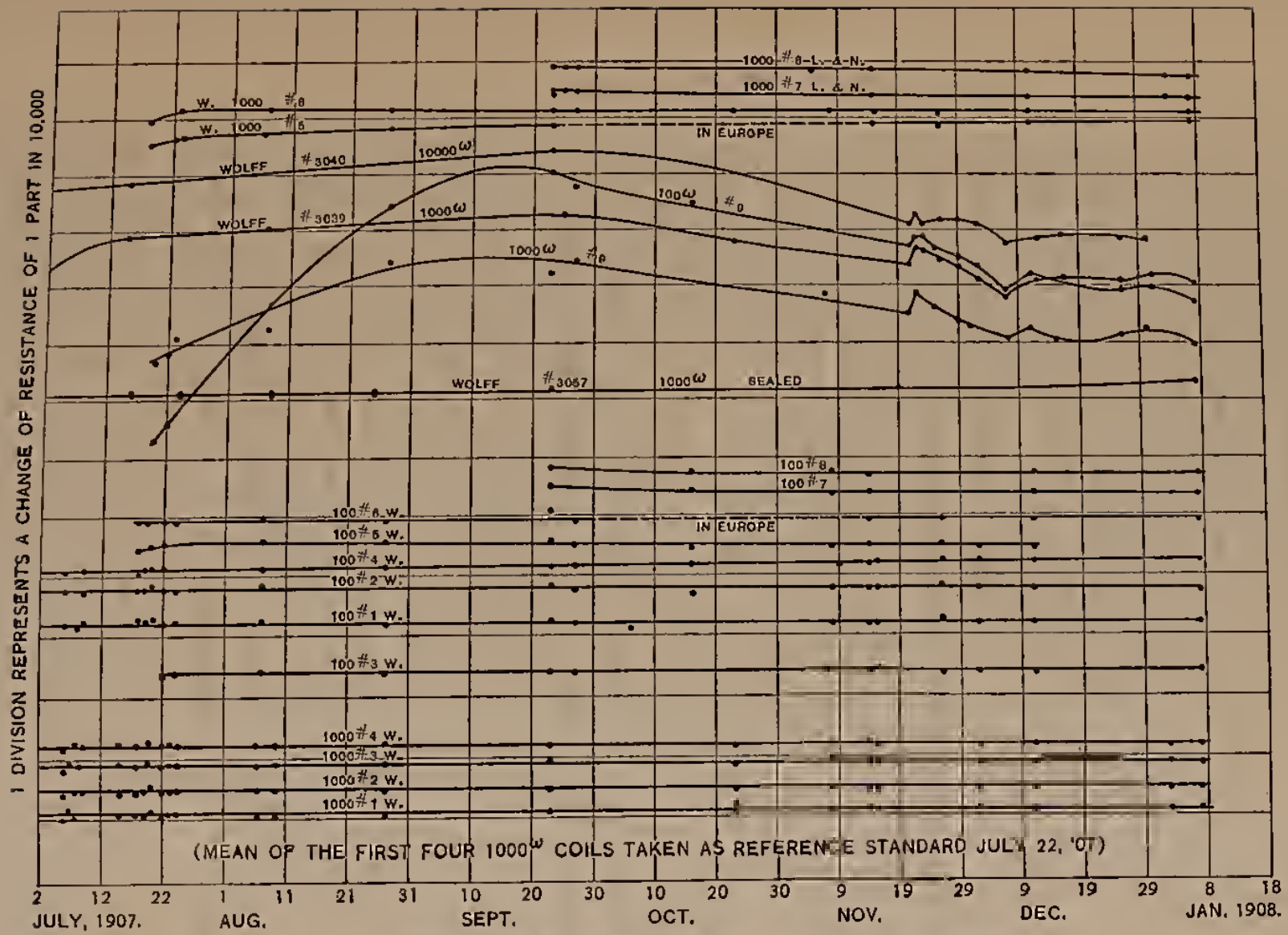
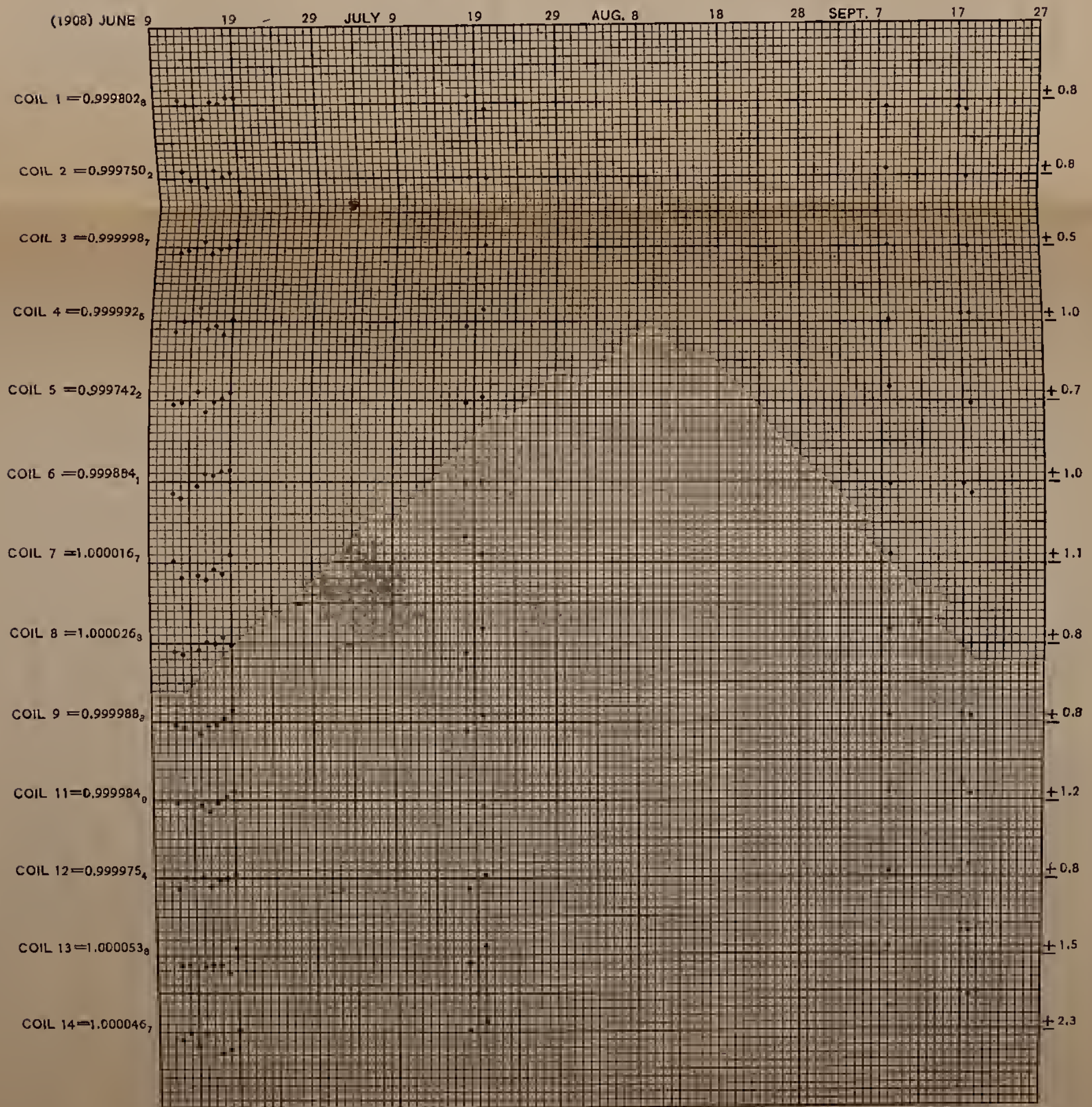


Fig. 12.—Showing Difference in Behaviour of Open and Sealed Standards.



The straight lines represent the average values of the coils, which are given at the left.  
The numbers at the right give the average deviation of the observed values from the average values, in millionths of the nominal values of the coils.  
Each small division represents 1 millionth of the nominal value of the coils.

Fig. 15.—Thirteen One-Ohm Sealed Standards.

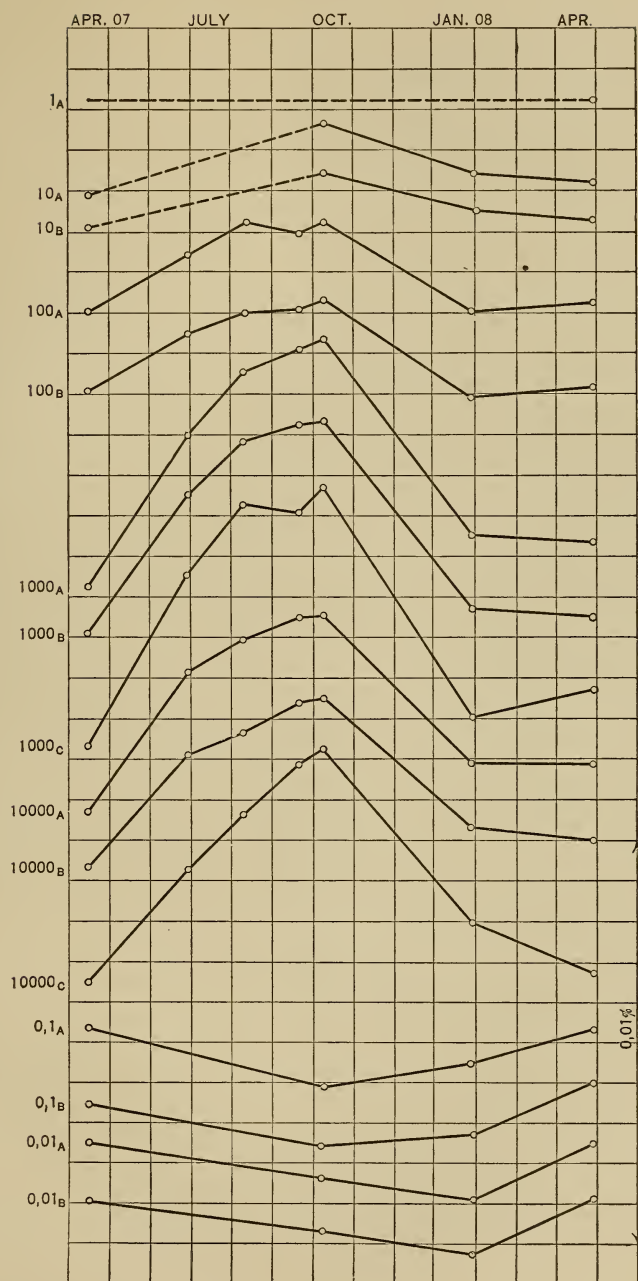


Fig. 16.—Variation of Resistance of Open Standards as found by Lindeck. One space=1 part in 100,000.



(wound with very coarse wire) and 0.01-ohm coils (wound with sheet manganin) seem to *decrease* in summer, all by about the same amount, namely, 13 parts in a million. This is, of course, as Dr. Lindeck points out, because the 1-ohm coil has really *increased* and the 0.1 and 0.01 ohm coils have remained constant. Hence the change in the 10-ohm coils is the sum of 15 parts in a million, as shown in the figure, and the 13 parts change of the reference coil, or 28 parts in a million altogether. The 100-ohm coils changed about 35 parts in a million, the 1000's about 73 parts on the average, and the 10,000-ohm coils about 71 parts in a million. Inasmuch as these coils can be compared to 1 part in a million, or better, and as standards ought to be known to at least 1 part in 100,000, it is evident that changes of the above magnitude, which correspond to temperature changes of from 1° to 7° C (when the coefficient is 10 parts in a million per degree), are altogether too great to be permanently satisfactory for important standards of reference. Moreover, these changes occurred in the favorable climate of Berlin, whereas in London or Washington the change could be expected to be much greater.<sup>7</sup>

Hence it appears that our sealed standards, most of which contain comparatively new coils, and of these most were made in our own instrument shop, have changed on an average far less than the standards of the Reichsanstalt (the latter being in the favorable climate of Berlin), while our 1-ohm sealed standards, which are of course wholly unaffected by atmospheric humidity and will have the same values in any climate, have not changed enough to discover during the past summer, and some of them have been constant as compared with one another for nearly a year.

It ought to be stated that the reference standards of the Reichsanstalt are now being kept in an atmosphere of constant humidity in order to avoid these changes, and at the National Physical Laboratory the reference standards are about to be sealed for the same reason.

A further study of these resistances is, of course, necessary, but I think it not improbable that if three or four national laboratories

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<sup>7</sup> Lindeck, *Zs. für Instrumentenkunde*, August, 1908, p. 236.

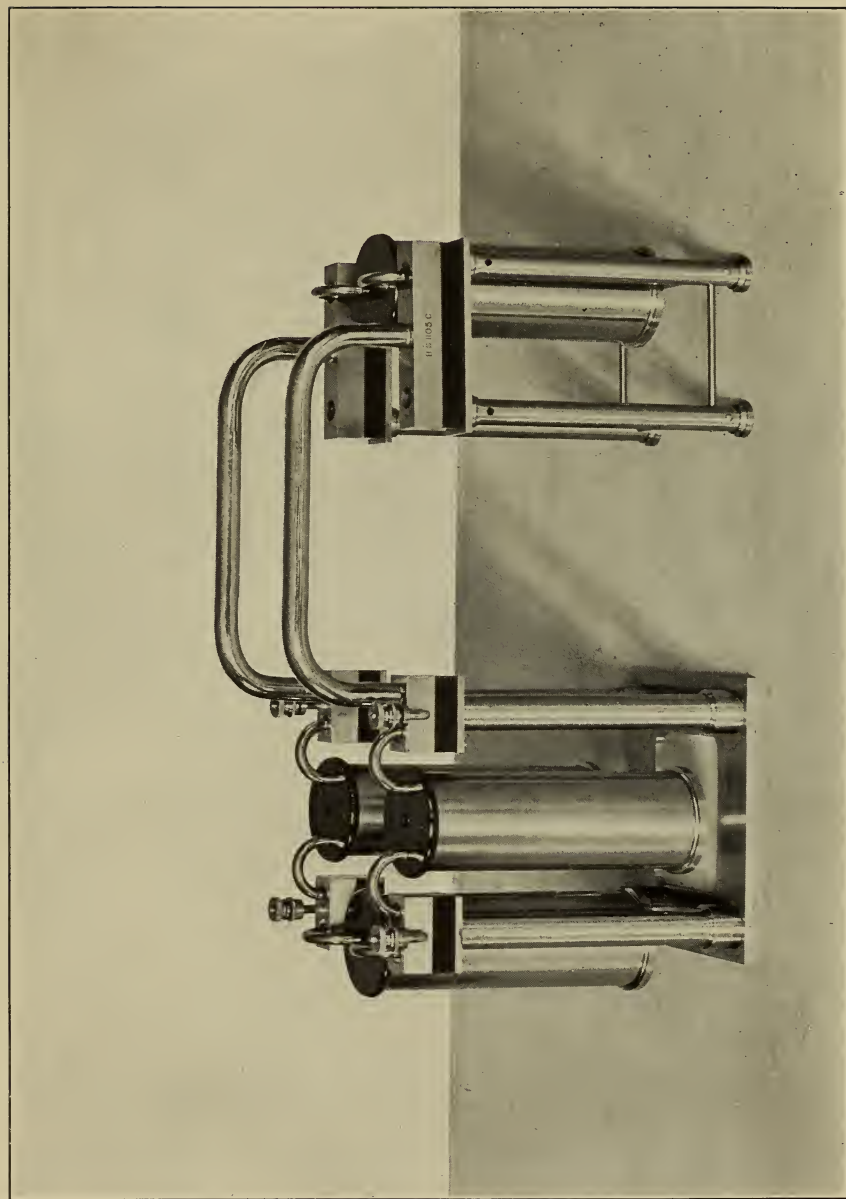


Fig. 13.—Bridge for Measuring Temperature Coefficients.

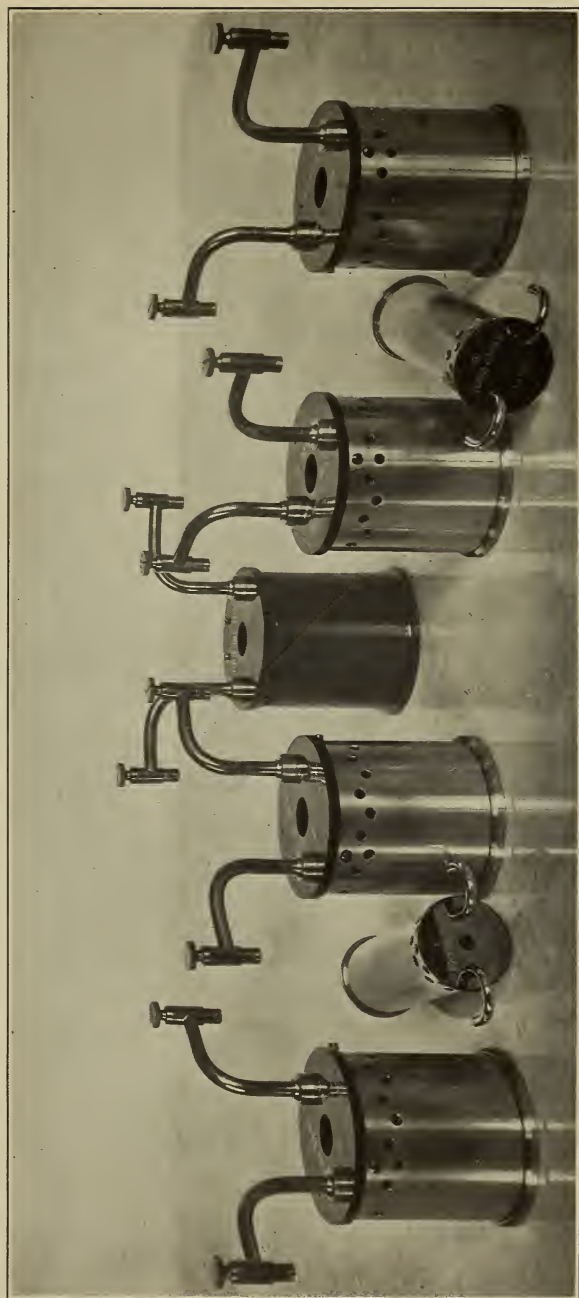


Fig. 14.—Resistance Standards of plate 12.

were each supplied with a dozen sealed standards of the Bureau of Standards type, and they were occasionally intercompared by means of a number of traveling coils of the same type, that a mean international ohm could thus be maintained constant to within 1 or 2 parts in a million, and a reference to primary mercury ohms would need to be made only at relatively infrequent intervals.

## 6. COMPARISONS OF RESISTANCES IN LONDON AND BERLIN.

In February, 1908, I took a number of these resistances to Europe and had them compared at the National Physical Laboratory, London, and the Physikalisch-Technische Reichsanstalt, Charlottenburg, partly to obtain a check on the value of the resistance unit of the Bureau and partly to obtain a comparison between the resistance standards of the above-named institutions. Such comparisons had been made between London and Berlin, but probably because of changes in the comparison coils the results were not entirely satisfactory. The recent comparisons show that the values assigned to the coils in Washington differed from the values found at the Reichsanstalt by about 1 part in 100,000 on the average for the 1-ohm and 100-ohm coils. This shows excellent agreement in the stepping up at the two institutions.

TABLE I.

Results of Measurements on Resistance Coils made in Berlin, London, and Washington.

Nominal Value	Coil No.	P. T. R.			N. P. L.	N. B. S.		Differences in millionths	
		Oct. 28, 1907	Mar. 12, 1908	Mar. 20/21, 1908	Feb. 18, 1908	Sept. 30, 1907	Feb. 3, 1908	P. T. R.-N. B. S.	N. P. L.-N. B. S.
1 ohm .....	1	.....	.....	0.99981 <sub>6</sub>	0.99982 <sub>9</sub>	.....	0.99980 <sub>1</sub>	+15	+28
	2	.....	.....	.99975 <sub>3</sub>	.99977 <sub>6</sub>	.....	.99975 <sub>0</sub>	+ 9	+26
	3	.....	1.00001 <sub>1</sub>	1.00000 <sub>0</sub>	1.00002 <sub>3</sub>	.....	1.00000 <sub>0</sub>	+10	+23
	12	.....	0.99997 <sub>5</sub>	0.99997 <sub>5</sub>	0.99999 <sub>7</sub>	.....	.99998 <sub>2</sub>	- 7	+15
100 ohms .....	1	.....	99.991 <sub>6</sub>	99.991 <sub>6</sub>	.....	.....	99.990 <sub>3</sub>	+13	+13
	2	.....	99.987 <sub>3</sub>	99.987 <sub>1</sub>	99.987 <sub>2</sub>	.....	99.985 <sub>8</sub>	+14	+14
	3	.....	.....	.....	.....	.....	99.994 <sub>1</sub>	.....	.....
	6	99.971 <sub>8</sub>	.....	.....	.....	99.971 <sub>0</sub>	.....	+ 8	.....
	9	.....	100.004 <sub>7</sub>	100.000 <sub>8</sub>	(open coil)	.....	.....	.....	.....
1000 ohms .....	1	.....	.....	.....	999.92 <sub>0</sub>	.....	999.90 <sub>2</sub>	.....	+18
	2	.....	.....	.....	1000.03 <sub>1</sub>	.....	1000.01 <sub>9</sub>	.....	+15
	3	.....	.....	.....	.....	.....	999.90 <sub>2</sub>	.....	.....
	5	999.78 <sub>9</sub>	.....	.....	.....	999.78 <sub>0</sub>	.....	+ 9	.....

The measurements made on these coils are given in Table I, the table being an extension of that prepared for me by Dr. Lindeck at the time of the measurements in Berlin in March. It shows that the difference between the Bureau of Standards' values and those of the Reichsanstalt for the 1-ohm coils was nearly the same for coils 1, 2, and 3, the difference for coil 12 differing appreciably from the others. This was due to the fact that the first three coils were seasoned and constant, having been made and mounted in August, 1907. Coil 12, on the other hand, was a new one, having been adjusted and sealed in January, 1908, just before being taken abroad.

The following table of differences in *millionths of ohms* shows how constant the relative values of 1, 2, and 3 have been.

	Washington, Jan., 1908	London, Feb. 18, 1908	Berlin, Mar. 20, 1908	Washington, Sept., 1908
1-2	51	53	57	53
3-2	250	249	250	249
3-12	18	26	34	24

The differences for the 3-12 would seem to indicate that 12 was decreasing at first, but that later it increased a little. This is not impossible, as the seasoning involves changes both in the shellac covering and the manganin itself. The mean difference *PTR-NBS* for the first three 1-ohm coils is 11 millionths, and *NPL-NBS* is 26 millionths for the same coils, giving a difference of +15 millionths for *PTR-NPL*. That is

$$\begin{aligned} PTR-NBS &= +11 \text{ millionths} \\ NPL-NBS &= +26 \text{ millionths} \\ NPL-PTR &= +15 \text{ millionths.} \end{aligned}$$

For the 2-100-ohm coils the differences are as follows:

$$\begin{aligned} PTR-NBS &= +13_5 \text{ millionths} \\ NPL-NBS &= +13_5 \text{ millionths} \\ NPL-PTR &= 0 \text{ millionths.} \end{aligned}$$

The measurements at the National Physical Laboratory on the 1000-ohm coils gave nearly the same difference *NPL-NBS* as the hundreds, i. e., 17 $\frac{1}{2}$  millionths.



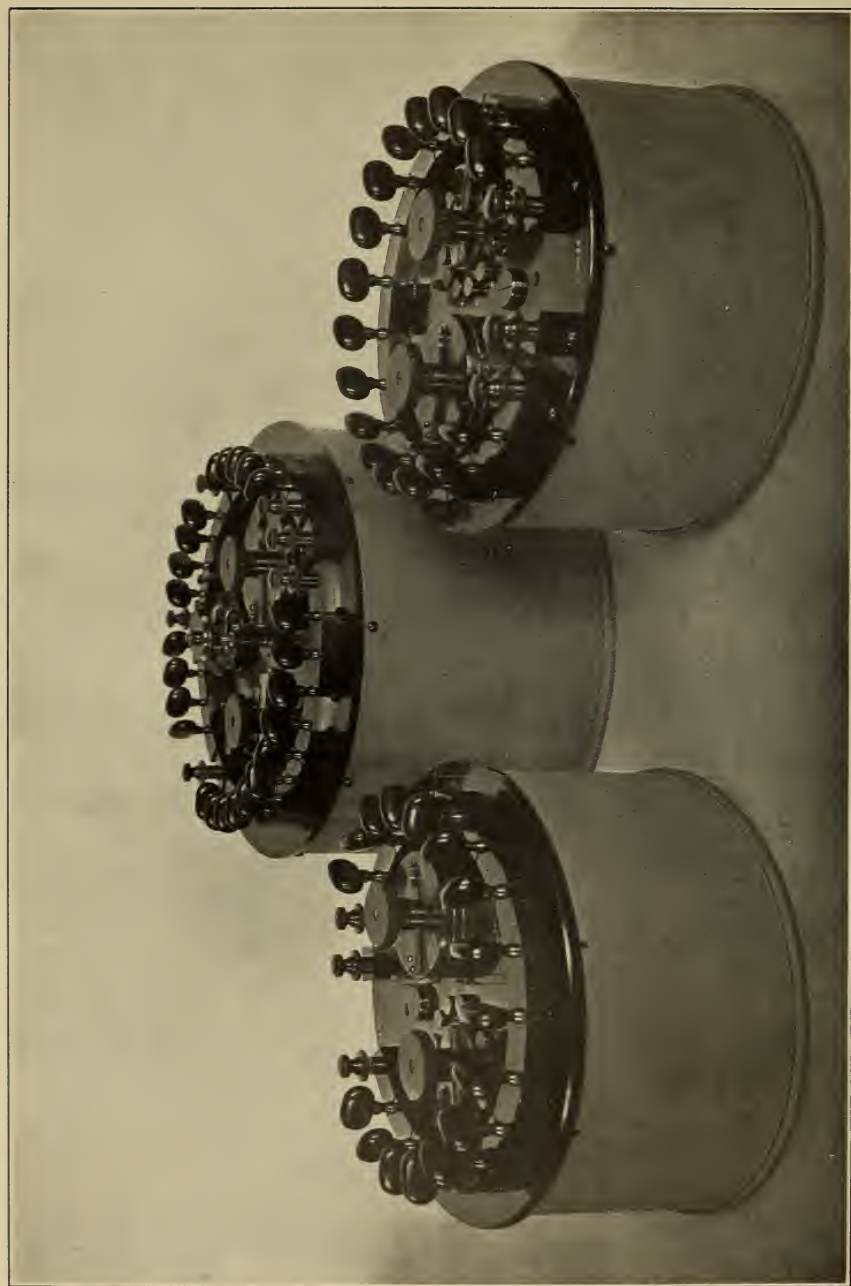


Fig. 17. — Scaled Resistance Boxes for Alternating Current Measurements.

It is only fair to say that the measurements at the National Physical Laboratory were not made under as favorable circumstances as could be wished, the bridge being adapted to a different style of coil. Hence, Mr. Smith regarded the 1-ohm comparisons as less reliable than the others.

Such intercomparisons of resistances between the several standardizing institutions should be made from time to time, and a mean value of the international ohm derived therefrom, which would be used by all countries. At present the values of resistances in England are in terms of their mercury ohm of the National Physical Laboratory, while in Germany they are in terms of the standards of the Reichsanstalt. The values used in America have been obtained from the Reichsanstalt, while in France they have been based on their own mercury ohms, which are different by an unknown amount from those of London and Berlin. Now that resistance standards are available that can be depended upon to within a few parts in a million, probably for long intervals of time a concrete international ohm can be maintained that can be used in all countries, and the value of a resistance standard will then be the same from whatever source it is derived. It only remains to have established some permanent official body as an international electrical commission which may cause the necessary intercomparisons of the several mercury standards to be made, and deduce therefrom the value of the common international ohm. In the same way intercomparisons of other concrete standards, as standard cells, inductance coils, etc., will fix the values concretely of the various international units and so promote uniformity in standards and advance the precision of electrical measurements.

## 7. USE OF SEALED RHEOSTATS AND BRIDGES.

In Fig. 17 is shown a special form of Wheatstone bridge which we have called an Anderson bridge, employed for measuring inductances,<sup>8</sup> and two special precision rheostats. The bridge is used with alternating currents, employing tuned galvanometers, and to increase its current carrying capacity, in order to give a high sensibility, the bridge has a metal case which is filled with petroleum. The resistances were sufficiently variable to render it necessary to

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<sup>8</sup> Rosa and Grover, this Bulletin, 1, p. 291; 1908.

make rather frequent calibrations until something more than a year ago, when the case was sealed practically air-tight. Since then nine coils have been measured frequently in terms of our sealed standards, and the values carefully reduced to 20° C. The record shows that during the past fourteen months the three 50-ohm coils, three 100-ohm coils, and the three 200-ohm coils have remained constant to within about one part in 100,000 on the average, there being no evident difference between the resistance in summer and winter. This is so much better than such a bridge has ever done before in this laboratory that it deserves notice. It is far better than the best open *standards* of the same denominations do. We have also other precision apparatus protected similarly by sealing, and also many boxes and potentiometers protected by paraffining the coils.

As stated above, and as might be expected, the sealed resistance standards are not perfectly constant; but the variations of a number of coils from the mean of the group are so slight that it requires extremely accurate measurements to detect them, and on the average in coils that have been properly prepared amount to a very few parts in a million in a year. Exceptional coils may change more, and for that reason they should be given an ageing test before being trusted as standards of highest precision. The work that has been done during the past year has clearly shown the great advantage which these sealed standards possess, but there is further work to be done in getting standards of smaller temperature coefficients and in studying the performance of these over a longer period. They do not, of course, displace primary mercury standards, but they will make it unnecessary to refer so often to them, and as they will travel in any climate they make it possible to get accurate intercomparisons of the various primary standards that may be set up in different parts of the world. A further study of the standards will be carried on by Dr. F. A. Wolff of this Bureau.

In conclusion, I wish to express my obligation to several members of the Bureau for assistance in the work. The earlier measurements of the standards were made chiefly by Mr. H. D. Babcock. The recent measurements have been made chiefly by Dr. C. A. Pierce and Mr. G. E. Post. The coils and the special bridges were constructed by Mr. Joseph Ludewig, of the instrument shop of the Bureau.

WASHINGTON, October 1, 1908.