more or less success, of many other forms of this combination, including some in which very porous hollow carbon poles were used, and through which the chlorine was forced, but the effects obtained were less than those recorded. The research has proved that it is possible to form pyro-batteries of the Upward type, although it is extremely difficult to realise the conditions required for effective action. In a future communication I hope to record the results of experiments made, with a view to utilise oxygen as a depolariser in connexion with cells with fused electrolytes.

VII. "Measurements of the Absolute Specific Resistance of Pure Electrolytic Copper." By J. W. SWAN and J. RHODIN. Communicated by Lord RAYLEIGH, Sec. R.S. Received February 28, 1894.

At the beginning of 1893 it was resolved to make some very careful measurements of the specific resistance of pure electrolytic copper, drawn into wire without previous fusion. Researches made during the latter end of 1892 had shown that the specific resistance of electrolytic copper varies considerably. The resistance of about thirty wires of the same length and diameter, made from specimens of electrolytic copper, prepared in different ways in the laboratory, showed differences of resistance amounting to a maximum of 1·4 per cent., both when in a hard and when in a soft or annealed state, and measured at the same temperature.

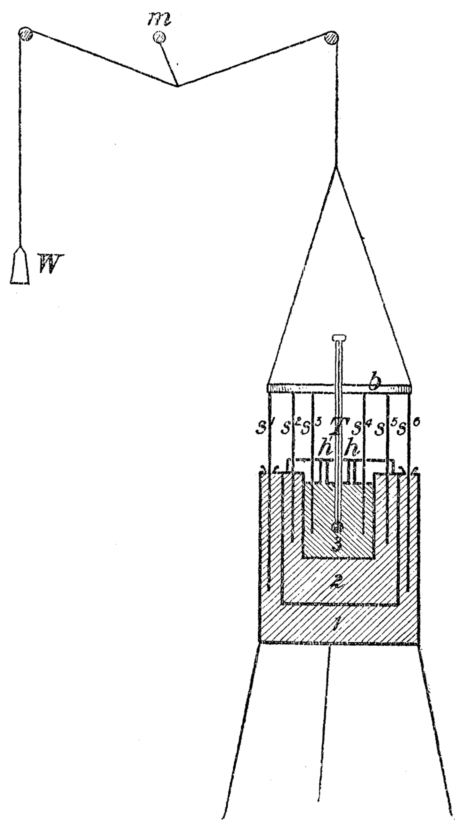
These preliminary measurements were made by means of a Wheatstone's bridge, constructed for comparing the unknown resistances of short well-conducting wires with the resistance of a standardised platinoid wire, according to Thomson's method. The accuracy obtainable by this method was 0·25 per cent. The best specimens of wire were subjected to a further and still more accurate examination.

The measurements of the specific resistance and temperature coefficient of one of these wires, and of some wire made from the same copper, after undergoing a second electrolytic refining, form the subject of this paper. It was resolved to make measurements giving an ultimate accuracy of 0·1 per cent. As they were intended to be absolute, the first problem was the determination of the exact dimensions of the wires to be measured. The measurement of the length was made by means of direct comparison with a standard metre rule; that of the diameter was determined by the specific gravity method, which consists in finding the absolute weight of a known length of wire and its density or unit volume weight as determined from its specific gravity, and then calculating its average diameter.

In the determination of the specific gravity, both the hydrostatic balance method and the picnometer method were used. The latter method was found to give more accurate results. A point of great importance was the estimation of the temperature of the specimens during measurement. To obtain as great accuracy as possible in the temperature readings, an apparatus similar to a calorimeter was employed for enclosing the coil of wire whilst it was measured. A standard thermometer divided in tenths of degrees centigrade was used, placed in the vessel containing the sample of wire. It was read at a distance by means of a telescope.

The arrangement is represented by fig. 1. It consists of three

FIG. 1.

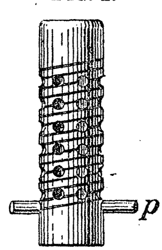


cylindrical tinned iron vessels arranged concentrically one inside the other. The section of the two outer vessels (fig. 1) is distinguished by the shading from that of vessel 3. The vessels formed three water-

tight compartments. Jackets 1 and 2 were filled with water, and the vessel 3 with paraffin oil having a flashing-point of 150° C. To stir the liquids, three circular rings of iron wire were enclosed, one in each of the compartments. These rings were suspended on the iron wires, s^1, s^2, &c. The iron wires themselves were fixed on a bar of brass, *b*. By means of the crank of an electromotor (*m*) and strings and pulleys, the bar *b* could be moved up and down, stirring each of the liquids simultaneously. To make the motion easy a balance weight, W, was used. The coil to be measured was enclosed in compartment 3. This compartment was closed at the top by a hollow lid of tinned iron, pierced with holes to allow for the passage of the stirring rods, &c. This lid effectually protected the paraffin oil from surface cooling. The two holes, *h* and *h'*, made to allow the wires connecting the ends of the coil to pass out, were lined with ebonite to prevent contact with the metal of the lid. The thermometer, T, was let down through a tube in the middle of the lid. As a proof of the effectiveness of the arrangement, it may be mentioned that a small Bunsen burner when burning at its full power, and placed under compartment "1" raised the temperature of the inner one "3" only 0·1° C. in thirty seconds, a length of time more than sufficient for making a resistance determination. When the temperature in "3" had been raised to 92° C. and then allowed to cool (being constantly stirred), the temperature (in "3") only fell to 40° C. in twenty-four hours, notwithstanding the temperature of the laboratory was only 15° C.

Another important detail was an arrangement for securing the wires whilst they were measured. Fig. 2 represents this. It consists

FIG. 2.



of a piece of ebonite tube 5 cm. diameter, with a deep double screw thread cut on the outside. It was pierced all over with large holes 1 cm. diameter, to allow the paraffin oil to freely circulate in the inside, where the thermometer was inserted. A short rod of ebonite (*p*) was put through and across the cylinder at the bottom. The wire to be measured was bent round this cross rod, so that equal

lengths were hanging down. The double bent wire was then wound up in the double screw thread, and secured at the top by means of string; the influence of self-induction was thus avoided. Each wire had four terminals, the main current terminals, and the shunt terminals, which were soldered to pieces of stout copper, the distance between which determined the length of the wire under examination. These reels saved the wires from being hardened or otherwise injured. The length of the wire was taken both before and after the electrical measurement. In some earlier experiments when mica strips were used for coiling the wire upon, great differences were observed. When the ebonite reels were employed hardly any difference could be observed.

The electrical measurements were made by the fall of potential method, refined as much as is possible. A D'Arsonval galvanometer was employed as an indicator of potential difference. The "dead beat" property of this instrument is an advantage which in this class of measurement cannot be over-rated. Finding in the first experiments with the D'Arsonval galvanometer, that its sensitiveness was not sufficient for our purpose, the upper suspension was lengthened very considerably. The coil was made to hang on the upper wire, the wire below the coil being left slack. By this means the required degree of sensitiveness was obtained. The galvanometer readings were made by means of a telescope and scale, a plane mirror being attached to the galvanometer coil. To gain the advantage of using very small deflections, the scale and galvanometer were widely separated, the distance between them was 8 m. The largest deflections used were 600 divisions of the scale (each division = 1/30 in.), corresponding to (at that distance from the mirror) an angle of $1^\circ\ 49'$, which falls within the limits for:—

(1.) $\tan 2\ \text{angle} = 2 \tan \text{angle} \pm 0{\cdot}001 \times 2 \tan \text{angle}.$

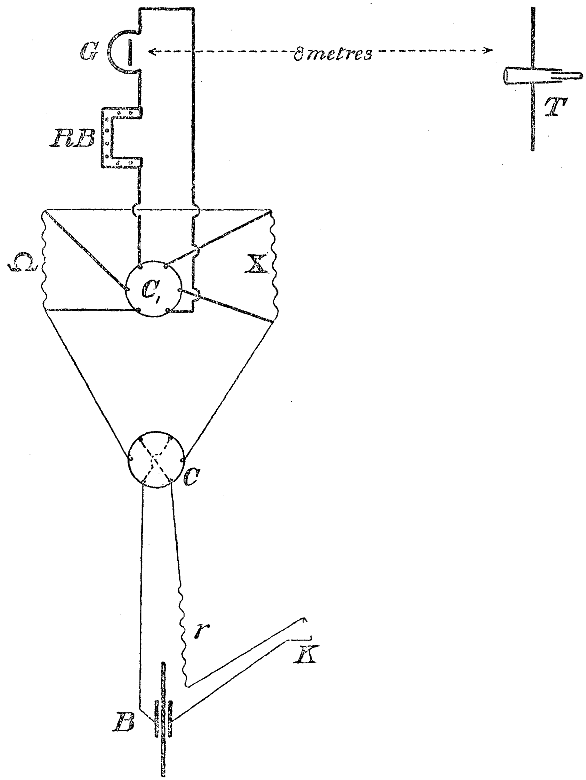
The readings of the deflections were found to be proportional to the P.D. by direct and carefully made measurements, they were always read in two directions, and the sum taken as the deflection; the accuracy was thus doubled, and possible error by displacement of the zero point avoided.

The limit of sensitiveness of the galvanometer was:—

1 scale division deflection $= \frac{1}{30000000}$ ampère (approximately), or $= 0{\cdot}00000003101$ ampère (accurately).

The resistance of the suspended coil was 10 ohms. The time required for the coil to come to rest was about two seconds. The accompanying diagram shows the arrangement for making the measurements. They were made by *direct comparison* between a standard ohm and the various coils to be measured, and in such a manner that error due to the resistance of the leads was eliminated.

FIG. 3.



The following is a description of the details :—B was a single lead and lead peroxide element, of a comparatively large capacity (30 ampère hours). It was found necessary to have the capacity of the cell tolerably large to avoid the necessity of making too large corrections for the fall of potential in the cell itself between different observations. By means of a mercury contact key, K, the battery could be short-circuited through a nickel wire resistance r (of about 6 ohms), the standard ohm R and the resistance to be measured X. All these resistances were in series. (The current in the main circuit was only 0·2 or 0·25 ampère, and did not produce any sensible heating of the various resistances.) By means of the current reverser, C (a mercury switch), the current direction could be easily changed. The galvanometer, G, was connected with another mercury switch, C_1, by means of which it could be put in shunt to the standard ohm and X alternately in rapid succession. In the galvanometer circuit the resistance box, RB, was inserted in order to render it possible to make the deflections nearly equal when X differed considerably from R.

The method of making a determination was as follows:—1st, C_1 was placed in the position which made the galvanometer circuit a shunt of the standard ohm. RB was adjusted so as to make the deflection of a convenient amount by placing in a resistance R_r (R_r having been determined by means of preliminary experiments). Then K was pressed down and a deflection of the galvanometer "a" observed. The current was then reversed, and a deflection "b" observed. $(a+b)$ was then placed in the observation table under the heading G_R. The key opened. The temperature of R observed and noted (T_R). 2nd, C_1 was then placed in the position which made the galvanometer circuit a shunt to X. RB adjusted to make the deflections of a suitable size by putting in a total resistance of R_X (determined by previous experiment). Then K was pressed down, and the deflection a_1 observed, the current was then reversed, and a deflection b_1 observed. (a_1+b_1) was then put down in the table under the heading G_X. The temperature of X observed and noted (T_X).

3rd observation. No. 1 repeated.

4th " " 2 "

A set of measurements like these were made in 20 seconds, thanks to the dead-beat quality of the galvanometer, and the easy manipulation of the mercury switches. It is evident that, *if the galvanometer deflections were exactly proportional to the current, and if the resistance of the galvanometer circuit was sufficiently high to be neglected, and also if the potential difference of the accumulator did not alter between observations* 1 *and* 2, the resistance X can be put

$$X = \frac{G_X(R_X+S)}{G_R(R_R+S)}R. \tag{2.}$$

S = resistance of the galvanometer + resistance of galvanometer leads.

The proportionality of the galvanometer deflections with the limited range employed was, as previously stated, experimentally proved. The conductivity of the galvanometer as a shunt was negligible, as is evident from the fact that it was more than 2000 ohms resistance (when a minimum), and then diminished the total resistance of the main circuit about 1/8000 ohm (it was shunted round $\frac{1}{4}$ ohm), the resistance of the main circuit amounting to 8 ohms. The fall of potential of the accumulator was very seldom appreciable during one set of measurements. This will be seen from the identity between observations 1 and 3 and 2 and 4 respectively in the tables. When appreciable a correction was applied. When all the arrangements were completed, a determination of the specific resistance of the best specimen of copper (marked "A") was made.

Origin of the Copper.—The copper was deposited in a large rocking

Table I.—Specific Gravity of the Rocking Tank A Deposit. Temperature 15° C.

Description of specimen.	Weight in air + tare.	Tare.	Weight in air.	Weight in H_2O + tare.	Tare.	Weight in H_2O at 15° C.	Repetition of weight in air.	Specific gravity.
	grams.	grams.	grams.	grams.	grams.	grams.	grams.	
I. Pieces of the deposit as it came out of the bath..............	103·5635	2·2548	101·3087	90·1530	0·1610	89·9920	101·3080	8·9521
II. Another piece of the same	95·1994	2·2550	92·9444	82·7217	0·1610	82·5607	92·9445	8·9500
III. Half of I hard drawn	26·7334	2·2551	24·4783	21·9176	0·1746	21·7430	24·4783	8·9491
IV. Half of I hard drawn and afterwards annealed in CO_2 gas	27·5580	2·2551	25·3029	22·6514	0·1746	22·4768	25·3028	8·9533

tank from ordinary sulphate of copper solution prepared from pure crystallised sulphate of copper, pure sulphuric acid, and distilled water. The anode was a large plate of ordinary commercial electrolytic copper, and the cathode was a large polished plate of rolled copper. Before placing the cathode in the bath it was silvered by rubbing it over with a solution of cyanide of silver in potassium cyanide. This coating of silver was converted into iodide of silver by means of a solution of iodine in potassium iodide. As is well known, this treatment renders the stripping of the deposit from the cathode an easy matter. On this cathode copper was deposited to a thickness of 2·5 mm., and then the deposit was stripped off. Several deposits were made and tested roughly, as stated in the beginning of this paper. The best of them was one marked "A."

Preparation of the Wire.—A strip was cut from the deposited sheet of copper, filed round, and then drawn through sapphire dies to a diameter of approximately 0·02 in.

These determinations were made by means of the hydrostatic balance principle. A re-determination of the specific gravity of the copper I in the above table was made by means of a picnometer.

Picnometer	+ distilled H_2O at 15° C.	= 91·2878	grams.
,,	+ specimen + ,, ,,	= 123·3562	,,
	Specimen	= 36·1012	,,
∴ weight of displaced H_2O	....	= 4·0328	,,

Specific gravity = 8·9519.

As is seen from the above numbers, the specific gravity of copper when it is pure varies very little with hardness and other conditions, the variations when at a maximum only amounting to 0·0004 of the whole. The mean of the above results may, therefore, be taken as the specific gravity of this copper at 15° C. The mean is

8·9511 = the specific gravity.

This value is not the one required for the calculation of the dimension of wires; what is required is the density or absolute weight of an ideal cubic centimetre of the metal at 15° C. The weight of 1 c.c. of water at 15° C. is, according to Kohlrausch, 'Praktische Physik,'

0·99915 gram.

The specific gravity of the copper divided by this figure gives the density:—

Weight of 1 c.c. of copper at 15° C. = 8·9587 grams (8·959).

Specific Resistance of Deposit "A" (hard drawn) at different Temperatures between 12·9° *C. and* 90·2° *C.*—A hard-drawn wire of the A deposit was measured by the apparatus described. For determining

the diameter a piece 300 cm. long was taken. The weight was found to be—

5·6009 grams.

The ascertained density of the copper being 8·959 indicates an average diameter of—

$$(3.)\qquad X = 2\sqrt{\frac{5\cdot6009}{300\times8\cdot959\pi}} = 0\cdot05151 \text{ cm. at } 15^\circ \text{C.}$$

This same wire was fitted with shunting terminals 250 cm. apart, and wound on one of the previously described reels, and then placed in the circuit. A large number of observations were made at different temperatures: they are arranged in Table II. The following are the headings of the columns:—T_X = temperature of the unknown resistance; G_X = deflection (proportional to the current) with the unknown resistance; G_R = deflection when standard ohm in circuit; T_R = temperature of standard ohm; G_X = deflection of unknown resistance (supposing G_R to be always 1240); G_X (6th column) is deflection with unknown resistance (X) in circuit corrected, so as to compare with G_R at 1240 and T_R at 15° C.; the figures in this column multiplied by a constant give the resistance of the wire.

Table II.

T_X.	G_X.	G_R.	G_X (G_R = 1240).	T_R.	G_X (G_R = 1240 T_R = 15° C.)
C°.				C°.	
12·9	1006	1250	998	13·5	997
16·0	1017	1249	1010	13·7	1010
17·2	1018·5	1245	1014	13·9	1014
18·15	1023·5	1246	1019	,,	1019
19·6	1027	1245	1022	,,	1022
20·3	1030·5	1244·5	1027	,,	1027
20·9	1033	1244	1030	13·8	1030
22·6	1039	1244	1036	,,	1036
23·3	1043	1244·5	1039	11·5	1038
24·2	1045·5	1243	1043	,,	1042
25·2	1048·5	1242	1047	,,	1046
26·2	1052	1242	1050	,,	1049
27·3	1056	1241	1055	,,	1054
28·4	1058·5	1239·5	1059	12·5	1058
29·4	1060	1238·5	1061	,,	1060
30·2	1065	1240	1065	,,	1064
31·1	1069·5	1239·5	1070	12·1	1069
32·2	1073·5	1239	1074	,,	1073
33·2	1077	1238·5	1078	,,	1077
34·2	1080	1237·5	1082	12·5	1081
35·3	1083	1237	1086	,,	1085
36·2	1086·5	1236	1090	,,	1089
37·2	1090·5	1237	1093	,,	1092

Table II—*continued.*

T_X.	G_X.	G_R.	G_X ($G_R = 1240$).	T_R.	G_X ($G_R = 1240$ $T_R = 15°$ C).
C°.				C°.	
38·2	1093	1236	1097	12·5	1096
39·2	1097	1236	1101	,,	1100
40·1	1101	1237	1104	,,	1103
41·2	1106	1237	1109	,,	1108
42·2	1108	1235	1112·5	,,	1111
43·5	1111	1234	1116·5	,,	1115
44·2	1114·5	1234	1120	,,	1119
45·2	1119·5	1235	1124	,,	1124
46·2	1123	,,	1128	,,	1127
47·2	1128	,,	1133	,,	1132
48·2	1133	1236	1137	,,	1136
50·2	1140·5	,,	1144	12·8	1143
51·2	936·5	1013	1146	14·5	1146
52	939·2	,,	1150	,,	1150
53·1	943	,,	1154	,,	1154
54·1	945·2	1012·7	1157·5	,,	1157·5
55·2	949	1013	1162	,,	1162
56·2	951·5	1012·5	1165	15·2	1165
57·2	955	1012·5	1169·6	,,	1169·6
58·2	958	1013	1173	,,	1173
59·2	960·5	1011·5	1177	,,	1177
60·2	963	1011	1181	,,	1181
61·2	966·5	1011·5	1185	15·5	1185
62·2	969·2	1011	1189	,,	1189
63·2	973	,,	1193	,,	1193
64·2	976	,,	1197	,,	1197
65·2	979	,,	1200	,,	1200
66·2	982·5	1012	1204	,,	1204
67·2	985·2	1011	1207·4	,,	1207·4
68·2	988·5	1011	1212·4	,,	1212·4
69·2	991	,,	1215·5	,,	1215·5
70·2	994	,,	1219	,,	1219
71·2	997·5	1010	1225	,,	1225
72·2	1000	,,	1228	,,	1228
73·2	1003	,,	1231·5	,,	1231·5
74·2	1006	,,	1235	,,	1235
75·2	1010·5	,,	1240·5	,,	1240·5
76·2	1013	,,	1244	,,	1244
77·2	1017	,,	1249	,,	1249
78·2	1020	,,	1252	,,	1252
79·2	1023·2	,,	1256	,,	1256
80·1	1027	1011	1260	,,	1260
81·2	1031	1010·5	1265	,,	1265
82·2	1034	1010·5	1269	,,	1269
83·2	1037	1011	1272	,,	1272
84·2	1039·5	1010	1276	,,	1276
85·2	1043	1010	1280·5	,,	1280·5
86·2	1047	1010	1285	,,	1285
87·2	1050	1009·5	1290	,,	1290
88·2	1052	1009	1293	,,	1293
89·2	1056	1009	1298	,,	1298
90·2	1060	1009	1303	,,	1303

The absolute specific resistance in C.G.S. units was calculated from the above numbers as follows. The resistance in ohms of the measured wire at any temperature is found by using Equation No. 2 :—

$$\text{(4.)} \qquad X = \frac{G_X(R_X+S)}{G_R(R_R+S)} R.$$

From the definition of the R, and that of specific resistance in C.G.S. units, formula 5 is deduced :—

$$\text{(5.)} \qquad \sigma = X \frac{\pi r^2}{l} 10^9,$$

where r = radius of the wire in centimetres.
l = length " "

If the value of X as given in Equation No. 2 is substituted in Equation No. 5, the following is obtained :—

$$\text{(6.)} \qquad \sigma = \frac{G_X(R_X+S)}{(R_R+S)} \frac{R}{G_R} \frac{\pi r^2}{l} 10^9.$$

In the previous table if G_X *is read as in the last column*, the following will be the values for the various elements of Equation No. 6 :—

R_R = 8000 B.A. units for all observations.
R_X = 2000 " " "
S = 17·3 " " "
R = 1 ohm.
G_R = 1240. Scale divisions for all observations.
$2r$ = 0·05151 cm.
l = 250· "
} At 15° C. But, according to Matthiessen, no correction is made for the variation of these constants.

In Equation No. 6 everything is constant except σ and G_X, and the equation results in the following, when the numerical values as above are substituted for the general expressions :—

$$\text{(7.)} \qquad \sigma = 1{\cdot}6906\ G_X \begin{pmatrix} G_R = 1240 \\ T_R = 15^\circ \text{ C.} \end{pmatrix}$$

log 1·6906 = 0·2280258.

The specific resistance in C.G.S. units of the hard-drawn rocking tank A deposit at any temperature can therefore be calculated by making use of the values given in the above table. In order to find the specific resistance at 0° C. it is necessary to calculate the temperature coefficient (Δ_t) from the above observations. The method of

least squares is the one which naturally suggests itself in calculating this coefficient, but the calculation would be too laborious in comparison with the value of the figure arrived at. Therefore, in order to ascertain which values could be used for calculating the temperature coefficient (Δ_t), the above observations were plotted in the usual way, the co-ordinates being x = temperature and y = specific resistance in C.G.S. units.

As previously stated, the values in column 6 of Table II have to be multiplied by 1·6906 to give the specific resistance in C.G.S. units; to save labour the multiplication was done graphically (Graphic Table No. 1).

The resistances in column 6 of Table I reduced to C.G.S. units by means of the graphical Table 1 are tabulated in another table (Table III).

The graphic Table No. 2 is a reproduction of Table III, and gives the results of the above measurements.

As the values formed so very nearly a straight line, two only are selected :—

1707 C.G.S. units at 16·0° C.
1937 ,, ,, 51·2° C.

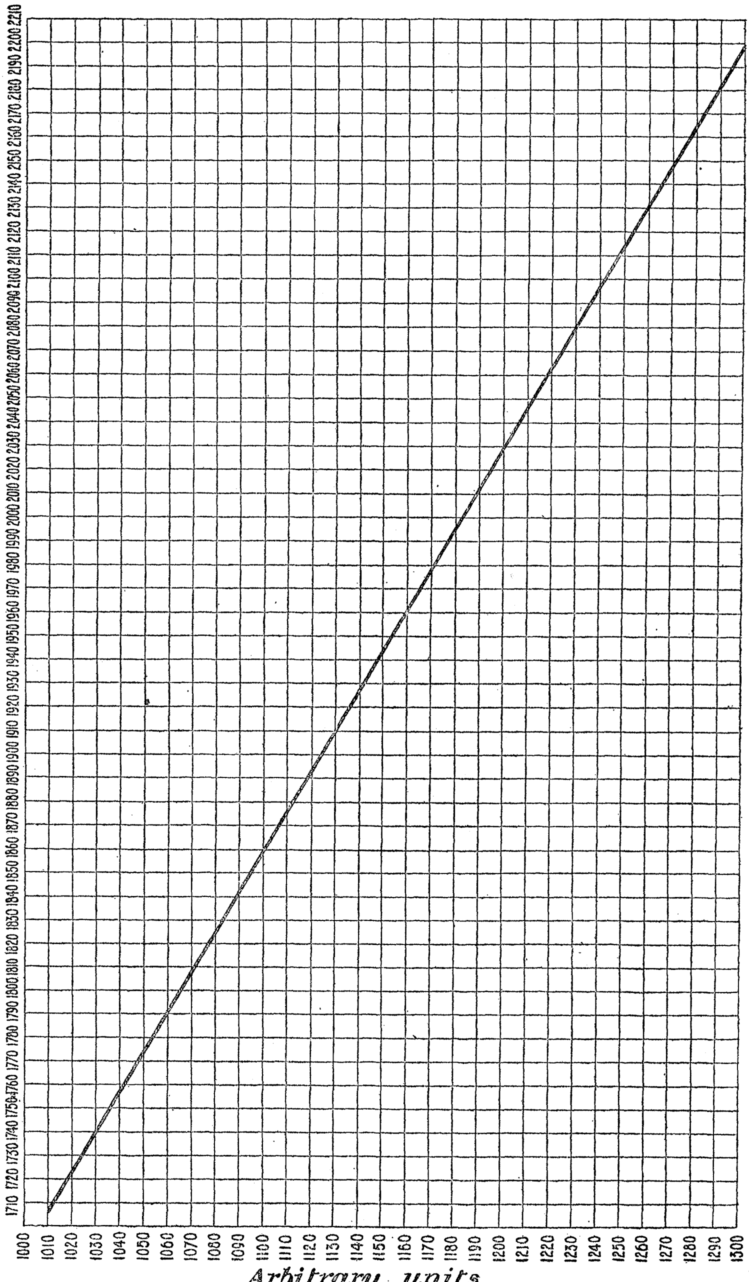
These gave the following equations :—

$$1707 = x(1+16y)$$
$$1937 = x(1+51{\cdot}2y), \text{ from which}$$
$$x = 1603{\cdot} \text{ C.G.S. units}$$
$$y = 0{\cdot}004077.$$

x is the specific resistance of the A deposit (hard drawn) at 0° C., and y is the temperature coefficient. By means of these values an extrapolation was made from 0° to 16° C. in the graphic Table No. 2.

Graphic Table 1.

C.G.S. units.

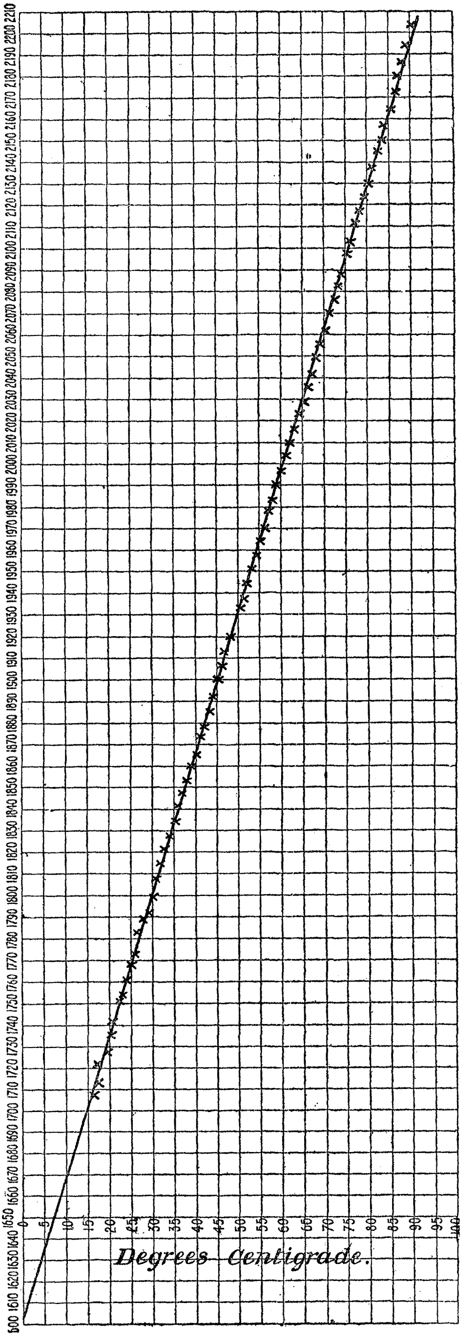


Arbitrary units.

Reduction of column 6, Table II, from arbitrary units.
To C.G.S. units by graphic method (multiplication by 1·6906).

Graphic Table 2.

Spec. resistance of Rockingtank A. copper in C.G.S. units.



Shows the result of the measurements of the specific resistance of Rocking tank A copper (hard-drawn). The crosses indicate the actual observations reduced to the C.G.S. system.

Table III.

Rocking Tank A Copper. Hard drawn.

Specific Resistance.

Temperature.	C.G.S. units.	Temperature.	C.G.S. units.	Temperature.	C.G.S. units.
C°.		C°.		C°.	
16·0	1707	47·2	1913	79·2	2123
17·2	1713	48·2	1920	80·1	2130
18·1	1722	50·2	1932	81·2	2138
19·6	1727	51·2	1937	82·2	2145
20·3	1735	52·0	1944	83·2	2150
20·9	1741	53·1	1951	84·2	2157
22·6	1751	54·1	1957	85·2	2164
23·3	1754	55·2	1964	86·2	2172
24·2	1761	56·2	1970	87·2	2180
25·2	1768	57·2	1978	88·2	2186
26·2	1773	58·2	1983	89·2	2194
27·3	1783	59·2	1990	90·2	2203
28·7	1787	60·2	1996		
29·7	1792	61·2	2003		
30·2	1799	62·2	2010		
31·1	1807	63·2	2016		
32·2	1814	64·2	2023		
33·2	1821	65·2	2029		
34·2	1827	66·2	2035		
35·3	1834	67·2	2041		
36·2	1841	68·2	2049		
37·2	1847	69·2	2055		
38·2	1853	70·2	2061		
39·2	1860	71·2	2070		
40·1	1865	72·2	2076		
41·2	1873	73·2	2082		
42·2	1878	74·2	2088		
43·5	1885	75·2	2097		
44·2	1892	76·2	2103		
45·2	1900	77·2	2111		
46·2	1906	78·2	2117		

Measurements with Rocking Tank A Copper, Soft.

A similar wire to that used in the previous measurements was annealed in a tube of hard glass, through which was passing a current of dry CO_2 gas, in order to prevent oxidation. The following measurements were made with it :—

Density at 15° C., 8·959 (see previous table).
Absolute weight of 300 cm. of the wire, 5·5746 grams.
Diameter.

$$X = 2r = 2\sqrt{\frac{5·5746}{\pi\ 8·959 \times 300}} = 2 \times 0·025694 = 0·051388 \text{ cm.}$$

250 cm. of this wire were compared with the standard ohm, according to the method described. The following are the observations:—

Table IV.

T_X.	G_X.	G_R.	G_X (G_R = 1240).	T_R.	G_X (G_R = 124° T_R = 15°C.).
16·8° C.	820·	1023	994	20° C.	—
,,	819·5	1023	993	,,	994
19·95	829·	1020	1008	,,	—
,,	828·5	1020	1007	,,	1008
48·0	916·	1019	1114	,,	—
,,	916·	1019	1114	,,	1115

From the numbers in column 6 the values of the specific resistance of this sample can be obtained by multiplication with the constant 1·6826 obtained in the same manner as the value for the hard variety, the difference being due to the difference in the diameters. All the other constants of the measurements were the same. The results by calculation give the following values:—

Specific resistance of rocking tank A copper, annealed in CO_2 gas:—

At 16·8° C. = 1672·4 C.G.S. units.
,, 19·95 = 1696·0 ,, ,,
,, 48·0 = 1876·0 ,, ,,

The temperature coefficient, calculated from the following formula:—

$$R_t = R_0(1 + xt), \quad (8.)$$

gives the value 0·00418 at ordinary temperatures.

Applying this value of x to the amount of specific resistance at 16·8° C., the following is obtained as the specific resistance of this special sample of annealed rocking tank A deposit:—

$$\sigma_{0°C} = 1566 \text{ C.G.S. units.}$$

Specific Resistance of Soft Annealed Copper Wire made from Deposited Sheet Copper named B, the Deposit being obtained from a Solution of Rocking Tank A Copper Dissolved in Pure Diluted Sulphuric Acid, using an Anode of the Tank A Copper.

Origin of the Copper.—A solution of sulphate of copper was prepared by using a piece of rocking tank A copper, as the anode in a

mixture of pure sulphuric acid and distilled water, the cathode being another strip of copper enclosed in a new and clean cell of porous earthenware. The current was continued until the solution had the desired strength. From this solution a sheet of copper was deposited on a polished copper plate, as described in the first part of this paper, the rocking tank A copper still being the anode. The deposit was then cut into narrow strips and drawn through sapphire dies to the requisite diameter. It was finally annealed by heating in a current of CO_2 gas.

Specific Gravity of the Copper B.—It was ascertained by weighing equal lengths of this wire and sample A (both drawn through the same die), that their specific gravities did not differ to any appreciable amount, the density 8·959 at 15° C. was therefore taken for this sample B.

Diameter of the Wire.—300 cm. of the wire weighed 5·5845 grams; the diameter is therefore

$$X = 2\sqrt{\frac{5{\cdot}5845}{\pi 8{\cdot}959 \times 300}} = 2 \times 0{\cdot}025717 = 0{\cdot}051434 \text{ cm.}$$

Electrical Measurements.—The same arrangements were employed as previously.

Table V.

T_X.	G_X.	G_R.	G_X ($G_R = 1240$).	T_R.	G_X ($G_R = 1240$, $T = 15°$ C.).
15·9° C.	832	1046·5	985·4	17·5° C.	986
,,	831	1046		,,	
,,	829	1044		,,	
,,	830	1045		,,	

To ascertain the specific resistance in C.G.S. units, the constant by which to multiply 986 (last column, Table V) was calculated in the same manner as in Equation No. 7, and by substituting 0·025717 for r instead of 0·025755, the constant 1·6856 is obtained. We thus have the specific resistance of the pure copper:—

$$\sigma_{15{\cdot}9°\text{ C.}} = 986 \times 1{\cdot}6856 = 1662 \text{ C.G.S. units.}$$

Measurements at higher temperatures for ascertaining the temperature coefficient were made, but the data were unfortunately lost. The result, however, was

$$\Delta_t = 0{\cdot}00415.$$

Applying this constant in the well-known formula, the following is found to be the specific resistance at 0° C. :—

$\sigma_{0^\circ C.}$ 1559·1 C.G.S. units.

Table of General Results.

	C.G.S. units.		Temp. coefficient Δt.
Specific resistance of A deposit (hard)...................	At 0° C. = 1603	....	0·00408
Same wire after annealing in CO_2	At 0° C. = 1566	....	0·00418
Specific resistance of Sample B (annealed)...............	At 0° C. = 1559	....	0·00415

As the difference between the last two values only amounts to 0·4 per cent., it is probable that both of the specimens were perfectly pure, and that the limit of electrolytic purification had been reached. The mean of the two gives the probable specific resistance of pure copper. Thus, as a general conclusion, it may be stated that the specific resistance for pure copper (hard and annealed) is :—

Hard variety, wire 1603 C.G.S. units and Δ_t = 0·00408.
Soft „ „ 1563 „ „ = 0·00416.

Presents, May 24, 1894.

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FIG. 2.