PHILOSOPHICAL TRANSACTIONS.

I. *On the Influence of Temperature on the Electric Conducting Power of Metals.*

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The results obtained by different observers in their researches on the influence of temperature on the electric conducting power of metals do not agree at all together. The differences in their results may be partly owing to their not having tested pure metals, and partly to their not having taken into consideration the fact that, when a wire of a pure metal is heated for the first time to 100° C., an alteration in the conducting power of the wire is observed on its again being cooled; in fact, it is necessary to keep the wire for several days at 100° before its conducting power, on again being cooled, becomes constant.

In the experiments we are about to detail we have taken great care to employ only pure metals, as well as a method and a disposition of the apparatus with which great accuracy could be obtained.

The method employed for the determination of the resistances is fully described in the 'Philosophical Magazine' for February 1857. Fig. 1 shows the disposition of the apparatus. B is the trough in which the wires were heated: these were soldered to two thick copper wires F (4–5 millims. thick), bent as shown in the figure, and ending in the mercury-cups E, which were connected with the apparatus by two other copper wires, F′, of the same thickness. C is a piece of board placed in such a manner as to prevent the heat of the trough from radiating on the apparatus. The mercury-cups O are made of small blocks of wood, through which holes are bored just large enough to take the thick wires, and to the bottoms of which blocks amalgamated copper plates are fastened. Now it is clear that if the ends of the thick copper wires are filed flat, and well amalgamated, and the mercury-cups are filled with mercury, this method of connexion may be looked upon as a soldering of the copper plates to the wires, or, in other words, as a perfect connexion; for the wires may be removed as often as required, and on replacing them the same resistance is always observed. The wires F″, to which the normal wire (in the glass cylinder G) is soldered, are also 4–5 millims. thick. The reason why such thick wires were chosen was to make any difference in their resistance, caused by the change of temperature in the room or by the heating of the ends in the oil-bath, so small that no correction was necessary. This was proved to be the case by the following experiment:—After having soldered a wire in the trough to the ends of the thick copper wires, and determined its resistance with the normal wire generally used, the wire F′ at *e* was heated with the 6-Bunsen burner much above

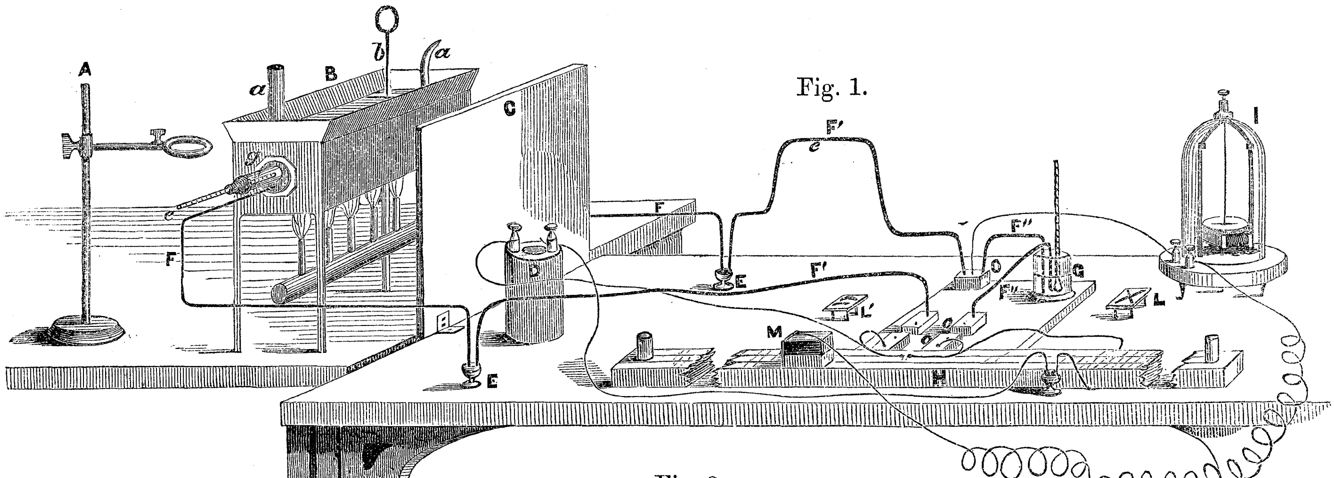

Fig. 1.

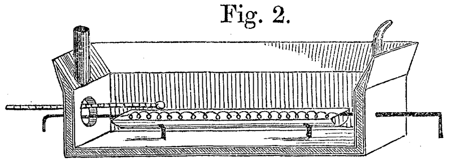

Fig. 2.

100° C., and the resistance of the circuit was again determined whilst the wire was at that temperature, when it was found to have increased only 0·08 per cent.; we did not, therefore, consider it necessary to make any correction for the increase of resistance caused by the heating of the ends of the thick wires in the trough. The resistance of the copper wires was determined at the ordinary temperature, and brought into calculation without further correction. Before the commencement of each series, all the ends of the wires dipping into the mercury-cups were carefully re-amalgamated. L, L′ are the two commutators fitting into four mercury-cups at *o*.

The wire stretched on the board H is of german silver instead of copper, as was formerly described; its half-length was 4550 millims. The length of the board is about 1500 millims.; the wire, therefore, was wound backwards and forwards several times on the one side; this is not visible in the figure. By using normal wires of different resistances, and by choosing proper lengths of the wire to be tested, it was always possible to begin the observations with the block M within 100 millims. of the middle of the wire. Great care was taken to lift the block M off the wire when it was moved, in order to prevent as much as possible its wearing. It may be mentioned that, although we generally worked with only one of the commutators, and therefore mostly used the one half of the wire, the zero-point of the wire only varied, during the whole of the experiments, which have taken almost a year to carry out, 3 millims. The zero-point was always determined before each series was begun. The distance the block M was moved when the resistance of a wire was determined, first at 0° and then at 100°, was, for pure metals in a solid state, about 800 millims., or about 8 millims. for 1°. As, however, the movement of the block M of 1 millim. caused a deflection of the needles of the galvanometer I of 20° to 30°, it is evident, with the apparatus employed, that the differences in the resistance of a wire to values less than those corresponding to 0°·1 C. can be accurately determined. Our results, moreover, prove this to be the case, as in many instances the difference between the observed and calculated conducting powers for the whole series do not amount to values equal to 0°·1 to 0°·2 C.

The trough B is a double one, the space between the inner and outer one being 20 millims. The dimensions of the inner trough were 400 millims. long, 80 millims. wide, and 80 millims. deep. Through the ends of both two holes of about 20 millims. wide were made, in which good corks were fitted, and through these passed the thick copper wires F; and also at one end a glass tube *d*, wide enough to allow the thermometer *c* to pass freely. A piece of india-rubber tubing, fitting over the glass tube *d*, and tightly round the thermometer, closed the tube, but allowed the thermometer to be moved either backward or forward with great ease. The tubes *a* are for filling the space between the inner and outer troughs with oil.

The wire to be tested lay in the trough, as shown in fig. 2, on a small glass tray, made by splitting a glass tube longitudinally, thereby preventing any possibility of its touching the trough, and also guarding it from being moved by the stirrer. A second trough, of somewhat smaller dimensions, was also used.

The use of an oil-bath for heating the wires has been objected to by a former observer*; it was therefore necessary to determine experimentally whether there was any real reason for the objection or not. He states that, as oil conducts electricity better on being heated than when cold, the differences between the conducting powers of cold and hot oil will materially affect the values obtained for the resistances of wire which had been determined at different temperatures in that liquid. In order to test the accuracy of this assertion, two copper plates of about 150 millims. diameter were connected, the one with the galvanometer, the other with a single Bunsen's cell; and to complete the circuit, this was connected with the galvanometer. A piece of filtering-paper, moistened with the olive-oil used, was placed between the copper plates, and these were pressed together with a weight. On completing the circuit not the slightest deflection of the needles was observed; the copper plates were then heated to above 100° C., and still no deflection was visible. To show that the connexions were good, a drop of water was put on the oiled paper; and immediately the needles of the galvanometer were sent with great violence to the stops. This proves that although oil may

* Arndsten, Poggendorff's 'Annalen,' vol civ. p. 1.

have a higher conducting power when hot than cold, yet in either case it is so infinitely small, that it cannot influence the results obtained in the manner just described.

Again, it was proved in a former research* that the formula for the correction of conducting power for temperature of a wire, deduced from the observations made in an oil- or air-bath, were exactly the same. Thus the formula obtained for an annealed wire of the gold-silver alloy heated in the oil-bath was

$$\lambda=15·052-0·01074t+0·00000714t^2,$$

and that for the same wire heated in an air-bath was

$$\lambda=15·059-0·01077t+0·00000722t^2.$$

As, however, more accurate results may be obtained by experimenting in an oil- than in an air-bath, on account of the wires taking more readily the temperature of the bath, and of their being more rapidly cooled if heated by the current passing through them, we have chosen this manner of heating the wires in preference to the other.

As oil, and more especially oil when hot, attacks most wires to a degree which would render the observations valueless, we were obliged to varnish them. The best varnish for the purpose is a solution of shell-lac in alcohol. For instance, a hard-drawn copper wire, not varnished, loses in conducting power after having been heated in an oil-bath to 100°, but if varnished, increases. To show that varnishing has no effect on the results, we give in Table I. the conducting power of a hard-drawn gold wire, first not varnished, and then varnished. Each result is the mean of two observations.

TABLE I.

Not varnished.				Varnished.			
T.	Conducting power.		Difference.	T.	Conducting power.		Difference.
	Observed.	Calculated.			Observed.	Calculated.	
15·30°	72·697	72·705	−0·008	13·85°	73·120	73·085	+0·035
30·55	68·806	68·879	−0·073	30·95	68·756	68·782	−0·026
48·65	64·659	64·717	−0·058	49·55	64·523	64·520	+0·003
69·55	60·409	60·423	−0·014	68·40	60·636	60·645	−0·009
83·25	57·915	57·906	+0·009	84·55	57·704	57·680	+0·024
99·85	55·151	55·174	−0·023	98·70	55·346	55·352	−0·006
84·55	57·704	57·680	+0·024	84·90	57·645	57·620	+0·025
70·80	60·224	60·184	+0·040	70·25	60·318	60·289	+0·029
50·85	64·239	64·239	0·000	51·20	64·149	64·164	−0·015
30·95	68·746	68·782	−0·036	30·60	68·886	68·866	+0·020
16·80	72·343	72·316	+0·027	17·85	72·111	72·045	+0·066

The formula deduced from the observations, and from which the conducting powers were calculated, was

$$\lambda=76·838-0·27973t+0·0006285t^2.$$

The thermometers used were:—1. One divided into degrees, each of which was 3·5

* Philosophical Magazine for February 1861.

millims. long. With very little practice the temperature could be read off to 0°·1 C. with accuracy. This thermometer was calibrated by ourselves, and afterwards compared with a normal thermometer from Kew Observatory, for which we were indebted to the kindness of Mr. BALFOUR STEWART. The corrected readings of our thermometer agreed perfectly with those of the Kew thermometer. 2. A normal thermometer from Messrs. NEGRETTI and ZAMBRA, divided into 0°·2 C. This was compared with the Kew thermometer and found to be correct. The boiling- and freezing-points of the thermometers were taken at intervals, and the necessary corrections made.

As the light in the room where the experiments were made came from above, and as the thermometers lay horizontally in the trough, by placing the eye in a position so that the division on the thermometer covered its reflexion on the column of mercury, all error of parallax was avoided. The thermometers were always read off with the help of the magnifying glass A through the oil in the glass tube *d*, so that the whole of the column of mercury had very nearly the temperature of the bath.

The normal wires were made of annealed german silver, and their resistances determined by comparing them with a hard-drawn wire of the gold-silver alloy*. They were soldered to two thick copper wires, varnished, and when used placed in the cylinder G, filled with oil, in which a thermometer hung. The temperature of the oil was taken immediately after each observation, and the conducting power of the normal wire corrected by the use of the formula

$$\lambda = 7{\cdot}803 - 0{\cdot}0034619t + 0{\cdot}0000003951t^2,$$

which was found by the determination of the conducting powers, at different temperatures, of a piece of wire from the same coil as that from which the normal wires were cut. In this paper we have taken as unit the conducting power of a hard-drawn silver wire at 0° C. = 100 (that of the hard-drawn gold-silver alloy at 0° being = 15·03), in order to be able to compare at sight the present determinations with those made by one of us a short time ago†.

Before beginning a series, as already stated, all the ends of the wires dipping in the mercury-cups were re-amalgamated, and the zero-point of the scale redetermined. The current from the cell D was only allowed to pass through the apparatus for a second or two at a time, for fear of heating the wires, &c.

From 0° to 100° seven intervals were chosen at which observations were made, viz. 12°, 25°, 40°, 55°, 70°, 85°, 100°. With a little practice the flames of the 6-Bunsen burner could be regulated so as to come within a degree or two of the above temperatures. For about five minutes before, and whilst making the observations, the oil in the trough was stirred, one observer being at the trough whilst the other determined the resistances. Four observations at each interval were generally made on heating the wire to 100°, and again four at each interval on cooling (where this was not the case it will be mentioned with the series).

* Philosophical Magazine, February 1861.

† Philosophical Transactions, 1858 and 1860.

To save space, the mean only of the eight observations will be given, as otherwise the number of figures would be very great. Table I. may be taken as a fair example of the results obtained. The formulæ from which the conducting powers have been calculated is

$$\lambda = x + yt + zt^2,$$

where λ is the conducting power at t° C., x the conducting power at 0°, and y and z constants. The values for x, y, and z were deduced from the mean of the observations by the method of least squares.

We will now proceed to the experiments made with each metal, making at the same time a few remarks on their purification, &c., and then see what general laws and conclusions we may draw from the results obtained.

Silver.

Purified by precipitating nitrate of silver with hydrochloric acid, and reducing the washed chloride with pure carbonate of sodium. Wires 1, 2, and 3 were of different preparations. Table II. gives the results obtained with these wires.

TABLE II.

	First wire.		Second wire.		Third wire.	
	Hard drawn.	Annealed.	Hard drawn.	Annealed.	Hard drawn.	Annealed.
Length............	1546 millims.	1535 millims.	1753 millims.	1741 millims.	1962 millims.	1953 millims.
Diameter............	0·462 millim.	0·462 millim.	0·596 millim.	0·596 millim.	0·448 millim.	0·648 millim.
Conducting power found before heating the hard-drawn wires............	97·645 at 15°·4	Reduced to 0°. 103·528	95·112 at 16°·0	Reduced to 0°. 101·149	94·053 at 16°·0	Reduced to 0°. 99·800
Conducting power after being kept at 100° for 1 day ...	98·138 at 16·2	104·364	96·618 at 15·6	102·585	95·241 at 15·4	100·839
Ditto, for 2 days...	98·913 at 15·6	104·951	101·544 at 16·8	108·303*	96·337 at 16·0	102·223
Ditto, for 3 days...	99·837 at 16·0	106·091	102·237 at 16·0	108·714	96·671 at 17·6	103·178
Ditto, for 4 days...	99·212 at 18·4	106·377	101·427 at 19·2	109·162	97·917 at 15·6	103·747
Ditto, for 5 days...	99·586 at 17·4	106·380	101·750 at 18·6	109·262	97·669 at 17·4	104·168
Ditto, for 6 days...	....	....	....	....	97·322 at 18·2	104·100

The means of the conducting powers found for each of the following temperatures were—

* During the day the temperature of the oil increased, by mistake, to 130°.

First wire, hard drawn.				Second wire, hard drawn.				Third wire, hard drawn.			
T.	Conducting power.		Difference.	T.	Conducting power.		Difference.	T.	Conducting power.		Difference.
	Observed.	Calculated.			Observed.	Calculated.			Observed.	Calculated.	
11°·00	102·238	102·272	−0·034	12°·20	103·927	103·927	0·000	9°·60	100·534	100·546	−0·012
26·17	96·710	96·645	+0·065	23·70	99·520	99·523	−0·003	23·90	95·452	95·437	+0·015
38·25	92·490	92·505	−0·015	41·70	93·224	93·236	−0·012	38·95	90·476	90·507	−0·031
55·40	87·130	87·149	−0·019	56·20	88·703	88·708	−0·005	56·00	85·513	85·478	+0·035
68·85	83·389	83·374	+0·015	68·90	85·142	85·137	+0·005	68·15	82·244	82·252	−0·008
84·00	79·540	79·572	−0·032	85·45	81·078	81·036	+0·042	84·47	78·393	78·391	+0·002
101·30	75·831	75·813	+0·018	99·20	78·073	78·103	−0·030	98·60	75·477	75·484	−0·007
First wire, annealed.				Second wire, annealed.				Third wire, annealed.			
11°·30	103·391	103·404	−0·013	8°·00	106·447	106·426	+0·021	9°·25	102·543	102·461	+0·082
24·25	98·589	98·576	+0·013	24·35	99·968	99·990	−0·022	25·55	96·371	96·495	−0·124
41·85	92·520	92·530	−0·010	38·05	95·051	95·077	−0·026	40·10	91·589	91·630	−0·041
56·45	88·006	87·965	+0·041	55·17	89·554	89·554	0·000	55·17	87·055	87·047	+0·008
67·75	84·670	84·714	−0·044	68·22	85·847	85·803	+0·044	68·55	83·483	83·367	+0·116
83·65	80·562	80·554	+0·008	83·62	81·882	81·888	−0·006	83·57	79·667	79·674	−0·007
98·80	77·046	77·042	+0·004	100·00	78·319	78·331	−0·012	100·00	76·124	76·163	−0·039

The formulæ deduced from the observations, from which the conducting powers were calculated, were—

For first wire (hard drawn) . $\lambda=106{\cdot}651-0{\cdot}40948t+0{\cdot}0010370t^2$.

For first wire (annealed) . . $\lambda=107{\cdot}880-0{\cdot}40698t+0{\cdot}0009601t^2$.

For second wire (hard drawn) $\lambda=108{\cdot}928-0{\cdot}42389t+0{\cdot}0011407t^2$.

For second wire (annealed) . $\lambda=109{\cdot}802-0{\cdot}43138t+0{\cdot}0011667t^2$.

For third wire (hard drawn) . $\lambda=104{\cdot}209-0{\cdot}39124t+0{\cdot}0010133t^2$.

For third wire (annealed) . $\lambda=106{\cdot}088-0{\cdot}40160t+0{\cdot}0010235t^2$.

From the above Table it will be seen that, after heating a silver wire to 100° C. for some days, its conducting power is increased almost to the same extent as if it had been annealed, and that wires 1 and 2 were not completely hard drawn. On comparing the difference in the conducting powers produced by annealing the wires, we find for wire 3 it is only 6 per cent., whereas for wire 2 it is almost 10 per cent., taking the conducting power of the hard-drawn silver wire =100. In a former research* this difference was found to be—

			Reduced to 0°.
1.	Hard drawn	95·28 at 14°·0	100·47
	Annealed	103·98 at 14·8	109·98
2.	Hard drawn	95·36 at 14·6	100·78
	Annealed	103·33 at 14·6	109·20

* Philosophical Transactions, 1860.

These values have been reduced by using a formula which is the mean of the six deduced from the experiments; for although there is a difference in the formula obtained for the annealed and hard-drawn (or rather partially annealed) wires, yet it is so small that they may be considered the same, more especially as the difference between the one obtained for the different wires is far greater. Taking the mean of the above values, and assuming the influence of temperature on the conducting power of hard-drawn and annealed wires to be the same, we find the following formulæ:—

For hard-drawn wires $\lambda=100{\cdot}00\ -0{\cdot}38287t+0{\cdot}0009848t^2$.

For annealed wires $\lambda=108{\cdot}574-0{\cdot}41570t+0{\cdot}0010624t^2$.

Copper.

Wires 1 and 2 were of the same piece of electrotype copper prepared for us by Dr. H. MÜLLER at Messrs. DE LA RUE and Co.'s. Wire 3 was cut off a piece of commercial electrotype copper from the same source. Table III. shows the results obtained with these wires.

TABLE III.

	First wire.		Second wire.		Third wire.	
	Hard drawn.	Annealed.	Hard drawn.	Annealed.	Hard drawn.	Annealed.
Length	2262 millims.	2245·5 millims.	1753 millims.	1738 millims.	1476 millims.	1461 millims.
Diameter	0·691 millim.	0·691 millim.	0·598 millim.	0·598 millim.	0·537 millim.	0·537 millim.
Conducting power found before heating the hard-drawn wires	95·672 at 10°·6	Reduced to 0°. 99·526	94·355 at 15°·0	Reduced to 0°. 100·021	92·568 at 20°·6	Reduced to 0°. 100·327
Conducting power after being kept at 100° for 1 day ...	96·324 at 9·9	99·943	94·965 at 13·2	99·971	93·263 at 19·0	100·461
Ditto, for 2 days...	96·750 at 11·8	101·097	94·880 at 14·2	100·268	93·720 at 18·0	100·563
Ditto, for 3 days...	96·914 at 12·2	101·418	94·501 at 15·9	100·524	93·434 at 19·0	100·645
Ditto, for 4 days...	97·950 at 9·8	101·671	94·153 at 17·2	100·656	93·278 at 19·6	100·708
Ditto, for 5 days...	98·437 at 8·7	101·682	95·570 at 14·4	101·074	92·865 at 20·6	100·649
Ditto, for 6 days...	....	....	94·327 at 18·2	101·230	92·738 at 21·1	100·705
Ditto, for 7 days...	....	....	96·575 at 12·7	101·469		

The means of the conducting powers found for each of the following temperatures were—

First wire, hard drawn.				Second wire, hard drawn.				Third wire, hard drawn.			
T.	Conducting power.		Difference.	T.	Conducting power.		Difference.	T.	Conducting power.		Difference.
	Observed.	Calculated.			Observed.	Calculated.			Observed.	Calculated.	
16·86	95·473	95·467	+0·006	19·17	94·359	94·334	+0·025	12·65	95·769	95·739	+0·030
29·88	91·063	91·002	+0·061	30·95	90·187	90·208	−0·021	25·61	91·061	91·076	−0·015
51·03	84·235	84·315	−0·080	48·53	84·518	84·544	−0·026	39·52	86·415	86·456	−0·041
69·52	78·997	79·044	−0·047	69·22	78·640	78·634	+0·006	53·92	82·069	82·090	−0·021
83·77	75·413	75·347	+0·066	83·77	75·015	74·968	+0·047	69·90	77·798	77·741	+0·057
98·60	71·829	71·838	−0·009	99·00	71·532	71·562	−0·030	84·87	74·172	74·142	+0·030
								99·92	70·951	70·987	−0·036
First wire, annealed.				Second wire, annealed.				Third wire, annealed.			
17·00	95·535	95·567	−0·032	18·96	94·987	94·959	+0·028	13·45	96·954	96·934	+0·020
29·63	91·291	91·239	+0·052	31·86	90·424	90·449	−0·025	26·15	92·246	92·260	−0·014
50·22	84·687	84·726	−0·039	52·05	83·974	84·003	−0·029	39·35	87·727	87·753	−0·026
69·60	79·223	79·209	+0·014	70·27	78·836	78·829	+0·007	55·50	82·675	82·722	−0·047
83·42	75·636	75·638	−0·002	83·81	75·428	75·377	+0·051	69·90	78·742	78·686	+0·056
99·39	71·891	71·893	−0·002	99·57	71·757	71·784	−0·027	84·67	75·047	74·988	+0·059
								99·05	71·766	71·816	−0·050

The formulæ deduced from the observations, from which the conducting powers were calculated, were—

For first wire (hard drawn) . . . . $\lambda=101·645-0·37963t+0·0007844t^2$.
For first wire (annealed) . . . . . $\lambda=101·791-0·37959t+0·0007921t^2$.
For second wire (hard drawn) . . $\lambda=101·614-0·39806t+0·0009546t^2$.
For second wire (annealed) . . . . $\lambda=102·143-0·39629t+0·0009179t^2$.
For third wire (hard drawn) . . . $\lambda=100·620-0·39885t+0·0010236t^2$.
For third wire (annealed). . . . . $\lambda=102·243-0·40850t+0·0010228t^2$.

The observations made with wires 1 and 2 were as follows: two at each interval on heating and two on cooling; again, two on heating and two on cooling, as shown in Table I.

On looking at the above, we observe that wire 1, after having been kept at 100° for several days, increased in conducting power almost to the same extent as if it had been annealed, wire 2 partially so, and wire 3 hardly at all. The annealing took place in a glass tube heated with a 4-Bunsen burner, whilst a current of hydrogen passed through it. Here, again, as in the case of the silver wire, we may assume that the formulæ of the hard-drawn and annealed copper wires are the same. In a former research * pure copper was found to conduct—

		Reduced to 0°.
1.	93·00 at 18°·6	99·877
2.	93·46 at 20·2	100·980
3.	92·02 at 18·4	99·824
4.	92·76 at 19·3	99·886
5.	92·99 at 17·5	99·453

* Philosophical Transactions, 1860.

The difference found between the conducting powers of hard-drawn and annealed wires was —

			Reduced to 0°.
6.	Hard drawn	95·31 at 11°·0	99·435
	Annealed	97·83 at 11·0	102·065
7.	Hard drawn	95·72 at 11·0	99·864
	Annealed.	98·02 at 11·0	102·263

These values have been reduced to 0° as follows: take for instance the first, 93·00 at 18°·6. The mean of the six formulæ obtained for copper (see Table XV.) is

$$\lambda=100-0·38701t+0·0009009t^2;$$

and calculating the conducting power for 18°·6 by this formula, we find it equal to 93·114.

Now $$\frac{93·00}{93·114}=0·99877;$$

and if all the terms of the above formula be multiplied by this number, we deduce a formula by which the above value can be reduced. All the reductions given in this paper of former determinations were made in this manner, using the formulæ given in Table XV. The reductions to 0° in the Tables were made in a like manner, the only difference being that the formulæ found for the respective wires were used instead of the mean. Taking the mean of all the values found for copper, and using the mean for the formulæ given in Table XV., we find as the formula for correction of the conducting power for temperature of

A hard-drawn wire $\lambda=\ \ 99·947-0·38681t+0·0009004t^2$

An annealed wire $\lambda=102·213-0·39557t+0·0009208t^2$.

The values given as first term in the formulæ were found as follows: on referring to the paper* from which the conducting powers of copper were taken, it will be seen that each of them is the mean of three determinations. The reduced values therefore of 1 to 5, the mean of 6, hard drawn, and 7, hard drawn, and the mean of the first determinations of the three wires given in Table III., were added together, and the mean taken as the conducting power of a hard-drawn copper wire at 0° C. For the annealed, the per-centage differences of the values of 6, hard drawn and annealed, 7, ditto, and of the first determinations of the three wires in Table III. and the annealed ones, were added together, and the mean added to the value found for the hard-drawn wire (as a percentage amount). All the formulæ given as end-result with each metal have been constructed in this manner.

Gold.

Purified as described in the Philosophical Transactions, 1860, p. 175. Wires 1, 2, and 3 were of different preparations. The results obtained with these wires are given in Table IV.

* Philosophical Transactions, 1860.

TABLE IV.

	First wire.		Second wire.		Third wire.	
	Hard drawn.	Annealed.	Hard drawn.	Annealed.	Hard drawn.	Annealed.
Length..............	2214 millims.	2200 millims.	837 millims.		759·5 millims.	742·5 millims.
Diameter	0·759 millim.	0·759 millim.	0·467 millim.		0·434 millim.	0·434 millim.
		Reduced to 0°.		Reduced to 0°.		Reduced to 0°.
Conducting power found before heating the hard-drawn wires	73·239 at 13°·2	76·821	72·550 at 15°·1	76·561	67·530 at 36°·8	77·229
Conducting power after being kept at 100° for 1 day ...	72·746 at 15·2	76·854	73·359 at 12·6	76·733	71·868 at 19·4	77·223
Ditto, for 2 days...	72·751 at 15·1	76·832	....	....	71·854 at 20·1	77·405
Ditto, for 3 days...	....	....	....	....	72·191 at 19·0	77·457
Ditto, for 4 days...	....	....	....	....	72·396 at 18·0	77·394

The means of the conducting powers found for each of the following temperatures were—

First wire, hard drawn.				Second wire, hard drawn.				Third wire, hard drawn.			
T.	Conducting power. Observed.	Calculated.	Difference.	T.	Conducting power. Observed.	Calculated.	Difference.	T.	Conducting power. Observed.	Calculated.	Difference.
15°·95	72·567	72·536	+0·031	13°·36	73·222	73·212	+0·010	12°·44	73·854	73·841	+0·013
30·76	68·798	68·828	−0·030	24·79	70·329	70·325	+0·004	23·27	70·965	70·975	−0·010
50·06	64·392	64·410	−0·018	40·80	66·515	66·544	−0·029	39·42	67·002	67·013	−0·011
69·75	60·397	60·385	+0·012	55·65	63·306	63·312	−0·006	55·47	63·441	63·448	−0·007
84·31	57·742	57·722	+0·020	69·52	60·528	60·531	−0·003	70·56	60·455	60·435	+0·020
99·27	55·248	55·263	−0·015	84·12	57·905	57·854	+0·051	84·79	57·904	57·893	+0·011
				100·00	55·203	55·232	−0·029	99·00	55·635	55·647	−0·012
First wire, annealed.								Third wire, annealed.			
14°·92	74·020	73·992	+0·028	At the commencement of the determinations this wire was torn away from its place by the stirrer.				14°·10	74·327	74·293	+0·034
30·05	70·039	70·068	−0·029					26·31	71·067	71·095	−0·028
48·87	65·575	65·611	−0·036					40·51	67·582	67·621	−0·039
69·90	61·220	61·191	+0·029					53·72	64·645	64·628	+0·017
82·82	58·811	58·768	+0·043					70·17	61·229	61·220	+0·009
99·62	55·915	55·948	−0·033					85·36	58·422	58·388	+0·034
								99·30	56·029	56·056	−0·027

The formulæ deduced from the observations, from which the conducting powers were calculated, were—

For first wire (hard drawn) . . . $\lambda=76{\cdot}838-0{\cdot}27973t+0{\cdot}0006285t^2$.

For first wire (annealed) . . . $\lambda=78{\cdot}161-0{\cdot}28935t+0{\cdot}0006664t^2$.

For second wire (hard drawn) . . $\lambda=76{\cdot}786-0{\cdot}27549t+0{\cdot}0005995t^2$.

For third wire (hard drawn . . $\lambda=77{\cdot}343-0{\cdot}29043t+0{\cdot}0007200t^2$.

For third wire (annealed) . . . $\lambda=78{\cdot}231-0{\cdot}28849t+0{\cdot}0006564t^2$.

The observations made with wire 1 (hard drawn) are given in Table I., those of the same wire (annealed) were made in the same manner.

Here we find no permanent change in conducting power with wire 1, after being kept at 100° for several days, and only a very slight increase with wires 2 and 3. The formulæ for the hard-drawn and annealed wires agree so closely that they may also, as with silver and copper, be considered the same.

In the paper just alluded to, the conducting power of pure gold was found—

		Reduced to 0°.
1.	72·68 at 19°·3	77·966
2.	73·08 at 23·3	79·524
3.	73·27 at 13·8	77·053
4.	73·99 at 15·1	78·178

The difference between hard-drawn and annealed wires was—

			Reduced to 0°.
5.	Hard drawn	74·20 at 14°·8	78·313
	Annealed	75·53 at 15·2	79·833
6.	Hard drawn	73·78 at 15·5	78·067
	Annealed	75·18 at 15·8	79·635

Taking the mean of the values as with copper, the following formulæ were deduced for the correction of conducting power for temperature:—

For hard-drawn wires $\lambda=77{\cdot}964-0{\cdot}28648t+0{\cdot}0006582t^2$.

For annealed wires $\lambda=79{\cdot}327-0{\cdot}29149t+0{\cdot}0006697t^2$.

Zinc.

Zinc free of arsenic was purified by distillation. All pressed wires. In Table V. the results obtained are given.

TABLE V.

	First wire.		Second wire.		Third wire.	
Length	502·2 millims.		394 millims.		372 millims.	
Diameter	0·588 millim.		0·513 millim.		0·519 millim.	
		Reduced to 0°.		Reduced to 0°.		Reduced to 0°.
Conducting power found before heating the wires	26·744 at 23°·1	29·093	26·903 at 18°·5	28·836	26·835 at 18°·0	28·639
Ditto, after being kept at 100° for 1 day	26·695 at 23·7	29·103	27·081 at 17·5	28·919	26·784 at 18·5	28·636
Ditto, for 2 days	....	....	26·980 at 18·5	28·919	26·885 at 17·4	28·632

The means of the conducting powers found for each of the following temperatures were—

T.	Conducting power.		Difference.	T.	Conducting power.		Difference.	T.	Conducting power.		Difference.
	Observed.	Calculated.			Observed.	Calculated.			Observed.	Calculated.	
11°·60	27·915	27·902	+0·013	11°·20	27·706	27·687	+0·019	11°·16	27·518	27·513	+0·005
24·24	26·639	26·653	−0·014	26·12	26·187	26·199	−0·012	25·96	26·088	26·090	−0·002
41·33	25·077	25·086	−0·009	39·55	24·951	24·959	−0·008	40·10	24·812	24·820	−0·008
55·08	23·925	23·926	−0·001	54·18	23·719	23·716	+0·003	56·85	23·423	23·428	−0·005
70·27	22·757	22·747	+0·010	72·32	22·330	22·330	0·000	71·73	22·306	22·295	+0·011
82·01	21·924	21·912	+0·012	85·77	21·407	21·414	−0·007	85·40	21·348	21·339	+0·009
98·07	20·865	20·875	−0·010	100·23	20·540	20·534	+0·006	98·95	20·462	20·472	−0·010

The formulæ deduced from the observations, from which the conducting powers were calculated, were—

For first wire . . $\lambda=29{\cdot}114-0{\cdot}10727t+0{\cdot}0002372t^2$.

For second wire . $\lambda=28{\cdot}881-0{\cdot}10949t+0{\cdot}0002616t^2$.

For third wire . . $\lambda=28{\cdot}649-0{\cdot}10424t+0{\cdot}0002182t^2$.

No permanent alteration in the conducting power takes place after heating the wires for several days to 100°.

The value formerly found for the conducting power of zinc (precipitated galvanoplastically, fused and pressed) was—

	Reduced to 0°.
27·39 at 17°·6	29·220.

Treating these values as before, we find the formula for zinc to be

$$\lambda=29{\cdot}022-0{\cdot}10752t+0{\cdot}0002401t^2.$$

Cadmium.

The metal was purified as described in the Philosophical Transactions, 1860, p. 177. The wires were pressed. Table VI. shows the results.

Table VI.

	First wire.	Second wire.	Third wire.
Length..............	625 millims.	559 millims.	439 millims.
Diameter...........	0·641 millim.	0·678 millim.	0·684 millim.

The means of the conducting powers found for each of the following temperatures were—

T.	Conducting power.		Difference.	T.	Conducting power.		Difference.	T.	Conducting power.		Difference.
	Observed.	Calculated.			Observed.	Calculated.			Observed.	Calculated.	
8°·87	23·327	23·329	−0·002	8°·89	23·374	23·400	−0·026	14°·60	21·849	21·859	−0·010
20·75	22·351	22·338	+0·013	21·59	22·280	22·270	+0·010	22·05	21·318	21·310	+0·008
34·47	21·241	21·255	−0·014	36·37	21·075	21·059	+0·016	39·65	20·072	20·061	+0·011
49·38	20·138	20·150	−0·012	48·52	20·157	20·146	+0·011	54·45	19·065	19·067	−0·002
63·39	19·188	19·186	+0·002	62·90	19·171	19·162	+0·009	68·10	18·179	18·194	−0·015
77·74	18·292	18·268	+0·024	80·00	18·109	18·131	−0·022	81·20	17·393	17·397	−0·004
93·55	17·325	17·339	−0·014					89·90	16·896	16·888	+0·008

The formulæ deduced from the observations, from which the conducting powers were calculated, were—

For first wire . . $\lambda=24\cdot100-0\cdot088554t+0\cdot0001740t^2$.

For second wire . $\lambda=24\cdot240-0\cdot096753t+0\cdot0002548t^2$.

For third wire . $\lambda=24\cdot974-0\cdot078004t+0\cdot0001147t^2$.

The values obtained for the alteration in the conducting power of these wires after heating them for several days to 100°, have unfortunately been lost. It may, however, be stated that the differences were very small, and that there was a loss in conducting power.

The conducting power of cadmium was found in the paper already referred to—

	Reduced to 0°.
22·10 at 18°·8	23·678.

Deducing the formula for cadmium in the manner before described, we find

$$\lambda=23\cdot725-0\cdot087476t+0\cdot0001797t^2.$$

Pure cadmium, when heated to about 80°, becomes exceedingly brittle, in fact it may be powdered in a hot mortar with great ease. We should not have been able to carry out the determinations if the wires had not been varnished, as the movement of the oil by the stirrer would have caused them to fall to pieces. It is worthy of remark that this change in the molecular arrangement of the wires does not make itself apparent in the conducting power to any very marked extent.

Tin.

Purified by dissolving commercial tin in nitric acid, and reducing the washed oxide by heating it with lampblack. Pressed wires were used. Table VII. gives the results.

TABLE VII.

	First wire.		Second wire.		Third wire.	
Length	279 millims.		375 millims.		315 millims.	
Diameter	0·559 millim.		0·634 millim.		0·729 millim.	
		Reduced to 0°.		Reduced to 0°.		Reduced to 0°.
Conducting power found before heating the wires	10·970 at 18°·2	11·710	11·532 at 18°·1	12·324	12·285 at 18°·2	13·108
Ditto, after being kept at 100° for 1 day	11·124 at 19·4	11·926	11·442 at 19·1	12·273	12·291 at 18·4	13·124
Ditto, for 2 days	10·852 at 27·0	11·956	11·448 at 18·6	12·257	12·296 at 18·4	13·129
Ditto, for 3 days	10·835 at 28·0	11·980	11·444 at 18·4	12·264		

The means of the conducting powers found for each of the following temperatures were—

T.	Conducting power.		Difference.	T.	Conducting power.		Difference.	T.	Conducting power.		Difference.
	Observed.	Calculated.			Observed.	Calculated.			Observed.	Calculated.	
12°·9	11·4110	11·4202	−0·0092	11°·80	11·7144	11·7227	−0·0083	10°·00	12·649	12·660	−0·011
25·27	10·9320	10·9246	+0·0074	26·32	11·1287	11·1153	+0·0134	26·54	11·944	11·934	+0·010
40·55	10·3570	10·3436	+0·0134	40·04	10·5805	10·5732	+0·0073	39·52	11·408	11·391	+0·017
54·15	9·8498	9·8558	−0·0060	54·02	10·0451	10·0526	−0·0075	56·27	10·717	10·727	−0·010
70·53	9·2980	9·3046	−0·0066	70·02	9·4883	9·4961	−0·0078	70·30	10·189	10·202	−0·013
83·13	8·9033	8·9078	−0·0045	85·02	9·0102	9·0127	−0·0025	85·72	9·654	9·657	−0·003
100·90	8·3937	8·3881	+0·0056	98·50	8·6158	8·6096	+0·0062	97·30	9·279	9·270	+0·009

The formulæ deduced from the observations, and from which the conducting powers were calculated, were—

For first wire . $\lambda = 11{\cdot}9613 - 0{\cdot}042902t + 0{\cdot}00007422t^2$.

For second wire $\lambda = 12{\cdot}2419 - 0{\cdot}044965t + 0{\cdot}00008213t^2$.

For third wire . $\lambda = 13{\cdot}1186 - 0{\cdot}046561t + 0{\cdot}00007206t^2$.

We see from the results that wires 1 and 2 decrease to a small extent in conducting power, whereas wire 3 increases slightly after being heated to 100°.

The conducting power of tin was found—

	Reduced to 0°.
11·45 at 21°·0	12·351;

and calculating the formula of tin as before, we find

$$\lambda = 12{\cdot}366 - 0{\cdot}044554t + 0{\cdot}00007588t^2.$$

Lead.

Purified by reducing by heat the twice recrystallized acetate. Wires 1 and 2 were pressed; wire 3 drawn. No permanent alteration in the conducting power of the wires was observed after they had been kept at 100° for two days. Table VIII. shows the results.

Table VIII.

	First wire.	Second wire.	Third wire.
Length	416 millims.	453 millims.	389 millims.
Diameter	0·669 millim.	0·698 millim.	0·959 millim.

The means of the conducting powers found for each of the following temperatures were—

T.	Conducting power.		Difference.	T.	Conducting power.		Difference.	T.	Conducting power.		Difference.
	Observed.	Calculated.			Observed.	Calculated.			Observed.	Calculated.	
14°·55	7·9365	7·9336	+0·0029	14°·50	7·8685	7·8653	+0·0032	12°·40	7·9038	7·9022	+0·0016
25·40	7·6129	7·6152	−0·0023	27·50	7·5336	7·5392	−0·0056	26·20	7·4967	7·4968	−0·0001
40·30	7·2036	7·2071	−0·0035	40·37	7·1405	7·1397	+0·0008	39·60	7·1309	7·1324	−0·0015
54·80	6·8423	6·8420	+0·0003	54·80	6·7789	6·7775	+0·0014	54·60	6·7565	6·7585	−0·0020
70·33	6·4881	6·4863	+0·0018	69·63	6·4392	6·4370	+0·0022	69·70	6·4205	6·4187	+0·0018
84·52	6·1964	6·1929	+0·0035	84·80	6·1189	6·1218	−0·0029	84·40	6·1250	6·1229	+0·0021
99·35	5·9159	5·9189	−0·0030	100·10	5·8388	5·8381	+0·0007	98·85	5·8642	5·8658	−0·0016

The formulæ deduced from the observations, from which the conducting powers were calculated, were—

For first wire . $\lambda=8\cdot3882-0\cdot032346t+0\cdot00007540t^2$.
For second wire $\lambda=8\cdot3147-0\cdot032055t+0\cdot00007307t^2$.
For third wire . $\lambda=8\cdot2925-0\cdot032468t+0\cdot00008011t^2$.

The value found for the conducting power of lead was

	Reduced to 0°.
7·77 at 17°·3	8·304.

Treating the mean of the values as above, the formula is

$$\lambda=8\cdot318-0\cdot032237t+0\cdot00007608t^2.$$

Arsenic.

Purified by sublimation. Small bars were cut from a comparatively solid piece and soldered to two copper wires; on account of the extreme brittleness of arsenic, the bars were placed in glass tubes closed at the ends with gypsum, through which the copper wires passed. As these were dried in a water-bath for several days, no permanent alteration of the conducting power of the bars was found after being heated in the oil-bath for two days. The values found for the conducting power of arsenic agree as well as could be expected, considering the bars were made by hand, and the metal somewhat porous. The difficulty of obtaining bars of metal of sufficient length is so great that we have been contented with two series. These are given in Table IX.

TABLE IX.

	First bar.	Second bar.
Length	50·4 millims.	55·5 millims.
Diameter	0·93 millim.	1·01 millim.

The means of the conducting powers found for each of the following temperatures were—

T.	Conducting power.		Difference.	T.	Conducting power.		Difference.
	Observed.	Calculated.			Observed.	Calculated.	
14°·20	5·0203	5·0180	+0·0023	13°·50	4·0051	4·0037	+0·0014
25·30	4·8007	4·8008	−0·0001	24·50	3·8371	3·8450	−0·0079
37·80	4·5710	4·5736	−0·0026	40·15	3·6367	3·6311	+0·0056
55·00	4·2854	4·2906	−0·0052	55·55	3·4447	3·4341	+0·0106
70·00	4·0767	4·0722	+0·0045	69·90	3·2559	3·2628	−0·0069
85·30	3·8810	3·8764	+0·0046	82·50	3·1144	3·1221	−0·0077
101·00	3·7005	3·7041	−0·0036	99·80	2·9485	2·9435	+0·0050

The formulæ deduced from the observations, and from which the conducting powers were calculated, were—

For first bar $\lambda=5\cdot3168-0\cdot021874t+0\cdot00005848t^2$.
For second bar $\lambda=4\cdot2078-0\cdot015506t+0\cdot00002843t^2$.

Taking the mean of the conducting powers at 0°, we deduce the formula for the correction of conducting power for temperature to be

$$\lambda=4{\cdot}7623-0{\cdot}018571t+0{\cdot}00004228t^2.$$

Antimony.

Purified by twice recrystallizing commercially pure tartrate of antimony and potassium, reducing by heat and re-fusing with antimonic acid. As antimony is so very brittle, it was not possible to manipulate with it in form of wire, it was therefore fused in the bowl of a tobacco-pipe, and when liquid allowed to run into the stem. After breaking off the bowl, the ends of the pipe were made so hot that the metal melted, and clean copper wires were pushed into the liquid metal, which on solidifying held them fast. The free ends of the copper wires were then soldered to the thick ones in the trough. Unfortunately in each case the copper wires in the pipe-stem became loose after heating for two or three days, and had to be therefore resoldered, so that no reliable determinations could be made as to the effect of heating to 100° for several days on the conducting power. It may be stated that the three wires lost in conducting power; but to what extent, we are of course not in a position to say. As the diameter of the pipe-stem could not be accurately determined, and as it could not be ascertained whether there were cavities in the wires (caused by contraction on cooling and crystallization) or not, the first observed conducting power was taken equal to 100. Table X. shows the results.

TABLE X.

The means of the conducting powers found for each of the following temperatures were—

First wire.				Second wire.				Third wire.			
T.	Conducting power.		Difference.	T.	Conducting power.		Difference.	T.	Conducting power.		Difference.
	Observed.	Calculated.			Observed.	Calculated.			Observed.	Calculated.	
10·00°	100·000	100·052	−0·052	8·40°	100·000	99·999	+0·001	13·80°	100·000	99·901	+0·099
26·35	94·062	93·910	+0·152	25·60	93·947	93·850	+0·097	22·30	96·378	96·514	−0·136
40·40	88·982	89·089	−0·107	42·45	88·139	88·329	−0·190	38·65	90·552	90·527	+0·025
54·55	84·633	84·664	−0·031	57·80	83·707	83·731	−0·024	53·50	85·671	85·692	−0·021
70·65	80·126	80·152	−0·026	69·45	80·691	80·517	+0·174	69·65	81·118	81·082	+0·036
83·50	77·071	76·953	+0·118	86·85	76·138	76·159	−0·021	84·45	77·480	77·454	+0·026
99·40	73·430	73·484	−0·054	101·25	72·922	72·953	−0·031	98·80	74·448	74·480	−0·032

The formulæ deduced from the observations, from which the conducting powers were calculated, were—

For first wire . $\lambda=104{\cdot}095-0{\cdot}41487t+0{\cdot}0010755t^2$.

For second wire $\lambda=103{\cdot}190-0{\cdot}38721t+0{\cdot}0008748t^2$.

For third wire . $\lambda=105{\cdot}801-0{\cdot}44541t+0{\cdot}0012995t^2$.

The observed conducting powers in this and the foregoing Table do not agree so well with the calculated as the others, on account of the temperature of the bath never being exactly the same as that of the wire; for in the one case the heat had to traverse the glass tube filled with air, in the other the thickness of the pipe-stem, before reaching the metal.

The conducting power of antimony was found equal to

	Reduced to 0°.
4·29 at 18°·7	4·6172

Using this value as before described, we obtain a formula for antimony where

$$\lambda=4{\cdot}6172-0{\cdot}018389t+0{\cdot}00004788t^2.$$

Bismuth.

Purified by reducing the basic nitrate of bismuth with lampblack. Table XI. gives the results. The wires were pressed.

TABLE XI.

	First wire.		Second wire.		Third wire.	
Length..............	117 millims.		121·4 millims.		42·5 millims.	
Diameter...........	0·596 millim.		0·596 millim.		0·217 millim.	
		Reduced to 0°.		Reduced to 0°.		Reduced to 0°.
Conducting power found before heating the wires......	1·1787 at 16°·6	1·2517	1·1036 at 18°·8	1·1773	1·2215 at 16°·6	1·2951
Conducting power after being kept at 100° for 1 day ...	1·3599 at 17·6	1·4494	1·3110 at 19·0	1·3995	1·3683 at 17·8	1·4569
Ditto, for 2 days...	1·3595 at 18·2	1·4521	1·3121 at 19·0	1·4006	1·3709 at 17·6	1·4587
Ditto, for 3 days...	1·3624 at 18·0	1·4541	1·3096 at 19·9	1·4023	1·3710 at 17·9	1·4603

The means of the conducting powers found for each of the following temperatures were—

T.	Conducting power.		Difference.	T.	Conducting power.		Difference.	T.	Conducting power.		Difference.
	Observed.	Calculated.			Observed.	Calculated.			Observed.	Calculated.	
9°·20	1·4059	1·4058	+0·0001	8°·60	1·3654	1·3641	+0·0013	9°·40	1·4129	1·4128	+0·0001
26·15	1·3226	1·3226	0·0000	24·00	1·2909	1·2935	−0·0026	25·65	1·3329	1·3339	−0·0010
39·50	1·2609	1·2614	−0·0005	38·75	1·2297	1·2287	+0·0010	43·05	1·2551	1·2538	+0·0013
57·25	1·1863	1·1858	+0·0005	55·30	1·1591	1·1593	−0·0002	57·45	1·1913	1·1912	+0·0001
68·95	1·1397	1·1397	0·0000	68·90	1·1058	1·1050	+0·0008	71·60	1·1315	1·1328	−0·0013
84·35	1·0833	1·0833	0·0000	84·00	1·0478	1·0474	+0·0004	88·60	1·0671	1·0666	+0·0005
96·35	1·0428	1·0429	−0·0001	95·90	1·0036	1·0042	−0·0006				

The formulæ deduced from the observations, by which the conducting powers were calculated, were—

For first wire . $\lambda=1{\cdot}4535-0{\cdot}0052883t+0{\cdot}00001060t^2$.

For second wire $\lambda=1{\cdot}4049-0{\cdot}0047972t+0{\cdot}000006453t^2$.

For third wire . $\lambda=1{\cdot}4603-0{\cdot}0051286t+0{\cdot}000007737t^2$.

From the above we see how bismuth increases in conducting power after being kept at 100° for one day. This increment is so rapid that it may be followed for the first two hours from five to five minutes. Wire 1 altered by one day's heating 16 per cent.; wire 2, 19 per cent.; and wire 3, 12 per cent. Wires 1 and 2 were cut from the same piece.

This behaviour explains why the conducting power of bismuth wires varies so much: for in the paper so often here alluded to, the maximum difference between twelve wires was found to be 22 per cent. In pressing the wires the heat applied to the press is never constant; so that, if pressed very warm, wires of high conducting power would probably be the result. The conducting power of bismuth was found equal to

	Reduced to 0°.
1·19 at 13°·8	1·2484

Taking the mean of the values as before, we find the formula for bismuth to be

$$\lambda=1{\cdot}2454-0{\cdot}0043858t+0{\cdot}000007134t^2.$$

Mercury.

Purified by allowing a solution of subnitrate of mercury to stand over the metal for several weeks, during which time it was often well shaken up with it. The determinations were made in a calibrated thermometer-tube, to the ends of which wide glass tubes (13 to 14 millims. wide) were fused and bent, as shown in fig. 3. Mercury prepared at different times was used for the determinations. For the experiments, the tube was filled with hot mercury, and its resistance was determined when cold. This was twice repeated; and the resistance being found the same each time, it was assumed that the tube filled in this manner did not contain air-bubbles; this is also proved by the close agreement of the formulæ found in the two cases for the variation of the conducting power at higher temperatures; for if in either case air-bubbles had been present, the formulæ must have differed to a much greater extent, as it can scarcely be assumed that in the two cases the bubbles were equal in bulk. The mercury was connected with the apparatus by amalgamated copper wires (4 to 5 millims. thick). Table XII. shows the results obtained.

Fig. 3.

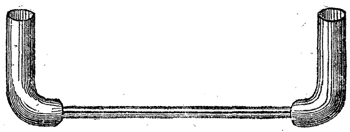

TABLE XII.

Length ...=	269 millims.
Diameter =	1·424 millim.

The means of the conducting powers found for each of the following temperatures were—

T.	Conducting power.		Difference.	T.	Conducting power.		Difference.
	Observed.	Calculated.			Observed.	Calculated.	
0°	1·6521	1·6530	−0·0009	0°	1·6529	1·6533	−0·0004
20·55	1·6276	1·6272	+0·0004	20·95	1·6272	1·6268	+0·0004
40·45	1·6003	1·6011	−0·0008	39·92	1·6010	1·6018	−0·0008
59·82	1·5750	1·5746	+0·0004	60·40	1·5741	1·5738	+0·0003
79·78	1·5465	1·5462	+0·0003	80·70	1·5454	1·5450	+0·0004
99·90	1·5162	1·5164	−0·0002	99·30	1·5174	1·5177	−0·0003

The formulæ deduced from the observations, by which the conducting powers were calculated, were—

For the first series . $\lambda=1·6530-0·0012240t-0·000001434t^2$.

For the second series $\lambda=1·6533-0·0012370t-0·000001297t^2$.

The value found for the conducting power of mercury was

	Reduced to 0°.
1·63 at 22°·8	1·6588

Taking the mean of the values as before, we find the formula for mercury to be

$$\lambda=1·656-0·0012326t-0·000001368t^2.$$

Tellurium.

Purified by dissolving the commercial metal in aqua regia, evaporating to dryness with excess of carbonate of sodium, fusing the residue, which was dissolved in water, and nitrate of barium added to precipitate any selenium present. The filtrate was evaporated to dryness with hydrochloric acid in excess, the residue dissolved in water, and precipitated by sulphurous acid.

On account of the low conducting power of tellurium, small bars of about 15 millims. in length and 3–5 millims. in diameter were used for the experiments. Bars I. and II. are of the same preparation. As the bars could not be accurately measured, we have called the first observed conducting power 100 in each case. Table XIII. gives the results.

Table XIII.

	Bar I.		Bar II.		Bar III.	
Conducting power found before heating the bars to 100°.	100 at 16°·4	......	100 at 15°·9	......	100 at 15°·6	
Ditto, after being kept at 100° for 1 day..................	79·145 at 15·4	......	86·50 at 13·0	......	83·16 at 12·6	
Ditto, for 2 days	45·449 at 16·0	......	76·51 at 13·6	......	69·23 at 14·1	
Ditto, for 3 days	22·378 at 16·0	......	70·43 at 16·4	......	61·25 at 16·9	
Ditto, for 4 days	16·129 at 15·0	......	65·68 at 16·6	......	54·92 at 17·2	
Ditto, for 5 days	8·068 at 15·2	......	61·68 at 16·8	......	50·69 at 17·8	
Ditto, for 6 days	6·989 at 15·0	......	56·85 at 17·2	......	46·11 at 16·6	
Ditto, for 7 days	5·781 at 14·2	......	54·88 at 16·6	......	42·35 at 16·4	
Ditto, for 8 days	4·830 at 15·5	......	51·33 at 16·1	......	38·64 at 15·8	
Ditto, for 9 days	4·621 at 16·8	......	46·27 at 15·6	......	35·31 at 16·2	
Ditto, for 10 days	4·302 at 15·3	......	45·26 at 16·2	......	33·50 at 16·4	
Ditto, for 11 days	4·181 at 15·0	Reduced to 0°.	42·10 at 16·6	......	30·97 at 16·8	
Ditto, for 12 days	4·1371 at 16·1	3·7662	41·31 at 17·4	......	29·98 at 18·2	
Ditto, for 13 days	4·0844 at 14·6	3·7646	39·28 at 16·0	......	28·21 at 15·6	
Ditto, for 14 days	....	......	37·72 at 17·1	......	26·73 at 16·8	
Ditto, for 15 days	....	......	35·35 at 15·4	......	23·68 at 15·4	
Ditto, for 16 days	....	......	32·23 at 15·6	......	19·43 at 16·0	
Ditto, for 17 days	....	......	29·92 at 17·0	......	16·65 at 17·6	
Ditto, for 18 days	....	......	28·11 at 17·6	......	14·43 at 17·0	
Ditto, for 19 days	....	......	26·25 at 16·2	......	12·59 at 16·4	
Ditto, for 20 days	....	......	25·54 at 13·0	......	11·68 at 14·4	
Ditto, for 21 days	....	......	24·12 at 13·4	......	10·34 at 13·6	
Ditto, for 22 days	....	......	23·29 at 12·8	......	9·32 at 13·6	
Ditto, for 23 days	....	......	22·00 at 13·6	......	8·64 at 14·1	
Ditto, for 24 days	....	......	21·45 at 14·1	......	7·92 at 13·8	
Ditto, for 25 days	....	......	20·86 at 14·6	......	7·36 at 14·6	
Ditto, for 26 days	....	......	20·17 at 15·8	......	6·97 at 14·2	
Ditto, for 27 days	....	......	19·74 at 16·0	......	6·66 at 14·8	
Ditto, for 28 days	....	......	19·68 at 13·0	......	6·52 at 15·8	
Ditto, for 29 days	....	......	19·65 at 12·2	Reduced to 0°.	6·35 at 15·8	
Ditto, for 30 days	....	......	19·633 at 12·0	20·145	6·12 at 12·6	
Ditto, for 31 days	....	......	19·633 at 11·9	20·137	6·04 at 12·0	Reduced to 0°.
Ditto, for 32 days	....	......	....	......	6·0330 at 11·8	5·6134
Ditto, for 33 days	....	......	....	......	6·0602 at 12·2	5·6191

The means of the conducting powers for each of the following temperatures were—

T.	Conducting power.		Difference.	T.	Conducting power.		Difference.	T.	Conducting power.		Difference.
	Observed.	Calculated.			Observed.	Calculated.			Observed.	Calculated.	
10°·40	3·9566	3·9575	−0·0009	3°·70	19·976	19·972	+0·004	4°·20	5·6646	5·6797	−0·0151
25·25	4·5212	4·5240	−0·0028	11·80	19·650	19·660	−0·010	22·80	6·7456	6·7392	+0·0064
38·85	5·3940	5·3846	+0·0094	22·40	19·477	19·466	+0·011	39·40	8·6703	8·5781	+0·0922
55·10	6·9089	6·9060	+0·0029	29·40	19·468	19·473	−0·005	53·90	10·8480	10·9426	−0·0946
70·45	8·8706	8·9019	−0·0313	29·40	19·468	19·496	−0·028	69·50	14·2472	14·3441	−0·0969
83·10	11·0316	11·0018	+0·0298	34·60	19·546	19·544	+0·002	83·60	18·4043	18·2406	+0·1637
99·40	14·3690	14·3764	−0·0074	39·70	19·689	19·653	+0·036	98·80	23·3209	23·3769	−0·0560
				55·30	20·513	20·464	+0·049				
				69·20	21·825	21·942	−0·117				
				86·40	25·096	25·019	+0·077				
				103·60	29·765	29·784	−0·019				

The formulæ deduced from the observations, and from which the conducting powers were calculated, were—

For first bar . . . . $\lambda=3\cdot7619+0\cdot011614t+0\cdot0006598t^2+0\cdot000002994t^3$.

For second bar to 29·4 . . $\lambda=20\cdot162-0\cdot055338t+0\cdot001085t^2$.

For second bar from 29·4 to 100 $\lambda=20\cdot014-0\cdot029569t+0\cdot00009390t^2+0\cdot000010635t^3$.

For third bar . . . . . . $\lambda=5\cdot5752+0\cdot019274t+0\cdot0013235t^2+0\cdot000003088t^3$.

From the above Table we learn that tellurium behaves in a very different manner from the other metals; for it will be seen how very much the conducting power decreases after it has been heated to 100° for some days, and how different is the time required before the conducting power of the different bars becomes constant, or, in other words, until the heating of the bars to 100° causes no further permanent alteration in the conducting power. Bar I. required 13 days; bar II. 32; bar III. 33. The first observed conducting power being taken equal to 100, bar I. is reduced to 4, bar II. to 19·6, and bar III. to 6. If we now look at the determinations of the conducting power at different temperatures of the three bars, we are struck at the great want of concordance in the results. With the first series we observe that the conducting power increases rapidly as the temperature rises; with the second it decreases with the rise of temperature to 29°·4, from which point it increases rapidly, as with bar I.; the third behaves as the first.

Bar I. showed no apparent difference in crystalline structure after being heated; it was thought very probable that the crystalline structure might have been altered by heating, and thus caused the enormous change in conducting power. The three bars, when first heated, behaved as metal to 70° or 80°, that is to say, they lost in conducting power up to that temperature, where it then began to increase. The temperature of this turning-point became lower after each day's heating, until, as in bars I. and II., it is below the lowest temperature at which observations were made.

The behaviour, therefore, of tellurium is intermediate between that of the metal and that of the metalloid; for, according to HITTORF*, selenium increases rapidly in conducting power with the temperature. Graphite and gas-coke † behave in the same manner; and BECQUEREL‡ found that gases when heated conduct better than when cold. From these facts we learn another marked difference in the physical properties of the metals and metalloids, viz. *that the metals lose in conducting power with an increase of temperature, whereas under the same circumstances the metalloids gain.*

In order to be better able to compare the results obtained with the pure metals, we give the following Tables. Table XIV. contains all the formulæ deduced from the observations by the method of least squares, with the conducting power of each metal taken =100 at 0°; Table XV. the mean of the formulæ found for each metal.

* POGGENDORFF'S 'Annalen,' vol. lxxxvi. p. 214.

† Philosophical Transactions, 1858, p. 386.

‡ Ann. de Chim. et de Phys. (iii.) vol. xxxix. p. 388.

TABLE XIV.

Silver	I.	Hard drawn ...	$\lambda=100-0{\cdot}38394\ t+0{\cdot}0009723\ t^2$
		Annealed	$\lambda=100-0{\cdot}37725\ t+0{\cdot}0008900\ t^2$
	II.	Hard drawn ...	$\lambda=100-0{\cdot}38915\ t+0{\cdot}0010472\ t^2$
		Annealed	$\lambda=100-0{\cdot}39287\ t+0{\cdot}0010625\ t^2$
	III.	Hard drawn ...	$\lambda=100-0{\cdot}37544\ t+0{\cdot}0009724\ t^2$
		Annealed	$\lambda=100-0{\cdot}37855\ t+0{\cdot}0009647\ t^2$
Copper	I.	Hard drawn ...	$\lambda=100-0{\cdot}37351\ t+0{\cdot}0007716\ t^2$
		Annealed	$\lambda=100-0{\cdot}37291\ t+0{\cdot}0007781\ t^2$
	II.	Hard drawn ...	$\lambda=100-0{\cdot}39173\ t+0{\cdot}0009394\ t^2$
		Annealed	$\lambda=100-0{\cdot}38797\ t+0{\cdot}0008986\ t^2$
	III.	Hard drawn ...	$\lambda=100-0{\cdot}39639\ t+0{\cdot}0010173\ t^2$
		Annealed	$\lambda=100-0{\cdot}39954\ t+0{\cdot}0010003\ t^2$
Gold	I.	Hard drawn ...	$\lambda=100-0{\cdot}36405\ t+0{\cdot}0008181\ t^2$
		Annealed	$\lambda=100-0{\cdot}37017\ t+0{\cdot}0008526\ t^2$
	II.	Hard drawn ...	$\lambda=100-0{\cdot}35877\ t+0{\cdot}0007807\ t^2$
	III.	Hard drawn ...	$\lambda=100-0{\cdot}37551\ t+0{\cdot}0009309\ t^2$
		Annealed	$\lambda=100-0{\cdot}36877\ t+0{\cdot}0008390\ t^2$
Zinc	I.	....	$\lambda=100-0{\cdot}36845\ t+0{\cdot}0008147\ t^2$
	II.	....	$\lambda=100-0{\cdot}37911\ t+0{\cdot}0009058\ t^2$
	III.	....	$\lambda=100-0{\cdot}36385\ t+0{\cdot}0007618\ t^2$
Cadmium	I.	....	$\lambda=100-0{\cdot}36745\ t+0{\cdot}0007220\ t^2$
	II.	....	$\lambda=100-0{\cdot}39915\ t+0{\cdot}0010511\ t^2$
	III.	....	$\lambda=100-0{\cdot}33953\ t+0{\cdot}0004995\ t^2$
Tin	I.	....	$\lambda=100-0{\cdot}35867\ t+0{\cdot}0006205\ t^2$
	II.	....	$\lambda=100-0{\cdot}36730\ t+0{\cdot}0006709\ t^2$
	III.	....	$\lambda=100-0{\cdot}35492\ t+0{\cdot}0005493\ t^2$
Lead	I.	....	$\lambda=100-0{\cdot}38561\ t+0{\cdot}0008989\ t^2$
	II.	....	$\lambda=100-0{\cdot}38553\ t+0{\cdot}0008788\ t^2$
	III.	....	$\lambda=100-0{\cdot}39153\ t+0{\cdot}0009661\ t^2$
Arsenic	I.	....	$\lambda=100-0{\cdot}41141\ t+0{\cdot}0011000\ t^2$
	II.	....	$\lambda=100-0{\cdot}36851\ t+0{\cdot}0006757\ t^2$
Antimony	I.	....	$\lambda=100-0{\cdot}39855\ t+0{\cdot}0010332\ t^2$
	II.	....	$\lambda=100-0{\cdot}37524\ t+0{\cdot}0008477\ t^2$
	III.	....	$\lambda=100-0{\cdot}42099\ t+0{\cdot}0012283\ t^2$
Bismuth	I.	....	$\lambda=100-0{\cdot}36383\ t+0{\cdot}0007293\ t^2$
	II.	....	$\lambda=100-0{\cdot}34146\ t+0{\cdot}0004593\ t^2$
	III.	....	$\lambda=100-0{\cdot}35120\ t+0{\cdot}0005298\ t^2$
Mercury	I.	....	$\lambda=100-0{\cdot}074047t+0{\cdot}00008672t^2$
	II.	....	$\lambda=100-0{\cdot}074820t+0{\cdot}00007844t^2$

TABLE XV.

Silver	$\lambda=100-0{\cdot}38287t+0{\cdot}0009848t^2$
Copper..................	$\lambda=100-0{\cdot}38701t+0{\cdot}0009009t^2$
Gold	$\lambda=100-0{\cdot}36745t+0{\cdot}0008443t^2$
Zinc.....................	$\lambda=100-0{\cdot}37047t+0{\cdot}0008274t^2$
Cadmium	$\lambda=100-0{\cdot}36871t+0{\cdot}0007575t^2$
Tin	$\lambda=100-0{\cdot}36029t+0{\cdot}0006136t^2$
Lead	$\lambda=100-0{\cdot}38756t+0{\cdot}0009146t^2$
Arsenic	$\lambda=100-0{\cdot}38996t+0{\cdot}0008879t^2$
Antimony	$\lambda=100-0{\cdot}39826t+0{\cdot}0010364t^2$
Bismuth	$\lambda=100-0{\cdot}35216t+0{\cdot}0005728t^2$
Mean of the above ...	$\lambda=100-0{\cdot}37647t+0{\cdot}0008340t^2$

From the last Table we see how closely the values found for the constants y or z agree together; and to show this more clearly, the conducting powers calculated from these formulæ for 0°, 20°, 40°, 60°, 80°, and 100° are given in Table XVI., together with values calculated from the mean of all the formulæ.

TABLE XVI.

T.	Silver.	Copper.	Gold.	Zinc.	Cadmium.	Tin.	Lead.	Arsenic.	Antimony.	Bismuth.	Calculated values from mean of formulæ.	Greatest difference from mean.
0°	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	0·00
20	92·74	92·62	92·99	92·92	92·93	93·04	92·62	92·56	92·45	93·18	92·80	0·38
40	86·26	85·96	86·65	86·50	86·46	86·51	85·96	85·82	85·73	86·83	86·27	0·56
60	80·57	80·01	80·98	80·75	80·60	80·59	80·04	79·80	79·84	80·93	80·41	0·61
80	75·67	74·80	76·01	75·66	75·35	75·10	74·85	74·50	74·77	75·49	75·23	0·78
100	71·56	70·31	71·70	71·23	70·70	70·11	70·39	69·88	70·54	70·51	70·69	1·01

Again, in Table XVII., we give the conducting power of the metals compared with hard-drawn silver wire at 0°=100, first at 0° and then at 100°, and, lastly, taking silver at 100°=100.

TABLE XVII.

	Conducting power		Taking silver =100 at 100°.
	At 0°.	At 100°.	
Silver (hard drawn)	100·00	71·56	100·00
Copper (hard drawn)	99·95	70·27	98·20
Gold (hard drawn)	77·96	55·90	78·11
Zinc	29·02	20·67	28·89
Cadmium	23·72	16·77	23·44
Tin	12·36	8·67	12·12
Lead	8·32	5·86	8·18
Arsenic	4·76	3·33	4·65
Antimony	4·62	3·26	4·55
Bismuth	1·245	0·878	1·227

From these Tables we think we may deduce the law, that *all pure metals in a solid state vary in conducting power between* 0° *and* 100° *to the same extent*, more especially as we find that wires of one and the same metal show almost the same differences as were found between the mean results obtained for the different metals. In Table XVIII. two examples of this are given.

TABLE XVIII.

T.	Copper.		Cadmium.	
	I. annealed.	III. annealed.	II.	III.
0°	100·00	100·00	100·00	100·00
20	92·85	92·41	92·44	93·41
40	86·33	85·62	85·72	87·22
60	80·43	79·63	79·84	81·42
80	75·15	74·44	74·79	76·03
100	70·49	70·05	70·60	71·04

In Table XIX. the resistances of the copper wires 1, 2, and 3, and those calculated from the mean of all the formulæ, are given; we do this to show that the resistance of a wire does not increase in direct ratio to the temperature (as stated by some experimenters in this direction), but, on the contrary, the formula for correction of the resistance of a wire for temperature is

$$r=x+yt+zt^2,$$

and not

$$r=x+yt.$$

TABLE XIX.

First wire, hard drawn.			First wire, annealed.			Second wire, hard drawn.			Second wire, annealed.		
T.	Resistance.	Increase of resistance for 1°.	T.	Resistance.	Increase of resistance for 1°.	T.	Resistance.	Increase of resistance for 1°.	T.	Resistance.	Increase of resistance for 1°.
0°	98·382	......	0°	98·241	......	0°	98·412	......	0°	97·902	......
16·86	104·74	0·3771	17·0	104·67	0·3782	19·17	105·98	0·3948	18·96	105·28	0·3891
29·88	109·81	0·3825	29·63	109·54	0·3813	30·95	110·88	0·4028	31·86	110·59	0·3982
51·03	118·72	0·3985	50·22	118·08	0·3950	48·53	118·32	0·4102	52·05	119·08	0·4069
69·52	126·59	0·4057	69·60	126·23	0·4021	69·22	127·16	0·4153	70·27	126·85	0·4119
83·77	132·60	0·4085	83·42	132·21	0·4072	83·77	133·31	0·4166	83·81	132·58	0·4138
98·60	139·22	0·4142	99·37	139·10	0·4112	99·00	139·80	0·4181	99·57	139·36	0·4164

Third wire, hard drawn.			Third wire, annealed.			Resistance calculated from the mean of the six formulæ found for copper.			Resistance calculated from the mean of all the formulæ.		
0°	99·384	......	0°	97·806	......	0°	100	......	0°	100	......
12·65	104·42	0·3981	13·45	103·14	0·3966	20	107·97	0·3985	20	107·76	0·3880
25·61	109·82	0·4075	26·15	108·41	0·4055	40	116·33	0·4082	40	115·91	0·3977
39·52	115·72	0·4134	39·35	113·99	0·4113	60	124·98	0·4163	60	124·36	0·4060
53·92	121·85	0·4167	55·50	120·95	0·4170	80	133·69	0·4211	80	132·92	0·4115
69·90	128·54	0·4171	69·90	127·00	0·4176	100	142·22	0·4222	100	141·46	0·4146
84·87	134·82	0·4175	84·67	133·25	0·4186						
99·92	140·94	0·4159	99·05	139·32	0·4190						

The calculations from a formula of four or more terms, as

$$\lambda=x+yt+zt^2+at^3,$$

agree better with the observed values than that of three. An example of this is shown in Table XX., where the formulæ, deduced from observations made with a hard-drawn wire (of course previously heated to 100° for several days), of three and four terms, with the differences, are given.

TABLE XX.

T.	Conducting power. Observed.	Conducting power. Calculated from formula of three terms.	Difference.	Conducting power, calculated from formula of four terms.	Difference.
10°·9	95·169	95·134	+0·035	95·166	+0·003
30·1	88·537	88·588	−0·051	88·534	+0·003
49·5	82·610	82·627	−0·017	82·605	+0·005
69·0	77·320	77·297	+0·023	77·304	−0·014
82·8	73·976	73·926	+0·050	73·966	+0·010
97·9	70·579	70·619	−0·040	70·580	−0·001

The formula of three terms, deduced from the observations, was

$$\lambda=99{\cdot}137-0{\cdot}37675t+0{\cdot}0008728t^2,$$

and that of four terms

$$\lambda=99{\cdot}307-0{\cdot}39301t+0{\cdot}0012318t^2-0{\cdot}000002193t^3.$$

From the above it will be seen how much better the observed values agree with the formula of four terms. We have, however, contented ourselves with a formula of three terms, as the conducting powers calculated from it agree with those observed to values corresponding to 0°·1 or 0°·2, and as the calculations for a formula of four terms would have increased the labour of the research to a very great extent. But it may be asked how it happens that the formulæ obtained for wires of one and the same metal vary so much, in fact, show differences almost equal to the mean of those deduced for the different metals?

That this is not due to errors of observation we have repeatedly satisfied ourselves; for compare only the formulæ of the hard-drawn (or rather partially annealed) and the annealed wires, and see how well they agree with each other. It appears, however, to be probably due to the molecular arrangement of the wires being different in each case. Take, for instance, the copper wires experimented with: wire 1 increased in conducting power by heating to 100° for several days, almost to the same extent as if it had been annealed, wire 2 partially so, and wire 3 hardly at all; and here it may be mentioned that silver and copper wires become softer and lose their elasticity, whereas gold does not seem to be annealed at all after having been kept at 100° for several days. Again, take cadmium, where we know that the wires become brittle and crystalline at 80°, and we find the formulæ vary more than those of any other metals; and, lastly, look at the results obtained with bismuth and tellurium, and there can be little doubt that the reason why the formulæ of the wires and bars of the same metal do not agree together is that the molecular arrangement is different in each; and that this is the cause of the differences in the formulæ, we may also assume from the fact that, when the wires on being heated do not at all or only to a very slight degree permanently alter in their conducting power, when cooled again, then the formulæ of wires of the same metal agree very closely with each other. Compare, for instance, those of lead, tin, mercury, &c.

The mean of the conducting powers given in the Tables agrees very well with the mean of the former determinations made with wires of metals of different preparation to that of those used for the experiments described in this paper.

The following questions have suggested themselves during the foregoing investigation, the answers to which we reserve for ourselves. It is intended to make them the subjects of short communications, which from time to time will be laid before the Royal Society:—

1. Will a hard-drawn wire become partially annealed by age? and, on the other hand, will an annealed wire become partially hard drawn?

2. Will bismuth or tellurium return to their original conducting power in time, or by exposure to intense cold?

3. Whether by heating tellurium or any of the metals to a higher temperature than 100° we should not arrive at the same result in a much shorter time.

4. What are the thermo-electric properties of bismuth, antimony, tellurium, &c. after being kept at 100° for several days? will they not have altered? It is remarkable that bismuth, which stands at one end of the thermo-electric series, should gain in conducting power after heating for some days, and that antimony and tellurium, at the other end of the series, should lose, the one slightly, the other, with a much higher thermo-electric number, to a very great extent.

5. Will tellurium conduct better in a melted state than the solid?

6. What law do the alloys follow as regards the influence of temperature on their conducting power?