

Note on the Measurement of the Electric Resistance of Liquids

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The last set of measurements had for its object to show that a compensating-magnet of the description proposed does not affect the readings. The results are embodied in Table V.; they were obtained with one of the older forms of solid-ring galvanometers provided with a sine-scale. The curved controlling magnet of a mirror-galvanometer, 20 centim. long and 2 centim. broad, was strongly magnetized and placed at a distance of 24 centim. in the manner formerly specified, and so arranged that it could be turned on a horizontal axis. Three different positions were given to the magnet—viz. one, in which it assisted the earth's magnetism, another, in which it did not act upon the needle, and a third, in which the earth's magnetism was partly neutralized. By altering the resistance in circuit, the deflections with the vertical ring were made equal in all three cases, viz. $63^{\circ}5$.

Table V. shows that the degree of accuracy did not materially differ under the three varying conditions. The magnet therefore does not appreciably interfere with the measurements. The mean error of all three positions of the magnet is 0.22 per cent., which is very low.

In conclusion, I may mention that a smaller model of the galvanometer, intended for practical use, is now being made, which will contain all the recent improvements, viz. the fine-wire coil besides the solid ring, the tangent-scale, the secant-marks, the air-damping, and the compensating-magnet. The latter will be so arranged that the "constant" will be considerably increased as compared with that due to the earth's magnetism alone; thus the needle should be much less influenced by outer disturbances than before.

Woolwich, June 1883.

XXXIV. *Note on the Measurement of the Electric Resistance of Liquids.* By Professors W. E. AYRTON, F.R.S., and JOHN PERRY, M.E.*

[Plate XIII.]

SOME time back a paper was communicated by Professors Reinold and Rücker to this Society on the Resistance of Liquid Films, which had a double interest, arising from the great

* Read June 9, 1883.

Fig. 1.

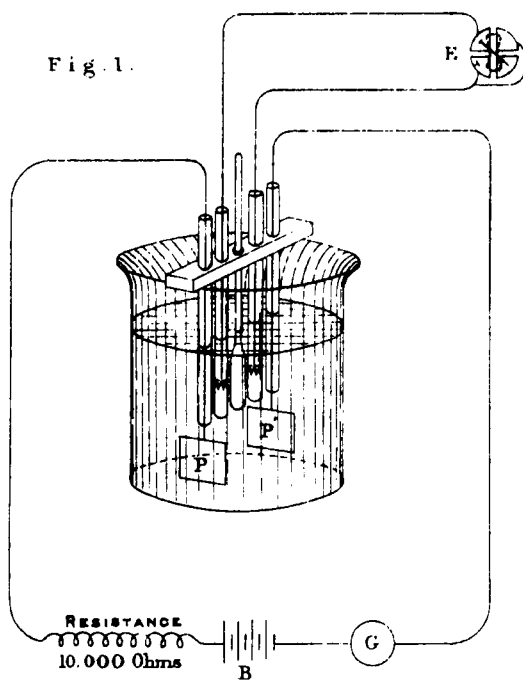
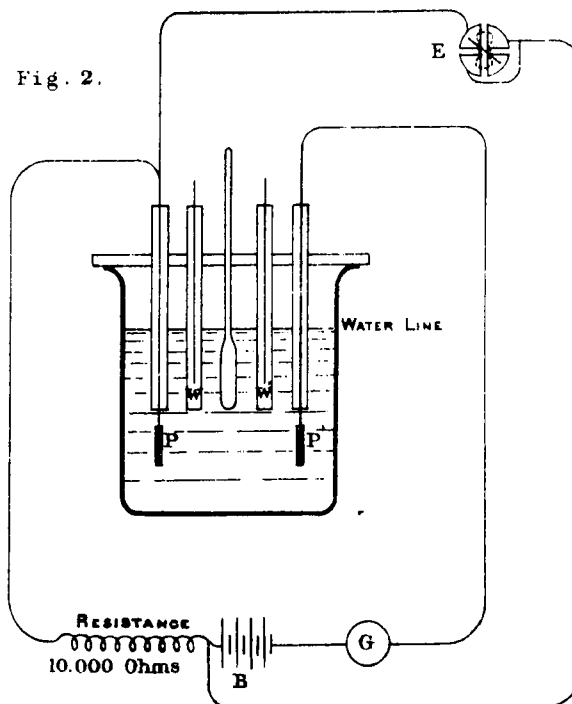


Fig. 2.



value of the results arrived at and from the method employed to obtain them. It is of course well known that the great difficulty in measuring the resistance of a liquid arises from the polarization of, or actual deposit of gases on, the anode and cathode, which makes the apparent resistance of the liquid far greater than the true value. To overcome this difficulty Kohlrausch employed rapidly alternating currents; and Dr. Guthrie, with Mr. Boys, dispensed altogether with the anode and cathode by observing the amount of twist produced in a fine steel wire supporting a vessel of liquid when a magnet was rotated at a fixed speed in the neighbourhood.

But there is another method of measuring the resistance of a liquid independently of its polarization—the one so successfully employed by Profs. Reinold and Rücker, and which consists in measuring by means of an electrometer the potential-difference at two fixed points in a column of the liquid when a current of known strength is passing through it.

At the time Profs. Reinold and Rücker communicated their paper, we mentioned that some years previously certain experiments had been conducted in our laboratory in Japan for the purpose of ascertaining how far the electrometer method of measuring the resistance of a liquid was entirely independent of polarization; and as we have since come across the results of these experiments in turning over some papers, we have thought that the information may possess some interest for the Members of this Society. The experiments were made at the commencement of 1878 by some of our students; and the first part of the investigation was for the purpose of ascertaining how the resistance of water varied with the electromotive force employed and with the temperature of the water when, first, the resistance was measured by the current which a known electromotive force could send between platinum plates of known size and at fixed distances apart in the water, and, secondly, when the resistance was measured by a comparison of the potential-differences of two platinum wires placed in the water at fixed distances apart, with the potential-differences when the same current was being sent through a known resistance.

Figs. 1 and 2, Pl. XIII., show the arrangement of the apparatus used in the experiments. B is the battery producing the

current passing between the platinum plates P and P'. G is a delicate reflecting galvanometer measuring the current. E is a quadrant-electrometer which measures the difference of potentials between the two wires W and W'. These two platinum wires W and W' were immersed in glass tubes; and their ends were above the bottom of the glass tubes as shown. Figure 1 shows the connexions when the differences of potentials between W and W' were being measured by the electrometer, and figure 2 when the differences of potentials at the two ends of the known resistance-coil, of 10,000 ohms, were being measured.

The following Table gives the dimensions of the various parts of the apparatus:—

Diameter of the beaker at water-line	8·5	centim.
Height of water-line above the bottom ...	5·76	„
Distance between centres of wire tubes } (W, W' in fig. 2).....	4·88	„
Distance between the platinum plates.....	7·3	
Part of the glass tube surrounding the } wire dipped in water.....	2·14	„
Part of the platinum wire in water.....	0·91	„
Outside diameter of the glass tube	0·87	„
Size of platinum plate : height	3·28	„
„ „ „ : width	2·29	„

Before each experiment, when no current was passing, the difference of potentials between the plates and wires was reduced to 0, if not 0 already. The wires W and W' were heated to redness before each experiment, and the platinum plates cleaned.

At the beginning pure distilled water was used; and this water was not added to all the time: it therefore lost a little by evaporation during the course of the experiment, and may have become a little dusty; but as the main object of the investigation was to examine the method of testing, and not for the purpose of measuring the specific resistance of water or of any other particular liquid, this result was of little consequence.

The following is a sample of the experiments made:—

January 25, 1878.—Battery-power employed $\frac{1}{6}$ of 23 Daniell's cells, having an E.M.F. of 4·08 volts, and which gave a deflection of 468 divisions on the galvanometer when

shunted with the $\frac{1}{49}$ shunt, and when a resistance of 10,000 ohms was introduced in the circuit.

Time after putting on battery.	Galvanometer-deflection.	Electrometer-deflection.		Temperature.
		Figure 1.	Figure 2.	
1 ^m	99	10		} 59°·5 F.
2	96	10		
3	94	10		
Plates and wires thoroughly discharged.				
1 ^m	99	14	} 61° F.
2	98	14	
3	90	14	

Time after putting on battery.	Resistance as determined by the galvanometer.	Resistance as determined by the electrometer.
1 ^m	37000	7100
2	38000	7100
3	39000	7100

The annexed Table gives the results of a long series of experiments:—

	Total electromotive force, in volts.	Temperature.	Resistance as determined by galvanometer at end of one minute.	Ratio of resistance at the end of second minute to the resistance at the end of the first.	Ratio of resistance at the end of third minute to the resistance at the end of the first.	Resistance as determined by electrometer.	Ratio of resistance determined by galvanometer to resistance as determined by electrometer.	Date.
A	0·93	58° F.	93900	1·27	1·4	15000	6·26	23rd Jan.
		60	133000	1·12	1·37	15000	8·87	23rd "
	0·93	100	56000	1·16	1·27	8000	7·00	24th "
	1·86	63	53000	1·10	1·14	10670	5	24th "
	1·86	62	51500	1·12	1·18	10300	5	24th "
B	1·86	102	32000	1·17	1·27	9670	3·31	24th "
	4·08	59·5	37000	1·03	1·05	7100	5·21	25th "
	4·08	102	19800	1·01	1·06	3270	6·06	28th "
	6·17	60	21000	1·0	1·0	4450	4·72	28th "
C	6·17	106	12000	1·08	1·08	2700	4·44	31st "
	16·45	62	12700	1·01	1·99	3170	4·01	31st "
D	16·45	107	7700	1·04	1·04	1953	3·94	31st "

Only one number is given for the resistance as determined by the electrometer in each case, because it was found not to vary much during the time of electrification; whereas the resistance as determined by the galvanometer, as will be seen, increased in the earlier experiments 30 to 40 per cent. during the three minutes' electrification.

The total electromotive force in each case was determined by making a comparison by means of the electrometer with one of Clark's standard cells.

From these observations the following conclusions may be drawn:—First, the resistance measured by the galvanometer is much greater when using about 1 volt than when using nearly 2, at the same temperature (compare observations A and B), whereas the electrometer-measurements altered very little at all. Again, comparing C and D, we see that the resistance measured by the galvanometer is much greater when using 6 volts than when using 16. In this case, however, the measurements of the electrometer are also considerably greater in the first case than in the second, the temperature being the same. Secondly, if the electromotive force is less than the decomposing electromotive force, then the smaller it is the more does the resistance alter from one to two minutes' electrification, and from two to three minutes'. Whenever, however, the electromotive force is sufficiently high for decomposition to take place, the electrification seems to produce but little change in the resistance. The resistance of the water diminishes as the temperature rises, the electromotive force being kept constant.

The following experiments were made preliminarily to explorations of the region between the two platinum plates in the water, for determining what were the directions of the lines of flow of current. We desired to see if there was any chance of being able to use platinum wires in glass tubes connected with the electrometer, as previously described.

In the following cases a long trough of water was used instead of the beaker.

The sensibility of the galvanometer was nearly the same throughout all the experiments, and was such that $\frac{1}{20}$ of the whole electromotive force employed produced a deflection of about 500 divisions when there was an external resistance

of 10,000 ohms and when the multiplying-power of the shunt employed was 100·7, which shunt was used throughout all the experiments.

Four Menotti cells, having an electromotive force of 3·7 volts, were employed in each of the following experiments. In A, B, C, D, E, F, and G the two platinum plates were placed parallel to one another at a distance of 90 centimetres apart. The two wires and their glass tubes were placed to commence at a distance of 80 centim.—that is, each being 5 centim. from the platinum plate. The lower ends of the

February 21, 1878.				
Distance between pla- tinum wires.	Time after putting on battery.	Galvanome- ter-deflection.	Electrometer- deflection.	Temperature of water.
centim.	m s			
A {	80	669	53	} 13° C.
	60	662	40	
	40	658	27	
	20	654	15	
B {	80	667	52	} 13° C.
	60	663	39	
	40	657	27	
	20	653	15	

February 22, 1878.				
C {	80	680	50	} 13° C.
	60	675	37	
	40	672	26	
	20	670	15	
D {	80	685	49	} 13° C.
	60	680	37	
	40	677	24	
	20	674	12	
E {	80	697	48	} 13° C.
	60	692	36	
	40	688	24	
	20	685	13	
F {	80	699	50	} 13° C.
	60	694	37	
	40	690	25	
	20	687	13	
G {	80	over 717	51	} 13° C.
	60	0 30	38	
	40	2 0	25	
	20	2 20	15	

platinum wires were each $1\frac{1}{2}$ centim. above the lower ends of the glass tubes; and the lower ends of the glass tubes were 1 centim. below the surface of the water. The two platinum plates and one of the platinum wires were kept immovable, while the other platinum wire was moved along the trough.

The object, of course, of taking the galvanometer-readings was to ensure that no material change was taking place in the current through the weakening of the battery or otherwise while the experiment was being made.

The experiments E and F appear most satisfactory of this set; and from these it seems that the resistance of the upper layer of water-column is nearly proportional to the distance between the platinum wires, except for the nearest distance, in which case the column seems to have a slightly larger resistance than it ought to have. This perhaps arose from the fact that, although the platinum plates nearly filled up the entire section of the trough, still the lines of flow at the platinum wire, which was kept stationary at a distance of 5 centimetres from one of the plates, were not quite parallel to the edge of the trough.

The two following sets of experiments, H and I, differ from the preceding only in that the lower end of the glass tube was one centimetre above the bottom of the trough; and from these two sets of experiments we see that the resistance of the lower layer of water-column, as measured by the electrometer, is nearly proportional to the distance between the wires, except, again, for the shortest distance.

Distance between pla- tinum wires.	Time after putting on battery.	Galvanome- ter-deflection.	Electrometer- deflection.
	m s		
H {	80 1 0	709	50
	60 1 35	703	37.5
	40 2 0	700	26
	20 2 20	698	13
I {	80 1 0	704	49
	60 1 20	700	37
	40 1 45	796	25
	20 2 20	792	13

The next experiments were for the purpose of seeing whether

the potential, as measured by the electrometer, would come out uniform at all points in one vertical transverse section of the trough as well as at all points in one of the glass tubes.

Distance between the platinum wires W and W', in centimetres.	Position of the lower end of one of the tubes.	Galvanometer-deflection.	Electrometer-deflection.
J {	80 Up.	696	49
	80 Down.	692	49
	80 Up.	689	49

“Up” means that the lower end of the glass tube was about 1 centim. below the surface of the water; and “Down” that it was about 1 centim. above the bottom of the glass trough. The platinum wire was now raised about 4 centim. above the bottom of the glass tube when the glass tube was down and the electromotive force was unaltered. The potential therefore, at all points in a vertical transverse section as well as at all points in the glass tube, is the same as measured by the electrometer.

The next set of experiments, K and L, were made under exactly the same conditions as A, B, C, D, E, F, and G, with the exception that the terminal platinum plates were now perpendicular to each other, the plate towards which the wire was moved being parallel to the long side of the trough.

Distance between the platinum wires, in centimetres.	Time after putting on battery.	Galvanometer-deflection.	Electrometer-deflection.	Temperature.
K {	m s			13° C.
	80 1 0	706	51	
	60 0 30	701	38	
	40 0 50	699	27	
	20 2 0	697	15	
L {	80 1 0	705	51	13° C.
	60 0 30	701	40	
	40 0 55	698	27	
	20 2 20	697	15	

The resistance of the longer column of the water as measured by the electrometer is about the same as before, whereas that of the shorter is even greater; so that the resistance for the 80-centimetre column is even still less than four times that for the 20-centimetre one. But since the platinum plate near the stationary platinum wire was in these last two sets of experiments K and L kept parallel to the trough (that is, parallel to the mean direction of the lines of flow), it follows that any want of parallelism of the lines of flow to the edge of the trough at the point where was the stationary wire would be exaggerated by this mode of placing the plate; and since we observe that the error in the proportional law for distance is also increased, we may conclude that the explanation given above of the want of perfect accuracy in the proportional law being due to want of perfect parallelism in the lines of flow is the correct one.

In all the previous experiments the distance between the electrometer-wires only was altered; but in the next set the distance between the platinum plates as well as that between the platinum wires was altered, the distance between each plate and wire being kept constant. Further, the resistance determined from the electrometer was calculated, not, as before, by comparing the electrometer-deflection when its electrodes were attached to the platinum wires with the deflection obtained when its ends were attached to a known resistance traversed by the same current, but by first determining the absolute value, in volts, of the electrometer-scale with the absolute value, in ampères, of the galvanometer-scale, and by observing the electrometer- and galvanometer-deflections in each experiment.

Battery-power employed, 4 Menotti's cells. Temp. 14° C.

Distance between the platinum plates 20 centim. " " " wires 10 "				
			Shunt $\frac{1}{990.2}$.	
Time after putting on battery, in minutes.	Galvanometer-deflection.	Electrometer-deflection.	Resistance, as determined by galvanometer, in ohms.	Resistance, as determined by electrometer, in ohms.
1	230	19	27000	11340
2	220	19	28000	11760
3	214	18.5	29000	11900
4	210	18	29600	11800
5	206	17	30000	11400
Distance between the platinum plates 90 centim. " " " wires 80 "				
			Shunt $\frac{1}{100.7}$.	
1	634	42	97000	90200
2	621	42	98980	92070
3	614	42	99960	92900
4	608	41	100940	91900
5	602	41	111960	101900
Distance between the platinum plates 90 centim. " " " wires 80 "				
			Shunt $\frac{1}{100.7}$.	
1	633	43	97000	93100
3	621	42	98000	91100
4	614	42	99000	92100
5	609	42	100000	93000
6	604	41	101000	92000
Distance between the platinum plates 20 centim. " " " wires 10 "				
			Shunt $\frac{1}{990.2}$.	
1	245	21	25500	11900
2	235	20	26600	11700
3	230	20	27200	11960
4	225	19	27800	11670
5	220	19	28400	11930

The resistance, therefore, as measured by the galvanometer,

does not increase as rapidly as the distance separating the plates, while that as measured by the electrometer is fairly in proportion to the distance. The explanation of the former is probably due to the fact that, since the electromotive force employed in all these four sets of experiments was constant, a greater current flowed when the plates were nearer than when they were far apart, hence that the resistance due to the layer of gas was greater when the plates were near than when they were far.

And this leads to a simple method of accurately measuring the resistance of liquids by using a galvanometer. The method, which was independently arrived at by one of our assistants (Mr. Mather), is now employed in our laboratory, and is so simple that we feel it can hardly be novel. It is as follows :—In a long vertical glass tube containing the liquid there are two metallic disks, not necessarily of platinum, and of about the same diameter as the tube. One of these can slide up and down the tube, so as to be able to be set at any fixed distance from the other. The disks are first put tolerably far apart, and a certain convenient current made to flow, which is measured on a galvanometer in the circuit. The plates are now made to approach and the current kept exactly the same by the insertion of an external resistance; whence it follows that the resistance of the column of liquid which has been subtracted from that originally separating the plates is equal exactly to the external resistance necessary to be inserted to keep the current constant.

February 28, 1878.

The next set of experiments was made to determine the alteration in resistance of a long trough of water when the distance between the centres of the platinum plates was kept constant at 90 centimetres, and the positions of the platinum plates varied as shown in the figures.

Galvanometer-Constant.—4 Menotti's cells with an E.M.F. 3·8 volts gave a deflection of 618 when a resistance of 10,000 ohms was in circuit and the galvanometer shunted with the $\frac{1}{990 \cdot 2}$ shunt.

The 4 Menotti's cells were employed and the galvanometer shunted with the $\frac{1}{100 \cdot 7}$ shunt, and the readings were

in each case taken one minute after the application of the battery.

	Position of plates.	Galvanometer-deflection.	Temperature.
I.	$\left\{ \begin{array}{cc} \text{---} & \text{---} \\ \diagdown & \diagdown \\ & \end{array} \right.$	642 640 622	$\left. \vphantom{\begin{array}{c} 642 \\ 640 \\ 622 \end{array}} \right\} 16^{\circ} \text{ C.}$
II.	$\left\{ \begin{array}{cc} & \\ \diagdown & \diagdown \\ \text{---} & \text{---} \end{array} \right.$	634 643 647	$\left. \vphantom{\begin{array}{c} 634 \\ 643 \\ 647 \end{array}} \right\} 16^{\circ} \text{ C.}$

Two sets of experiments in the reverse order were taken to eliminate any change that might take place in the deflection from weakening of the battery, or from polarization of the plates, or from set of the galvanometer-fibre. The constant distance between the centres of the plates was now diminished to 20 centimetres, when the following results were obtained, the $\frac{1}{990.2}$ shunt being employed.

	Position of plates.	Galvanometer-deflection.	Temperature.
III.	$\left\{ \begin{array}{cc} & \\ \diagdown & \diagdown \\ \text{---} & \text{---} \end{array} \right.$	245 291 304	$\left. \vphantom{\begin{array}{c} 245 \\ 291 \\ 304 \end{array}} \right\} 16^{\circ} \text{ C.}$
IV.	$\left\{ \begin{array}{cc} \text{---} & \text{---} \\ \diagdown & \diagdown \\ & \end{array} \right.$	315 285 239	$\left. \vphantom{\begin{array}{c} 315 \\ 285 \\ 239 \end{array}} \right\} 16^{\circ} \text{ C.}$







Both therefore at the greater and at the less distance the resistance is least when the platinum plates are edge on; a result that could hardly have been expected for the longer distance, considering that the width of each plate was only about 6 centimetres.

March 1, 1878.




In the following experiments one plate only was turned. The galvanometer had about the same sensibility as before. The $\frac{1}{100.7}$ shunt was used when the distance between the

centre of the plates was 90 centimetres, and the $\frac{1}{990.2}$ shunt when it was 20 centimetres. An electromotive force of 3.8 volts was employed in each test.




Distance between the centres of the plates 90 centimetres.

	Position of plates.	Galvanometer- deflection.	Temperature.
V.		633	} 15° C.
		634	
		637	
VI.		660	} 15° C.
		655	
		651	

Distance between the centres of the plates 20 centimetres.

VII.		403	} 15° C.
		368	
		358	

Battery reversed.

VIII.		208
		211
		229

Here again, then, the resistance is least with the plate end on, even when the distance between the centres of the plates is as much as 80 centimetres.

This apparent anomaly of the smaller resistance obtained when one or both plates is put end on is, as was pointed out by Mr. Boys, probably due to the smaller density of the gas which is deposited on a plate when it is put end on (in consequence of the current flowing from both sides of the plate into the liquid under these circumstances) more than compensating for the want of parallelism of the lines of flow when one or both of the plates are put end on.