

THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

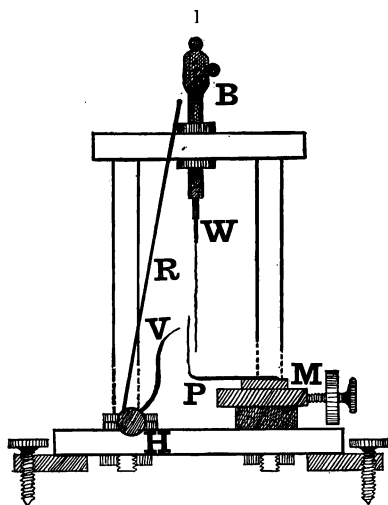
ART. IX.—*Experiments on High Electrical Resistance*, Part II; by OGDEN N. ROOD, Professor of Physics in Columbia University.

New method of measuring high electrical resistance.—In the first part of this paper,* I have given a general account of a mode of measuring electrical resistances which are far too large to be dealt with by ordinary methods. Since then the electrometer, there indicated, has been improved, and a large number of units of resistance has been constructed. Experiments have also been made with regard to the best modes of using them, and, in particular, with respect to the best way of building up a set of high resistances, from a low, but known, resistance. Attention has been paid to electrical leakage, to the composition of the units, to their reliability during short and long intervals of time. Their behavior under different electromotive forces has been somewhat attended to, and is still under examination. A large number of details have presented themselves, and it will require considerable time before they all can be satisfactorily studied. Meanwhile this much has been ascertained: it is possible to take a low standard of resistance, measured by old methods, employing fifty or a hundred volts, and from this to build up a set of resistances, the highest of which shall be equal to fifteen or twenty millions of megohms, the original electromotive force being always adhered to. With such units of resistance it is of course easy to measure any resistance which lies within their range, employing always one and the same electromotive force. The reliability of such measurements can be judged from the results given at the end of this article. It is also certain that the

* This Journal, x, 285, 1900.

cores of the units about to be described are inaccessible to moisture, and that in ordinary weather there is no surface conduction that interferes with their accuracy. Less is known about the invariability of the units during long periods of time; this matter is being investigated by Mr. H. C. Parker, and the results thus far obtained are promising. If it should turn out that none of the varieties I have devised has this desirable quality, it would merely necessitate on each occasion where accuracy was required, a galvanometer measurement, and a building up process from it, involving two or three hours of extra labor, as changes in the units do not occur which would interfere with the ease of a building up process once established in all its details. In every case thus far examined, the resistance of the unit immediately after making it has increased with some regularity, week by week, but at a diminishing rate, and now at the present time, it is not my custom to employ units till they are at least three months old.

Electrometer.—The construction of this apparatus is shown in the sketch, fig. 1, where all the shaded portions are metallic, and the unshaded parts made of the best quality of ebonite. B is a brass binding post, to which may be attached the wire conveying the charge, also a Leyden jar or a small mica condenser. It terminates below in an aluminum leaf, bluntly pointed, and provided with a long hinge of gold leaf for flexi-



bility. The latter is attached to a brass wire W, that slides into a well-fitting tube, from which it can readily be removed for repairs. P is a springy brass plate faced with platinum. When the apparatus has received a sufficient charge the aluminum leaf is attracted to P, and usually remains attached; V is a narrow strip of thin sheet brass fastened to an axis, not shown in the diagram, which is terminated by the milled head H; it can be made to slightly scrape the edge of the plate P, and communicate

to it a trifling vibratory movement, which instantly detaches the gold-aluminum leaf. Mere contact from behind, even when made with some violence, is not sufficient for this pur-

pose. R is a stiff brass wire attached to the same axis with V, and serves to discharge the apparatus; it has an arm bent at a right angle which can be brought into contact with the binding post B. A single motion discharges the electrometer and sets the gold leaf free. The axis carrying R and V is connected with the ground. The micrometer, M, is provided with a millimeter screw and carries the plate P. In all of my recent experiments it was connected with the ground. The height of the electrometer from the table, to the top of the binding post, is 27^{cm}. It is covered by a glass case to prevent air currents, the case being in contact only with the ebonite base. When in actual use the apparatus is covered by a paste-board box coated with tin-foil, through the sides of which suitable openings are made for observation, and for the introduction of the two wires that are attached to the binding post. The electrometer as thus described, with a striking distance of a half or of one millimeter, is suitable only for measuring resistances of a million megohms and upwards; lower resistances bring about a stroke in a very few seconds, and to measure these, its capacity must be increased.

Condensers.—A series of these have been employed, the greatest being a large Leyden jar with a capacity of .00507 of a microfarad; four smaller jars with diminishing capacities and three small mica-condensers have been used. When the electrometer is once made, and a few suitable resistances, such a set of condensers can easily be produced. The mica-condensers were supported by silk threads that had been heated up in a bath of wax and rosin. A long wooden rod above the apparatus carried the mica-condensers and the units, when more than three or four of them were used in a series, and in this way excellent insulation was readily obtained.

Table of Capacities of Condensers.

	Capacity in microfarads.
Leyden jar, No. 10050
“ “ 20025
“ “ 30013
“ “ 40008
“ “ 500044
Mica cond., No. 100024
“ “ 200014
“ “ 3000037
Electrometer000014

It may be remarked that the apparatus described in this paper can easily be used to determine the capacities of quite small condensers, and of conductors or semiconductors sus-

pended in the air by insulating threads. With a set of condensers like the above, the capacity of any condenser within their range can be quickly obtained.

Units of resistance.—After a number of experiments in different directions, it was decided to employ peroxide of manganese painted on strips of blue cobalt glass, which was found to be a much better insulator than colorless plate glass. The mode of construction, briefly, is as follows: washed commercial peroxide of manganese is painted with a brush on cobalt glass, the edges of the strip being avoided, and it is then dried with gentle heat. The layer thus obtained is quite adherent in spite of the fact that only water is used in making the mixture, and it can be laid on with different thicknesses and have desirable breadths. The two ends of the glass slip are then wrapt with tin-foil, and about 7^{cm} of the foil allowed to remain free at the two ends to hold the unit when it is immersed in a rosin-wax bath. Fine brass wire is used to prevent the unit from unrolling itself when it is lifted up. The rosin-wax bath contains only so much wax as does not dim the polish of the finished unit, the polish of the bath itself, when it cools, being about half destroyed. Pure yellow wax was employed, and the temperature of the bath was about 150° C. Immersion in this bath drives out air and moisture, and as more than half of the tin-foil is also immersed, it results that the unit is embedded in the insulating substance, conduction to its interior being furnished by the free tin-foil at the ends. Afterwards, while still as hot as allowed handling, the units were finished with a hot knife, care being taken repeatedly to press down the foil at the places of contact. The superfluous rosin being removed, the remainder of the tin-foil was wrapt around the ends of the units and suitable terminals of sheet brass supplied. These again were wound with flexible iron wire having a diameter of 0.4^{mm}. In this operation as much force as was considered safe was employed, in order to secure fixity, and to make sure that the pressure exerted on the foil should be far greater than any experienced afterwards in the use of holders to connect the units, or to introduce them into the circuit. It will be seen that the units are completely inaccessible to moisture, and experiments have shown that in ordinary weather their surface conduction, practically, is zero. Three-quarters of the insulating surface between the terminals have been wrapt with tin-foil without lowering the resistance, even when the hygrometer indicated 60 per cent of moisture.

The process which has been explained is suitable for the production of units having resistances from one up to ten thousand megohms. For higher units the oxide of manganese

is to be diluted with Chinese vermilion, when good substantial layers can still be used. If the amount of the oxide of manganese be reduced as low as twenty per cent, as high resistances can be obtained as any that have been handled by me. The thickness of oxide of manganese giving a resistance of only one megohm was not measured, but must have been less than one millimeter. Some of these low units, of from one to a hundred megohms resistance, were given to Mr. H. C. Parker, who is engaged in testing their constancy; he finds that they exhibit no polarization, neither have I, experimenting with higher units, detected anything of this kind, by which is meant that in neither case does the resistance increase while the current is flowing.

As already indicated, the best results were obtained by the use of an insulating material of rosin with a small percentage of yellow wax. Paraffin was also tried, but even with low units exhibited a tendency to break down and lower its resistance, temporarily; plain yellow wax was better, but both of them were liable to break down rather suddenly when the resistances were quite high. Plain peroxide of manganese on cobalt glass, not insulated by immersion in any bath, answered admirably in dry weather for rather low units (under 50,000 Ω) but in damp weather became quite unreliable.

The units employed by me were 10^{cm} long, 2^{cm} broad, each brass terminal having a length of 2^{cm}. For the higher resistances they might be made two or three times as long with advantage.

Battery.—In the earlier experiments the street current was employed with an E.M.F. of 112 volts, but was found to be unsatisfactory owing to its small variations; an arrangement of 200 cells or tubes with copper and zinc and very dilute acid is preferable, but the so-called dry cells are far better, as with such high resistances their electromotive force is almost perfectly constant, and they need no care.

Leakage.—It would appear tolerably certain that when the electrometer, with or without a condenser, is first employed, a small amount of electricity is, so to speak, absorbed by it, so that with a given unit, the time of a stroke becomes in a few minutes somewhat shorter and then remains constant. This leakage reduces itself to a minimum, but there is reason to believe that some always remains. For example, if two equal units are joined in a series, and matters are arranged so that the time of the stroke does not exceed thirty or forty seconds, then this joint time will be equal to the sum of their times used separately. If, however, this joint time is allowed to rise as high as one or two minutes, then it always exceeds the sum of the separate times by anything from four to ten per cent or

more, according to the dryness of the atmosphere. Various expedients were tried to measure and allow for this loss, but it was finally decided to compare together only resistances that were nearly equal, which is not a matter of difficulty after one has accumulated a stock of resistances, those which had been accounted failures now becoming useful. It is hardly necessary to add that if a unit, of about a given resistance, is desired, it is best, after due consideration of the case, to make five or six.

Manipulation.—One pole of the battery is connected with a contact maker which must be carefully insulated; from thence the current flows to the unit or resistance, and finally to the binding post, B. The electrometer having been discharged and the gold leaf set free, the wire R is allowed to remain for ten seconds in contact with post B, the current meanwhile flowing through the unit or resistance into the ground. As R and V are turned to the left the time is noted with a stop watch, and the leaf watched with a lens for the stroke, after which contact is immediately broken. An attempt is always made to arrange matters so that the time noted shall not be less than fifty nor more than eighty seconds, and in the case of two resistances which are being compared together, care is taken to make their times as nearly equal as possible, so as to avoid errors due to leakage. This is accomplished by the use of small subsidiary units of known resistance, which are added to either of the resistances under consideration as occasion may require. When a string of units is being compared with another string, the actual number of pieces in both cases should be the same, any deficiency being made up by the use of dummies which in all respects imitate real units, except that they have no resistance at all.

The second pole of the battery and the plate P are permanently connected with ground. The striking distance usually employed has been one millimeter throughout whole sets of experiments. Striking distances as large as seven millimeters can be used for regulating the time of the stroke, but it is better to manage this with the aid of condensers. In any case, the striking distance and the electromotive force of the battery should remain constant in a set of experiments, so that comparable results can be directly obtained without the use of coefficients. Not only can the units be used "in series," but also "in parallel," to measure smaller units.

Building up a set of resistances.—Mr. H. C. Parker measured for me a resistance which turned out to be 32,000 megohms, the electromotive force being 50 volts, and this was used as a base in building up a set which reached as high as fourteen million megohms. The plan for building up

having been arranged so that only units or sets of units of about the same resistance were compared together, it was possible to run through the entire series in three hours, and on April 20th this was done, and repeated on April 21st. The number of readings in no case exceeded three; the striking distance was one millimeter. The degree of accuracy obtainable under such circumstances can be judged from the table here given, where the resistances are expressed in megohms.

April 21st.	April 22d.
34,000	34,000
12,580	12,260
23,910	24,140
26,970	27,200
73,580	73,460
190,560	189,700
217,800	220,800
440,200	431,400
520,400	517,600
1,420,200	1,420,000
1,849,000	1,761,200
1,862,400	1,645,400
2,570,000	2,360,000
4,768,000	4,944,000
6,364,000	6,110,000
7,432,000	7,092,000
14,658,000	13,724,000

Columbia University, New York, June 1st, 1901.