XXVIII. On the determination of the conductivity of liquids in thin layers

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magnetic field so as to be transversely magnetized. This variation is greatest in nickel and in cobalt, and least in iron; the variation can be observed in nickel at much lower fields than in cobalt, in some cases with a strength of 1000 C.G.S. units: in cobalt it can be with certainty observed from 2000 C.G.S. units onwards. In iron the variation can usually not be observed with fields weaker than 6000 C.G.S. units.

(2) In cobalt films a direct relation exists between the variation of the resistance and the Hall effect: from it we conclude that the latter is proportional to the magnetization squared.

(3) In nickel the variation of resistance differs very considerably according to the specimen used. In all the mirrors, however, it shows signs of attaining a maximum, but at a higher field than that required for the Hall effect maximum.

Again, the variation becomes greater in some plates after they have been used, so that a plate which originally had a resistance variation proportional to the magnetization squared has, after first being used, a higher variation than this relation would lead us to expect.

(4) In iron the variation of resistance is less than proportionality to magnetization squared would lead us to expect.

I have to express my thanks to Professors Warburg and Rubens for their great kindness and assistance to me while engaged in carrying out the above experiments.

South African College, Capetown,
December 1897.

XXVIII. *On the Determination of the Conductivity of Liquids in Thin Layers.* By G. B. BRYAN, B.Sc., 1851 Exhibition Science Scholar, University College, Nottingham, St. John's College, Cambridge*.

INTRODUCTION.

INTEREST in this subject has been aroused by the work of Koller †, who found that, with certain liquids, the conductivity decreased as the thickness of the layer was decreased; and it was suggested by Prof. J. J. Thomson that it might be worth while repeating some of Koller's experiments. In doing this the apparatus and method of measuring the resistance differed from Koller's, and therefore his method of experimenting will be briefly described.

To obtain a thin layer of a liquid, Koller took two flat circular metal plates, and placed one horizontally on the bottom of a glass vessel; the other was laid on this and

* Communicated by Prof. J. J. Thomson, F.R.S.

† *Wien. Ber.* 98 ii. a, p. 201 (1889).

separated from it by three small pieces of glass, all of the same thickness, which was carefully measured. These plates formed the electrodes, and as the glass vessel was of very little greater diameter than the plates, the specific resistance of the liquid was calculated from the formula, $\text{Sp. R.} = ra/d$, where a is the area of the plates, d the thickness of the layer, and r its resistance. Two pairs of plates were used; one pair of brass, gilded and polished, and the other pair of zinc, carefully amalgamated. The diameter of the gilded plates was 6.6 cm.; that of the zinc plates was slightly less.

To measure the resistance between the electrodes they were connected in series with a standard resistance and a battery of constant E.M.F. The potentials at the terminals of the electrodes and the standard resistance were compared by means of an electrometer, and the unknown resistance thus determined. Readings were taken at a given time, T , after starting the current.

Koller tested a large number of substances, including turpentine, benzol, toluol, xylol, and CS_2 , with which the gilded electrodes were used. The following is a specimen of the results obtained:—

Turpentine.

E.M.F. = 1 Daniell Cell. Temp. = 24°C .

d .	Specific Resistance in C.G.S.	
	$T = 1\frac{1}{2}$ minutes.	T very great.
0.15 mm.	$228 \cdot 10^{19}$	$273 \cdot 10^{19}$
1.135 „	$20.5 \cdot 10^{19}$	$176 \cdot 10^{19}$
7.49 „	$2.37 \cdot 10^{19}$	$158 \cdot 10^{19}$

Water, alcohol, and ether were also tested, and the following figures obtained:—

Water.

E.M.F. = 1 Daniell Cell. Temp. = 24°C .

d .	I. $T = 1$ minute.	II. $T = 2$ minutes.
	Sp. Resistance.	Sp. Resistance.
1.135 mm	$109 \cdot 10^{12}$	$136 \cdot 10^{12}$
3.015 „	80	74
7.49 „	58	51

Alcohol.

E.M.F. = 1 Daniell Cell. Temp. = 24° C.

<i>d.</i>	I. T = 4 minutes.	II. T = 1 minute.
	Sp. Resistance.	Sp. Resistance.
1.135 mm.	251 . 10 ¹³	162 . 10 ¹³
3.015 „	123	135
7.49 „	101	84

Ether.

E.M.F. = 1 Daniell Cell. Temp. = 24° C.

<i>d.</i>	T = 1 minute.
	Sp. Resistance.
1.135 mm.	160 . 10 ¹³
3.015 „	118
7.49 „	111

With water, alcohol, and ether the zinc electrodes were used.

The above figures were taken from a large series of readings which all agreed in showing that the specific resistance increased as the thickness of the layer decreased.

Koller concluded, from his experiments, that this effect was due neither to "transition resistance" nor to polarization, but to dielectric effects. If this were the case it was thought that the subject would be well worth further investigation.

DESCRIPTION OF APPARATUS.

In carrying out the present investigation it was decided, after some preliminary experiments, not to use glass separators between the plates, for being small they were troublesome to work with, and also necessitated the removal of the upper plate and disturbance of the liquid when it was required to change the thickness of the layer. It was therefore resolved to attach the upper plate to a vertical screw, and a piece of apparatus was found in the laboratory which, it was thought, would

answer the purpose very well. It is shown in fig. 1. The micrometer-screw S carries two parallel brass plates p_1, p_2 ; p_1 is fixed at right angles to the screw, and p_2 attached to p_1 by three adjusting screws $s_1s_1s_1$ round the circumference. From p_2 is suspended the upper electrode A , by means of a glass rod g_1 .

Fig. 1.

Diagram of First Form of Apparatus. $\frac{1}{4}$ nat. size.

To the iron base-plate P is attached a vertical glass rod g_2 , which carries two brass plates p_3, p_4 connected together by adjusting screws $s_2s_2s_2$ similarly to the plates p_1, p_2 . p_3 is another brass plate connected to p_4 by the glass rod g_3 , and on this plate is placed the glass vessel V which contains the lower electrode B , resting on three glass points. The glass vessel is covered by an ebonite plate T which fits loosely

round the glass rod g_1 . The lead wire, b , from the lower plate is brought up through a thin glass tube.

The micrometer-screw has 20 threads to the inch, and passes through a very long nut; and as it carries a considerable weight there is no backlash. The micrometer head is divided into 100 parts, so that one division represents $\frac{1}{2000}$ inch. The screw was examined by observing the edge of the upper plate A with a microscope, and the error was found to be so small as to be negligible.

Adjustment of the Plates.—(1) As the upper plate A rotates with the screw it must be made to move parallel to itself. To do this the lower edge of A was observed with a horizontal microscope containing a micrometer-scale; each of the three screws $s_1s_1s_1$ was brought opposite the microscope in turn (the exact position being read on the divided head) and adjusted until the downward or upward motion during each third of a revolution was the same.

(2) The lower plate B must then be made parallel to the upper one. To do this a strong light was placed behind the plates and looked at through the space between the plates. The screws $s_2s_2s_2$ were adjusted until, on screwing down the upper plate, the light was extinguished right across at the same instant. The light was moved round the plate, and when it disappeared at the same moment, whatever its position, the adjustment was assumed to be correct, and the reading of the divided head at that instant was taken as the zero. This method was tested by making the adjustments with the glass vessel removed, and then measuring the thickness of a piece of thin glass at several points round the edges of the plates. The measurements were found to agree very closely amongst themselves and with the thickness of the glass, as measured by a spherometer, to $\cdot 01$ mm. The adjustment was probably not always as good as this; but it could not be tested when the glass vessel was in position.

The Plates.—The plates first used were of brass, 10 cm. in diameter and 3 mm. thick. They were ground flat on an emery-wheel, and then on plate-glass with fine emery-powder. They were then carefully amalgamated. It was found impossible to get these plates perfectly flat on account of their springiness; both were found to be slightly concave. The correction for this was estimated to be $0\cdot 013$ turn of the screw $= 0\cdot 0165$ mm., to be added to the distance between the plates given by the reading of the divided head.

As these plates were not considered satisfactory two others were made. These were 5·64 cm. in diameter and about 1 cm. thick, so as to avoid springiness. The metal was zinc.

They were turned up all over and the surfaces were then ground on plate-glass with fine emery until, after washing, one plate would hold the other up when they were pressed together. These plates were then sent to a jeweller's to be gilded, and unfortunately the gilder, contrary to instructions, cleaned the surfaces in the usual way and rather spoilt them; they were found to be slightly irregular, so that a correction could not be estimated. Thus the only advantage of these plates over the others was the gilding.

METHODS OF DETERMINING THE RESISTANCE.

Three methods of finding the resistance were tried in various cases :—

(1) Comparison with a standard resistance by direct deflexion, using a continuous current from a battery of secondary cells. The galvanometer used had a resistance of 17,380 ohms and gave a deflexion of one division with a current of about 10^{-8} amperes.

Fig. 4.

- AB. Electrodes.
- C. Commutator.
- B. Battery.
- G. Galvanometer.
- S. Standard resistance.
- K. Key.
- PQR. Slide wire.

Fig. 3.

(2) Comparison with a standard resistance by direct deflexion, using an alternating current. The same galvanometer was used as in (1). The alternating current was obtained by means of a revolving commutator. This commutator had two brass segments on an ebonite drum, and is shown, together with the connexions, in fig. 2. The commutator was

driven by means of a small water-motor. It will be seen from the diagram that the current through the galvanometer was always continuous, but the sensibility was reduced slightly owing to the insulating spaces between the segments of the commutator. When the four brushes were set right the deflexion was quite steady and was not affected by slight changes in speed, with the liquid layer in circuit.

(3) The third method was the modification of the Wheatstone bridge described by T. C. Fitzpatrick*. By means of a double commutator, designed by Prof. Threlfall, an alternating current is supplied to two corners of a Wheatstone bridge, whilst the connexions to the galvanometer are reversed at the same time as the current, so that any current through the galvanometer is always in one direction. The commutator employed at first had two drums, each with two brass segments and four brushes. It is shown in fig. 3, with the connexions. Driven at full speed the commutator gave about 60 alternations per second.

METHOD OF EXPERIMENTING.

With the direct deflexion methods of measuring the resistance the upper electrode was set at the required distance from the lower one, the current switched on, and a reading of the galvanometer taken at a definite interval of time, T , afterwards; usually about 1 minute. A series of readings was taken, increasing the thickness of the layer before each reading, and then a series decreasing the thickness. The means of these two sets, when they agreed fairly closely, were usually taken.

In the case of the bridge-method the measurements were made as quickly as possible one after the other, so as to avoid any changes in the state of the liquid, or of the surfaces of the electrodes.

The specific resistance is calculated from the formula

$$\text{Sp. R.} = \frac{ra}{d}.$$

RESULTS WITH FIRST FORM OF APPARATUS.

The first liquids tried were paraffin-oil, turpentine, benzol, and CS_2 , using method (1) to find the resistance; but their resistance was so high that only a small deflexion could be obtained with the thinnest layer ($\cdot 317$ mm.), about 50 mm at the most. No results were therefore obtained for these substances.

* B. A. Report, 1886.

Aniline was then tested, its conductivity being much higher. The amalgamated plates were used. The standard resistance was a megohm box; the battery, five secondary cells. The galvanometer was shunted.

A large number of readings were taken with aniline, which was distilled several times during the experiments. Its resistance was found to change considerably with the duration of the current, increasing as a rule*.

Thus for a sample of brown aniline :—

TABLE I.
E.M.F. = 10 volts. $\theta = 11^{\circ} \text{ C.}$

d , mm.	T , minutes.	r , ohms.
.65	$\frac{1}{2}$	11,800
	1	14,000
	5	21,000
	20	23,800
1.28	$\frac{1}{2}$	16,400
	1	20,800
	5	34,000
Same aniline distilled.		
.65	$\frac{1}{2}$	298,000
	$4\frac{1}{2}$	329,000
	20	400,000
	120	343,000
1.28	$\frac{1}{2}$	542,000
	$1\frac{1}{2}$	590,000
	$8\frac{1}{2}$	573,000
	120	623,000

These figures show that the change is very considerable, especially in the first few minutes. Two causes were found to be producing this change: (1) due to the metal electrodes, which were found to produce a slow darkening of the aniline, and a slow decrease in the resistance. (2) Due to the passage of the current; this produces an increase of resistance, and the rate of this increase depends upon the purity of the aniline. Thus before distilling, with a thickness of 0.65 mm., the resistance rose in 20 minutes from 11,800 to 23,800, *i. e.* 100 per cent., whilst after distilling, the resistance rose from 298,000 to 400,000, *i. e.* 30 per cent., in the same time.

After passing the current in one direction for some time.

* Cf. Warburg, Wied. Ann. liv. 1895.

on reversing it the resistance appeared to drop suddenly to a minimum, and then begin to rise again gradually. The following figures show this effect with a layer .628 mm. thick. D is the deflexion of the galvanometer :—

TABLE II.

T, minutes.	D.	r, ohms.
2½	156	28,300
13½	114	38,700
Reversed.		
13½	144	30,600
14	124	35,600
24	108	40,900
Reversed.		
24½	182	24,200
31½	126	35,000

With a thicker layer the fall of resistance after reversal was not so sudden. Thus for a thickness of 2.55 mm. :

TABLE III.

T, minutes.	D.	r, ohms.
½	153	104,000
5½	74	236
Reversed.		
5½	86	203
6	93	188
8½	134	131
9½	131	133
15	85	206
Reversed.		
15½	96	182
15½	110	159
17½	145	121
22½	102	171
Reversed.		
22½	118	148
23	139	126
23½	144	121

The same results were obtained after distilling the aniline and thus decreasing its conductivity about 20 times.

These figures show that there is probably considerable polarization of the electrodes, or else some change in the liquid which is reversed with the current, and most likely takes place at the electrodes.

The polarization was measured in some cases, just after

stopping the current, by balancing against a Clark cell. As much as 0.3 volt was found with a thickness of 0.628 mm., which would not account for the large increase in resistance during the passage of the current, since the applied E.M.F. was 10 volts.

The polarization, however, fell off very rapidly and might have been much greater whilst the current was on.

Hence it would appear that although the conductivity of aniline might not vary with the thickness of the layer, it would be very difficult to prove it by means of a continuous current.

A large number of readings were taken with different thicknesses, and on the whole they appeared to show that the conductivity decreased with the thickness. The following are specimens of the results obtained:—

TABLE IV.
Distilled Aniline. E.M.F. = 10 volts. $\theta = 9^\circ \text{C.}$

T = 1 min.			<i>d</i> , mm.	T = 1 min.	T = 17 min.
<i>d</i> , mm.	<i>r</i> , ohms.	Sp. R. C.G.S. $\times 10^{-15}$.		Sp. R. $\times 10^{-15}$.	Sp. R. $\times 10^{-15}$.
0.245	30,300	119	.334	85.1	134
0.651	89,300	110	.651	84	125
1.29	150,000	94	1.29	81.8	93.3
2.55	232,000	73.4	10.17	41.7	51
5.10	370,000	58.3			
7.64	464,000	49			
10.17	880,000	46.6			

In these experiments the current-density is much greater in the thin layers than in the thick ones. The following are some readings in which the current-density was kept constant by varying the E.M.F. by means of a liquid rheostat until the deflexion of the galvanometer was approximately the same in each case. The time taken to do this was about 1 minute:—

TABLE V.

<i>d</i> , mm.	Sp. R. $\times 10^{-15}$.
.334	85.6
.651	48.1
1.29	35.0
2.55	35.8
5.10	27.7
7.64	25.8
10.17	25.2

The difference of conductivity between the thick and thin layers is here much greater than before.

As this difference might be due to the rise in resistance caused by the current immediately after starting being greater with the thinner layers than with the thicker ones, it was decided to try the effect of an alternating current, and the second method of measuring the resistance was used.

The aniline was redistilled and the plates were cleaned with alcohol and readjusted.

The results at first obtained appeared to show that the conductivity *increased* as the thickness of the layer decreased. But it was found that, as time progressed, whilst the conductivity of the thinnest layer remained practically constant, that of the thicker ones gradually increased until a steady state was reached, when it was nearly the same for all layers. This is shown in the following tables:—

TABLE VI.
E.M.F.=10 volts. Temp.=11°.

d , mm.	Specific Resistance $\times 10^{-15}$.			
	(1)	(2) 5½ hours after (1).	(3) 29 hours after (1).	(4) 49 hours after (1).
·175	...	...	43·9	37·9
·334	39·9	42·5	44·8	34·0
·651	50·8	49·1	45·1	
1·290	80·0	59·1	45·2	37·4
2·55	123	74·0	45·0	
5·10	165	69·5	44·2	
10·17	192	64·2	43·4	36·5

The readings in the fourth column are one set out of a large number, taken on the same day, which agreed in showing that the conductivity was practically the same for all layers.

The aniline was redistilled and again tested. The conductivity was now much less, but the same gradual change to a steady state was found to occur.

TABLE VII.
E.M.F.=10 volts. $\theta=11^\circ$.

d , mm.	Specific Resistance, C.G.S. $\times 10^{-15}$		
	(1)	(2) 18 hours after (1).	(3) 40 hours after (1).
0·175	105	124	114
·334	111	127	107
·651	130	133	111
1·29	159	139	108
2·55	209	143	110
5·10	242	147	112
10·17	263	147	112

Water.—The ordinary water from the laboratory-still was used. This had a comparatively high conductivity, and was in fact a dilute solution. The gilded zinc electrodes were employed, and to keep the conduction as much as possible to the space between the plates they were surrounded by a close-fitting inner cylinder of glass, as shown in fig. 1.

Before putting the plates into position they were cleaned with dilute acid and alcohol.

The resistance was measured by method 3, two Daniells being used to give the E.M.F.

A large number of readings were taken, and they all agreed in showing that the apparent specific resistance was considerably greater in the thin layers. The plates were removed and cleaned several times, but the results were always the same. The following is one set of readings:—

TABLE VIII.—*Distilled Water.*

Temp. 12° C.

Turns of screw.	<i>d</i> , mm.	<i>r</i> , ohms.	Sp. R. C.G.S. $\times 10^{-11}$.	Differences between the nos. in col. 3.	Resistance of 1 turn = .127 mm. from last column.
·1	·127	65·9	1055		
·3	·381	132	704	66·1	330
·5	·635	202	646	70·0	350
1·0	1·270	375	600	173	346
2·0	2·54	740	592	365	365
4·0	5·08	1438	575	698	349
7·0	8·89	2440	559	1002	334
					345·7 mean.

The values of the specific resistance in the fourth column show a large falling off as the thickness increases. In the fifth column are given the differences between consecutive values of the resistance in column 3, and these are multiplied by constants to give the resistance of a thickness of .127 mm. The approximate equality of these numbers shows that the great increase in specific resistance in the thin layers is probably due to the plates not being perfectly clean to begin with; to polarization, and changes at the electrodes produced by the current; and to errors of adjustment. As the end effect was probably rather different with different thickness, the following experiment was made to find the conductivity at each position of the plates.

At each position the resistance was measured, then the

upper plate was screwed down one-tenth of its distance from the lower plate and the resistance again measured. The plate was then brought back to its original position, and one-tenth above it, the resistance being measured in each case. This series was repeated several times and the differences between consecutive readings gave the resistance of a layer equal to one-tenth the distance between the plates.

From the mean of these differences was calculated the resistance of a layer equal to one turn of the screw (1.27 mm.). Thus, at the position $d = .5$ turn, the readings were :—

TABLE IX.

d , turns.	r , ohms.	Differences.
.50	202.5	16.5
.55	219	16.5
.50	202.5	17.0
.45	185.5	17.0
.50	202.5	17.5
.55	220	18.5
.50	201.5	17.9
.45	183.6	16.4
.50	200	
		17.16 mean resistance of 0.05 turn.

Whence resistance of 1 turn = 343.2 ohms.

The mean values for all positions were :—

TABLE X.—*Distilled Water.*

d , turns.	d , mm.	Resistance of 1 turn at each position.
.1	.127	357
.3	.381	363
.5	.635	343
1.0	1.27	340
2.0	2.54	353
4.0	5.08	349
7.0	8.89	343
		349.7 mean.

The greatest difference from the mean is about 4 per cent., and the mean is about 1 per cent. greater than that in Table VIII.

Alcohol (absolute).

TABLE XI.

d , turns.	d , mm.	r , ohms.	Sp. R. C.G.S. $\times 10^{-12}$.	Differ- ences.	Resist. of 1 turn.
·1	·127	572	915	349	3490
·2	·254	921	737	365	3650
·3	·381	1286	686	719	3595
·5	·635	2005	641	1810	3620
1·0	1·27	3815	610	3595	3595
2·0	2·54	7410	592		
					3590 mean.

Here again there is a great increase in the specific resistance in the thin layers, whilst the differences between the layers give an approximately constant value for the resistance of one turn, as was the case with water. For this reason it was expected that by improving the apparatus the differences in the apparent conductivity of the layers could be considerably reduced.

DESIGN OF NEW APPARATUS.

The chief improvements to be made were :—

(1) To make the upper plate move parallel to itself without turning with the screw. This would increase the accuracy of the adjustment as well as reduce the time required for it.

(2) To so fix the plates that they could be removed after adjusting, to be cleaned, and replaced without spoiling the adjustment. The liquid could then be poured into the vessel immediately after refixing the plates, so that there would be much less time for them to get dirty again than in the old arrangement.

(3) To improve the surface of the plates.

(4) To increase the rapidity of alternation of the current so as to reduce the polarization.

With the rate of alternation already used (about 60 per sec.) the balance-point with the very thin layers of water was not quite steady, and it was thought that this was probably due to slight polarization.

The new arrangement for holding the plates is shown in fig. 5. My best thanks are due to Professors Heaton and Robinson, of University College, Nottingham, for the use of their workshops while I was making this apparatus.

Condition (1) is fulfilled by attaching the upper plate A to a steel rod r which slides without turning in the two v 's, v_1 v_2 .

Fig. 5.

Diagram of Second Form of Apparatus. $\frac{1}{4}$ nat. size.

Condition (2) is fulfilled thus:—The shaft of the upper plate has a $\frac{1}{4}$ in. hole bored in it, and slips without shake on to the reduced end of the steel rod r , and is fixed by a set-screw which screws into a small hole in the rod and draws the shaft tight up against the shoulder at the same time. The lower plate B screws on to an ebonite rod e_1 which is attached by means of the iron screw s_1 to the iron plate P_1 ; s_1 passes through a hole much larger than itself so as to admit of some lateral adjustment. The plate P_1 is fixed laterally by the three levelling-screws which rest, by hole slot and plane, on

three ebonite plugs e_1, e_2, e_3 . After adjusting the lower plate B parallel to the upper one the levelling-screws are fixed by lock-nuts, and the plate can then be removed and replaced without impairing the adjustment. The glass vessel V_1 consists of a cylinder ground to fit the shoulder on the lower plate, and of such internal diameter that the upper plate just slides easily inside it. Just before pouring in the liquid to be tested this cylinder was fastened down with clean paraffin wax.

The Plates.—These were of cast brass, turned to the shape shown in the figure. The surfaces were very carefully scraped up to a good surface-plate, until, after cleaning, one would hold the other up (weight of each plate about 1 lb.). They were then gilded, great care being taken not to damage the surfaces in any way, and only a very thin coating of gold was put on, just enough to prevent oxidation. These plates were very satisfactory, and the error due to irregularities of the surfaces negligibly small. Area of plates = 20.82 sq. cm.

To realize condition (4) a new commutator was made. It is similar to the one shown in fig. 3, but each drum has eight segments instead of two, thus increasing the number of reversals per revolution four times. If the drum were rolled out it would appear as in fig. 4. Two brushes press on the outer rims, and two others on two consecutive teeth.

This commutator was driven by an electromotor, and the speed could be varied so that from 100 to $250 \sim$ per second of the current could be obtained. The speed used gave about $200 \sim$ per second.

The galvanometer used was a dead-beat one of 1430 ohms resistance, and figure of merit, with the interrupted current, of 10^{-7} ampere.

The connexions were the same as in fig. 3. The adjustment of the lower plate parallel to the upper one was made in the same way as before; but could now be easily tested by placing a piece of glass of known thickness between the plates. The error was found to be about $.01$ mm., but was probably sometimes less than this.

The micrometer-screw s has 30 threads per inch, and the head H is divided into 100 parts. The screw was compared with a standard.

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RESULTS WITH SECOND FORM OF APPARATUS.

Battery, 2 Leclanché's. Temp. about 16° C.

TABLE XII.—*Distilled Water.*

<i>d</i> , turns of screw.	<i>d</i> , mm.	<i>r</i> , ohms.	Sp. R. C.G.S. $\times 10^{-12}$.
·1	·0846	54	133
·2	·169	95	117
·5	·423	225	110·5
1	·846	433	106·6
2	1·692	875	107·5
5	4·23	2149	105·6
7	5·92	3026	106·3
10	8·46	4310	106

TABLE XIII.—*CuSO₄. 1 gm. in 5,000 c.c. water.*

<i>d</i> , turns of screw.	<i>d</i> , mm.	<i>r</i> , ohms.	Sp. R. C.G.S. $\times 10^{-10}$.
·2	·169	5·15	633
·5	·423	12·2	599
1	·846	24·0	590
2	1·692	47·1	582
5	4·23	119	584
10	5·92	237	582
20	8·46	472	581

TABLE XIV.—*CuSO₄. 1 gm. in 50,000 c.c. water.*

<i>d</i> , turns.	<i>d</i> , mm.	<i>r</i> , ohms.	Sp. R. C.G.S. $\times 10^{-11}$.
·4	·338	54	331
·5	·423	66	322
·6	·508	77	315
·8	·676	100	307
1	·846	122	300
2	1·692	243	299
5	4·23	621	305
10	8·46	1260	310
20	16·92	2510	309

TABLE XV.—*KCl. 1 gm. in 10,000 c.c.*

<i>d</i> , turns.	<i>d</i> , mm.	<i>r</i> , ohms.	Sp. R. C.G.S. $\times 10^{-10}$.
·5	·423	12·4	609
1	·846	23·6	582
2	1·692	47·1	579
5	4·23	117·7	579
10	8·46	236·5	582
20	16·92	471·7	589

TABLE XVI.—*KCl*. 1 gm. in 50,000 c.c.

<i>d</i> , turns.	<i>d</i> , mm.	<i>r</i> , ohms.	Sp. R. C.G.S. $\times 10^{-11}$.
·1	·0846	10·5	258
·2	·169	18·8	231
·5	·423	45·5	223·4
1	·846	90	221·5
2	1·69	182	224
5	4·23	458	225
10	8·46	917	225·5
20	16·92	1833	225

TABLE XVII.—*Absolute Alcohol*.

<i>d</i> , turns.	<i>d</i> , mm.	<i>r</i> , ohms.	Sp R C.G.S. $\times 10^{-13}$.
·1	·0846	459·5	113
·2	·169	959	118
·5	·423	2436	120
1	·846	4970	122·3
2	1·692	9965	122·6
4	3·384	19960	122·4
8	2·768	39800	122·2
12	10·152	60300	123·8

TABLE XVIII.—*Aniline*.

(Pure, but had been in store some time, and was slightly brown.) Battery, 5 accumulators.

<i>d</i> , turns.	<i>d</i> , mm.	<i>r</i> , ohms.	Sp. R. C.G.S. $\times 10^{-14}$.
·2	0·1692	20,500	252
·4	0·3384	41,100	252
·5	0·423	51,500	253
1	0·846	103,900	256
2	1·692	205,800	253
5	4·23	505,000	248
10	8·46	1,010,000	248

In all the above readings the current was not kept on longer than was necessary to obtain a balance, so as to avoid changes in the liquid which might be produced by the passage of the current, especially in the case of the thinnest layers of dilute solutions, where the resistance was small. With aniline quickness was very necessary: for, as was found previously, its conductivity is altered very much by the passage of the current.

CONCLUSION.

It will be seen that the expectation of reducing the apparent differences in conductivity of the different thicknesses (Tables VIII. and XI.) has been realized to a great extent; in most cases reduced within the limits of error of adjustment. This is partly due to the improvement in the surfaces of the plates, and partly to better cleaning. The plates were washed in alcohol, after dipping in dilute sulphuric acid, until the liquid to be tested would thoroughly wet them.

The readings, in the case of the very thin layers of dilute solutions, depended very much on the state of cleanliness of the plates. Thus for water (Table XII.) the Sp. R. of $\cdot 1$ turn is 27 per cent. greater than that for 10 turns (of this difference about 12 per cent. can be accounted for by error of adjustment); whilst for very dilute KCl (Table XVI.) when the plates were more carefully cleaned, the corresponding difference is only 15 per cent., although the resistance is five times less.

With alcohol (Table XVII.) the readings from 1 to 12 turns agree very closely, and below 1 they are within the limit of error of adjustment.

With aniline (Table XVIII.) all the values of the Sp. R. agree fairly closely, the greatest difference from the mean being less than 2 per cent.

The range of the experiments may be considered to be from $\cdot 5$ turn ($\cdot 423$ mm.) to 20 turns ($16\cdot 92$ mm.); below $\cdot 5$ the values of the Sp. R. show a difference from the rest which could not be got rid of; above 20 turns several experiments were made with a tube 16 cm. long and about 4 cm. in diameter. The values of the Sp. R. obtained were in very close agreement with those at 10 or 20 turns for the same liquid.

The above results show that for dilute solutions, alcohol, and aniline, the conductivity is the same for all thicknesses within the limits of the experiments. It has been found that the great differences obtained by Koller, for water and alcohol, can be eliminated by taking care that the plates are true and clean, and by using an alternate current instead of a continuous one. Koller allowed for polarization by estimating it immediately after stopping the current, but this is not satisfactory, since the polarization falls off very rapidly. He estimated that the greatest polarization could not have been greater than $\cdot 02$ volt., which, though great compared with the whole E.M.F. (1 Daniell) would not account for the difference of

100 per cent. between the conductivity of a layer 7.49 mm. thick and one 1.135 mm. thick. I think that what is not accounted for by polarization can be explained by unevenness and uncleanness of the plates.

In conclusion, I wish to thank Prof. J. J. Thomson for his kind encouragement during this investigation.

XXIX. *On Air Electrified by the Discharging Action of Ultra-violet Light.* By JOHN ZELENY, B.Sc., Assistant Professor of Physics, University of Minnesota*.

THE following experiments were made to compare some of the electrical properties of air into which a body is being discharged by the action of ultra-violet light, with those when Röntgen rays are the cause of the discharge.

The apparatus was arranged as is shown in the figure. T is a brass tube. At M it is joined by a lead cylinder which contains on the inside an insulated metal tube filled with glass wool G, which latter is connected to a pair of quadrants of the electrometer E.

The light of an arc lamp A was concentrated by the quartz lens L, and after passing through the quartz window P fell upon the freshly cleaned, negatively charged, zinc plate D.

If air was blown into the apparatus at C, it passed by D, through G, and out at R. When now the air was at rest and the light was turned on, or when the air was blown through while the light was cut off, the glass wool at G received no charge. But if both the light and air-blast were in action,

* Communicated by Prof. J. J. Thomson, F.R.S.