X. *On the Electric Conducting Power of Alloys.* By A. Matthiessen, *Ph.D.* *Communicated by Professor* Wheatstone.

Received November 17,—Read December 22, 1859.

The method employed for the following determinations is described in the Philosophical Magazine (February 1857). The precautions taken were the following:—

1. Almost all the wires were determined in naphtha (rock-oil), and the temperature observed.

2. They were all soldered to two thick copper wires, whose resistances were known and brought into the calculations.

3. Two separate wires of each alloy, of different diameters, were generally pressed or drawn (as it was thought possible that in pressing out the wires they might contain alloys of different compositions, as, for instance, when the amalgams are pressed, we find that at first almost pure mercury comes out of the small hole), and two determinations were made with wires cut from the first, and a third from the second wire.

4. The higher bismuth alloys were pressed in very fine wires, about 0·2 millim. diameter, in order to obtain concordant results*.

5. The diameters of the wires were measured at each end, and generally also in the middle; pieces of the wire, after the resistance had been determined, being bent at the ends, so that they were at right angles to each other, and to the intermediate portion of the wire, in order that the diameter might be measured in two directions, which are also at right angles with each other, by laying the wire with its two ends vertical in succession. The brittle wires were broken in short lengths, a number of them measured, and the mean taken of the values so found.

6. A number of normal wires of different lengths were used, so that when the resistances were great, equally accurate results could be obtained.

7. Those bismuth-alloys which expand on cooling, so much that the liquid metals break through the crust and form globules on the surface, were recast in small pieces, so that one whole piece was used for pressing the wire; for it is very possible that the globules which form on the surface have a different composition from the part which first solidifies.

All the wires which were not pressed were hard drawn, and they were compared with a hard drawn pure silver wire, whose conducting power, taken at 0°†, =100.

To save space only the mean of the three determinations will be given; the bismuth-tin series, however, is given in full, and serves as a fair specimen of the accuracy of the experiments; and when no concordant results could be obtained, a mark (+) will be

* Philosophical Transactions, 1858.

† All the temperatures are in the Centigrade scale.

put to the alloy, and the value for its conducting power is the mean of several determinations. A greater accuracy than that which has been obtained could not be expected, on account of the great difficulty of pressing or drawing a wire perfectly round and of a homogeneous composition. Those alloys which were drawn into wire will be underlined, and when the whole series was drawn, it will be mentioned in a foot note.

TABLE I.

Bismuth-Tin Series.

Alloy.	Conducting power, I. wire.	Temperature.	Conducting power, II. wire.	Temperature.	Conducting power, III. wire.	Temperature.	Mean of	
							Conducting power.	Temperature.
Bi_{200} Sn	1·08	25·0	1·08	25·2	1·07	25·3	1·08	25·2
Bi_{90} Sn	0·420	27·0	0·414	27·2	0·421	27·2	0·418	27·1
Bi_{60} Sn	0·262	26·2	0·267	26·4	0·262	26·4	0·264	26·3
Bi_{44} Sn	0·246	26·7	0·244	26·9	0·244	26·9	0·245	26·8
Bi_{30} Sn	0·256	23·6	0·253	23·8	0·256	24·8	0·255	24·1
Bi_{10} Sn	0·352	24·4	0·357	24·8	0·360	24·8	0·356	24·7
Bi_{6} Sn	0·513	29·6	0·515	29·8	0·510	29·7	0·513	29·7
Bi_{4} Sn	0·630	29·4	0·629	29·6	0·637	29·8	0·632	29·6
Bi_{2} Sn	1·03	30·0	1·02	29·9	1·06	29·9	1·04	29·4
Bi Sn	2·22	28·3	2·23	28·5	2·28	28·7	2·24	28·5
Bi Sn_{2}.........	3·93	25·6	3·97	25·7	3·97	25·8	3·96	25·7
Bi Sn_{4}.........	5·84	23·0	5·85	24·2	5·83	24·4	5·84	23·8
Bi Sn_{6}.........	7·02	27·8	7·12	28·0	6·99	28·0	7·04	27·9
Bi Sn_{8}.........	7·79	24·8	7·82	24·8	7·84	25·0	7·82	24·9
Bi Sn_{44}	10·22	24·0	10·43	24·4	10·57	24·3	10·41	24·2

Determinations made with pressed and drawn lead wires gave exactly the same values.

The following alloys, viz. the two last silver-lead, the two last silver-tin, the two last gold-tin, and all the gold- and silver-copper alloys, were made in the manner which will be described in a paper "On the Conducting Powers of Copper," &c., by Dr. M. HOLZMANN and myself.

The alloys used for the determinations were those whose specific gravities have been determined*; and the metals composing them may be classed under two heads, viz.—

Class A. Those metals which, when alloyed with one another, conduct electricity in the ratio of their relative volumes.

Class B. Those metals which, when alloyed with one of the metals belonging to Class A, or with one another, do *not* conduct electricity in the ratio of their relative volumes, but *always* in a lower degree than the mean of their volumes.

To Class A. belong lead, tin, zinc, and cadmium.

To Class B. belong bismuth, mercury, antimony, platinum, palladium, iron, aluminium, gold, copper, silver, and in all probability most of the other metals.

I shall now say a few words—

1. On the conducting power of the metals employed.

2. On the conducting power of the alloys made of the metals of Class A. with one another.

* On the Specific Gravity of Alloys in this volume, p. 177.

3. On that of alloys made of the metals of Class A. with those of Class B.
4. On that of alloys made of the metals of Class B. with each other.
5. General conclusions.

1. *On the Conducting Power of the Metals employed.*

They have all been redetermined, and the values found the same as those given in my paper "On the Electric Conducting Power of the Metals*," with the exception of gold (see Appendix at the end of this paper) and copper ("On the Electric Conducting Power of Copper," &c.). These values are given in Table II.

TABLE II.

Specific gravities used for the calculation of the result.	Metal.	Conducting power.	Equivalent used.
10·468	Silver	100 at 0°	108
8·921 †	Copper	93·16 at 19·4	
19·265	Gold	72·88 at 21·3	197
——	Aluminium.........	33·76 at 19·6	
7·148 ‡	Zinc	27·39 at 17·6	32·6
8·655	Cadmium	22·10 at 18·8	56·0
——	Iron §	14·14 at 20·4	
——	Palladium	12·64 at 17·2	
7·294	Tin	11·45 at 21·0	58
——	Platinum	10·53 at 20·7	
11·376	Lead	7·77 at 19·3	103·7
6·713	Antimony	4·29 at 18·7	122·3
13·573	Mercury...........	1·63 at 22·8	100
9·822	Bismuth	1·19 at 13·8	208

2. *On the Conducting Power of the Alloys made of Metals belonging to Class A. with one another.*

The mean of the three determinations found for the conducting power of these alloys is given in Table III., and also their calculated conducting powers, supposing that the conducting powers of the metals employed take part in that of the alloy in the ratio of their relative volumes ||.

* Philosophical Transactions, 1858.

† Taken from GMELIN's 'Chemistry,' as no concordant results could be obtained.

‡ Prepared by distilling zinc which contained no arsenic. Three determinations, the pieces being re-fused between each, gave $\left\{\begin{array}{ll} 7\cdot144 & 15^{\circ}\cdot5 \\ 7\cdot150 & 14^{\circ}\cdot4 \\ 7\cdot149 & 15^{\circ}\cdot0 \end{array}\right\}$ mean 17·148 at 15°.

§ The iron used in making the alloys was precipitated galvano-plastically by a very weak current from a solution of pure protosulphate of iron.

|| $P=\frac{vc+v'c'}{v+v'}$, where P= conducting power of the alloy.

v and v'= the volumes of the two metals used.

c and c'= their respective conducting powers.

Table III.

Lead-Tin Series.

Alloy.	Volume per cent.	Mean of		Calculated conducting power from the	
		Conducting power.	Temperature.	Volume.	Diff.
	Pb				
$Pb_6\ Sn$	87·31	8·13	18·6°	8·22	−0·09
$Pb_4\ Sn$	82·09	8·28	9·1	8·43	−0·15
$Pb_2\ Sn$	69·63	8·71	16·0	8·89	−0·18
$Pb\ Sn$	53·41	9·29	15·0	9·48	−0·19
$Pb\ Sn_2$	36·43	10·15	15·9	10·11	+0·04
$Pb\ Sn_4$	22·28	10·57	16·2	10·63	−0·06
$Pb\ Sn_6$	16·04	10·78	18·6	10·86	−0·08

Tin-Cadmium Series.

	Sn				
$Sn_6\ Cd$	88·06	12·72	22·1	12·72	
$Sn_4\ Cd$	83·10	13·23	22·3	13·25	−0·02
$Sn_2\ Cd$	71·08	14·44	20·2	14·53	−0·09
$Sn\ Cd$	55·14	16·14	20·9	16·23	−0·09
$Sn\ Cd_2$	38·06	18·36	19·6	18·05	+0·31
$Sn\ Cd_4$	23·50	19·62	20·3	19·60	+0·02
$Sn\ Cd_6$	17·00	20·42	20·5	20·29	+0·13

Tin-Zinc Series.

	Sn				
$Sn_6\ Zn$	91·28	12·66	21·3	12·84	−0·18
$Sn_4\ Zn$	87·46	13·32	20·0	13·45	−0·14
$Sn_2\ Zn$	77·71	15·28	20·0	15·00	+0·28
$Sn\ Zn$	63·56	17·35	19·9	17·26	+0·09
$Sn\ Zn_2$	46·58	19·67	21·1	19·96	−0·29
$Sn\ Zn_4$	30·36	22·28	20·1	22·55	−0·17

Cadmium-Zinc Series.

	Cd				
$Cd_6\ Zn$	89·49	22·48	19·4	22·65	−0·17
$Cd_4\ Zn$	85·02	22·86	20·3	22·90	−0·10
$Cd_2\ Zn$	73·94	23·45	21·3	23·48	−0·03
$Cd\ Zn$	58·66	23·87	22·3	24·29	−0·42
$Cd\ Zn_2$	41·50	24·13	22·2	25·19	−1·06
$Cd\ Zn_4$	26·19	25·15	20·3	26·00	−0·85
$Cd\ Zn_6$	19·12	25·86	20·0	26·38	−0·52

Lead-Cadmium Series.

	Pb				
$Pb_6\ Cd$	89·43	8·38	21·9	9·29	−0·91
$Pb_4\ Cd$	84·93	8·99	23·0	9·93	−0·94
$Pb_2\ Cd$	73·81	10·20	18·5	11·52	−1·32
$Pb\ Cd$	58·49	12·61	21·8	13·72	−1·11
$Pb\ Cd_2$	41·33	14·63	21·2	16·18	−1·55
$Pb\ Cd_4$	26·05	17·70	20·7	18·37	−0·67
$Pb\ Cd_6$	19·02	18·98	21·4	19·38	−0·40

Although the values found for some of the alloys of cadmium-zinc and lead-cadmium do not agree exactly with their calculated conducting powers, yet we see from their curves which are drawn on Plate V.*, that they do not vary much from straight lines, and we shall see further on that we cannot group them with either of the other classes.

3. *On the Conducting Power of Alloys made from the Metals belonging to Class A. with those of Class B.*

The values found for the alloys of this class are given in Table IV., together with their calculated conducting powers.

TABLE IV.

Bismuth-Lead Series.

Alloy.	Volume per cent.	Mean of Conducting power.	Mean of Temperature.	Calculated conducting power from the volume.
	Bi		°	
Bi_{160} Pb	99·73	0·904	25·8	1·208
Bi_{125} Pb	99·66	0·610	23·8	1·213
Bi_{100} Pb	99·57	0·428	24·8	1·218
Bi_{85} Pb	99·50	0·310	25·6	1·223
Bi_{70} Pb	99·39	0·291	25·0	1·23
Bi_{48} Pb	99·11	0·270	21·3	1·25
Bi_{30} Pb	98·59	0·261	22·9	1·28
Bi_{24} Pb	98·24	0·257	24·1	1·31
Bi_{20} Pb	97·89	0·271	24·0	1·33
Bi_{14} Pb	97·01	0·289	23·9	1·39
Bi_{12} Pb	96·54	0·303	23·5	1·42
Bi_{10} Pb	95·87	0·313	21·3	1·46
Bi_8 Pb	94·89	0·357	22·6	1·53
Bi_6 Pb	93·31	0·405	21·5	1·63
Bi_4 Pb	90·28	0·521	20·0	1·83
Bi_2 Pb	82·29	0·859	19·9	2·35
Bi Pb	69·91	1·41	19·2	3·17
Bi Pb_2	53·74	2·09	22·2	4·23
Bi Pb_4	36·74	2·87	22·5	5·35
Bi Pb_6	27·91	3·47	21·3	5·93
Bi Pb_8	22·50	4·02	21·7	6·29
Bi Pb_{10}	18·85	4·35	20·9	6·53
Bi Pb_{24}	8·83	5·55	24·4	7·19
Bi Pb_{100}	2·27	7·03	24·0	7·62

Antimony-Lead Series.

	Sb			
Sb_2 Pb	80·00	2·86	24·2	4·99
Sb Pb	66·67	3·31	26·3	5·45
Sb Pb_2	50·00	3·93	23·4	6·03
Sb Pb_4	33·33	4·72	24·1	6·61
Sb Pb_6	25·00	5·52	26·1	6·90
Sb Pb_{10}	16·66	6·03	25·4	7·19
Sb Pb_{20}	9·09	6·64	25·5	7·45
Sb Pb_{50}	3·85	7·09	23·7	7·64

* The dots on the lines indicate the points at which the experiments were tried.

TABLE IV. (continued.)

Lead-Gold Series.

Alloy.	Volume per cent.	Mean of		Calculated conducting power from the volume.
		Conducting power.	Temperature.	
	Pb		°	
Pb_{20} Au	94·69	5·84	25·4	11·23
Pb_{10} Au	89·91	4·31	23·0	14·34
Pb_8 Au	87·70	3·76	26·1	15·78
Pb_6 Au	84·25	2·83	19·7	18·03
Pb_4 Au	78·10	3·01	22·3	22·04
Pb_2 Au	64·07	3·59	16·8	31·18

Lead-Silver Series.

	Pb			
Pb_{50} Ag	97·69	7·91	25·3	9·81
Pb_{20} Ag	94·64	8·06	24·3	12·71
Pb_8 Ag	87·60	8·49	26·6	19·20
Pb_4 Ag	77·94	8·98	26·1	28·11
Pb_2 Ag	63·86	10·68	15·6	41·10
Pb Ag	46·90	11·69	16·5	56·73
Pb Ag_2	30·64	15·63	13·9	71·74
Pb and Ag*	1·39	47·62	23·8	98·72
Pb and Ag*	0·89	67·13	23·4	99·18

Bismuth-Tin Series.

	Bi			
Bi_{200} Sn	99·81	1·08	25·2	1·21
Bi_{90} Sn	99·58	0·418	27·1	1·23
Bi_{60} Sn	99·38	0·264	26·3	1·25
Bi_{44} Sn	99·15	0·245	26·8	1·28
Bi_{30} Sn	98·76	0·255	24·1	1·32
Bi_{10} Sn	96·38	0·356	24·7	1·56
Bi_6 Sn	94·11	0·513	29·7	1·79
Bi_4 Sn	91·42	0·632	29·6	2·07
Bi_2 Sn	84·19	1·04	29·9	2·81
Bi Sn	72·70	2·24	28·5	3·99
Bi Sn_2	57·19	3·96	25·7	5·59
Bi Sn_4	40·05	5·84	23·8	7·35
Bi Sn_6	30·81	7·04	27·9	8·29
Bi Sn_8	25·04	7·82	24·9	8·89
Bi Sn_{44}	5·73	10·41	24·2	10·86

Antimony-Tin Series.

	Sb			
Sb Sn_4	36·42	6·07	20·7	8·84
Sb Sn_6	27·63	6·56	20·4	9·47
Sb Sn_{10}+	18·64	7·21	22·4	10·12
Sb Sn_{20}	10·28	7·70	27·4	10·71
Sb Sn_{40}	5·42	8·49	27·0	11·06
Sb Sn_{100}	2·24	9·62	25·7	11·29
Sb Sn_{200}	1·13	9·98	27·9	11·37

* These two alloys were analysed; the silver in them was determined.

TABLE IV. (continued.)

Tin-Gold Series.

Alloy.	Volume per cent.	Mean of		Calculated conducting power from the volume.
		Conducting power.	Temperature.	
	Sn.		°	
Sn_{100} Au	98·73	11·11	23·6	12·23
Sn_{30} Au	95·89	9·97	23·8	13·98
Sn_{18} Au	93·33	9·18	24·2	15·55
Sn_{12} Au	90·32	7·76	19·8	17·40
Sn_8 Au	86·15	6·13	19·2	19·96
Sn_6 Au	82·35	4·98	21·7	22·30
Sn_5 Au	79·54	4·28	21·3	24·03
Sn_4 Au	75·67	5·12	22·3	26·41
Sn_3 Au	70·00	8·86	21·0	29·90
Sn_2 Au	60·87	14·27	18·1	35·51
Sn Au	43·75	8·88	15·9	46·03
Sn Au_2	28·00	5·18	15·0	55·72
Sn and Au *	2·11	13·12	21·4	71·58
Sn and Au *	1·17	19·59	18·8	72·16

Tin-Silver Series.

	Sn			
Sn_{180} Ag	99·28	11·37	21·9	12·08
Sn_{50} Ag	97·47	11·46	20·3	13·69
Sn_{36} Ag	96·52	11·46	20·3	14·53
Sn_{24} Ag	94·87	11·57	20·3	15·99
Sn_{18} Ag	93·28	11·56	20·1	17·40
Sn_{12} Ag	90·25	11·53	20·1	20·09
Sn_6 Ag	82·23	12·23	23·3	27·19
Sn_4 Ag	75·51	12·58	19·8	33·14
Sn_2 Ag	60·66	14·35	20·6	46·29
Sn and Ag †	2·01	23·95	20·6	98·22
Sn and Ag †	0·93	35·71	20·7	99·17

Here we find some curious results, viz. that some alloys conduct less than either of the metals composing them; and on looking at Plate VI.‡, on which the curves of the conducting powers of the alloys belonging to this class are represented, we see how rapidly the conducting power decreases on the one side of the curve with small per-centages of the other metal; and if we follow it to the other side, we find how little the conducting power of the metal of Class A. is affected by large per-centages of the metal of Class B. To this fact I shall return when I come to the general conclusions.

The lead and tin alloys, with a large proportion of antimony, could not be made into wire, on account of their extreme brittleness and hardness. The alloys of lead with a large proportion of gold were so excessively hard, brittle and infusible, that they could

* The gold in these alloys was determined.

† The amount of silver in these alloys was determined.

‡ On the same Plate, in order to show the decrement of the conducting power of the bismuth alloys, parts of the bismuth-lead and bismuth-tin curves are drawn on a scale in which silver is taken as 1000.

not be pressed; even gold alloyed with 0·25 per cent. of lead could not be drawn; it appears to be perfectly rotten. Most of the gold-lead alloys which were determined were much more brittle than glass. The gold-tin alloys, although just fusible enough to press, were yet excessively brittle. Silver with lead and tin could only be pressed or drawn within certain limits; and where no wires could be obtained, that portion of the curve is denoted by dotted lines. Nearly all the gold alloys, especially those rich in gold, were made with gold which had been precipitated by algaroth powder, &c. (see Appendix).

In Table V. are given some experiments made with certain commercial metals alloyed with pure tin or lead. The values are the mean of two determinations; and from the values found we see that they all belong to Class B, as they all conduct *less* than the calculated values.

TABLE V.

	Mean of	
	Conducting power.	Temperature.
Hg Sn	3·78	22°·0
Pb alloyed with 10 per cent. Pd	6·22	24·5
Sn alloyed with 10 per cent. Pd	9·06	24·2
Pb alloyed with 10 per cent. Pt	5·18	21·4
Sn alloyed with 10 per cent. Pt	9·37	21·1
Sn alloyed with 2·5 per cent. Fe*	9·71	20·5
Zn alloyed with 10 per cent. Al	24·02	24·5

4 *On the Conducting Power of Alloys made of the Metals of Class B. with one another.*

The values found for these alloys are given in Table VI., and their curves on Plate V.

TABLE VI.

Bismuth-Gold Series.

Alloy.	Volume per cent.	Mean of		Calculated conducting power from the volume.
		Conducting power.	Temperature.	
	Bi			
Bi_{90} Au	99·47	1·01	24°·0	1·57
Bi_{40} Au	98·81	0·998	21·6	2·04
Bi_{20} Au	97·64	1·09	19·9	2·88
Bi_{8} Au	94·31	1·25	21·9	5·27
Bi_{4} Au	89 23	1·42	22·6	8·92
Bi_{2} Au	80·55	1·82	13·7	15·14
Bi Au	67·43	2·95	14·3	24·55

* The iron in this alloy was determined; the numbers placed by the side of the metals denote the percentage by weight.

TABLE VI. (continued.)

Bismuth-Silver Series.

Alloy.	Volume per cent.	Mean of		Calculated conducting power from the volume.
		Conducting power.	Temperature.	
	Bi		°	
Bi_{200} Ag	99·76	1·12	21·3	1·43
Bi_{50} Ag	99·04	1·11	21·4	2·14
Bi_{24} Ag	98·01	1·14	21·4	3·16
Bi_{12} Ag	96·10	1·32	19·9	5·05
Bi_{6} Ag	92·49	1·65	21·6	8·61
Bi_{4} Ag	89·15	1·78	20·3	11·92
Bi_{2} Ag	80·42	2·45	20·1	20·54
Bi Ag	67·23	3·30	21·4	33·56
Bi Ag_{2}	50·64	4·66	22·4	49·95
Bi Ag_{4}	33·91	8·08	20·3	66·49
Bi and Ag*	2·33	47·87	22·9	97·70

* The amount of silver was determined.

Gold-Copper Series.

	Au			
Au and Cu	97·72	46·66	19·1	73·34
Au and Cu	95·67	33·01	19·4	73·75
Au and Cu	91·54	22·45	17·9	74·58
Au and Cu	83·83	15·35	20·3	76·16
Au and Cu	73·15	12·66	19·6	78·32
Au and Cu	53·20	11·45	17·8	82·37
Au and Cu	38·05	12·49	20·1	85·44
Au and Cu	31·07	14·00	17·1	86·91
Au and Cu	19·36	19·86	16·9	89·23
Au and Cu	11·43	28·74	19·5	90·84
Au and Cu	9·06	33·16	17·0	91·32
Au and Cu	3·53	53·18	18·0	92·44
Au and Cu	1·64	65·36	18·1	92·82

All hard drawn; the amount of gold was determined.

Gold-Silver Series.

	Au			
Au_{84} Ag	98·81	59·09	25·1	73·25
Au_{56} Ag	98·23	53·24	25·7	73·41
Au_{36} Ag	97·27	48·86	25·9	73·67
Au_{16} Ag	94·07	38·12	26·4	74·54
Au_{8} Ag	88·80	28·58	26·6	75·96
Au_{6} Ag	85·61	24·99	21·5	76·83
Au_{4} Ag	79·86	20·91	21·0	78·38
Au_{2} Ag	66·47	16·20	20·2	82·01
Au Ag	49·78	14·59	22·2	86·52
Au Ag_{2}	33·14	16·30	19·9	91·03
Au Ag_{4}	19·86	20·94	21·2	94·62
Au Ag_{6}	14·18	25·29	19·9	96·16
Au Ag_{8}	11·02	29·87	19·5	97·02
Au Ag_{16}	5·84	41·19	20·5	98·42
Au Ag_{36}	2·68	56·54	23·8	99·27
Au Ag_{56}	1·74	60·63	21·9	99·58
Au Ag_{84}	1·17	73·85	22·1	99·68

All hard drawn, not analysed.

TABLE VI. (continued.)

Copper-Silver Series.

Alloy.	Volume per cent.	Mean of		Calculated conducting power from the volume.
		Conducting power.	Temperature.	
	Cu		°	
Cu and Ag..............	98·96	86·91	20·7	93·23
Cu and Ag..............	97·94	79·38	19·7	93·30
Cu and Ag..............	94·84	75·64	20·0	93·51
Cu and Ag..............	89·83	69·92	21·1	93·86
Cu and Ag..............	78·33	67·82	18·8	94·64
Cu and Ag..............	67·45	67·90	19·0	95·38
Cu and Ag..............	63·29	68·16	22·2	95·67
Cu and Ag..............	45·37	67·43	19·0	96·89
Cu and Ag..............	38·87	64·94	19·6	97·34
Cu and Ag..............	28·21	63·71	17·2	98·07
Cu and Ag..............	17·84	63·71	17·0	98·74
Cu and Ag..............	13·15	67·44	17·5	99·10
Cu and Ag..............	6·12	74·48	16·8	99·58
Cu and Ag..............	3·23	78·23	17·1	99·78
Cu and Ag..............	2·01	83·87	17·0	99·86

All hard drawn, and the silver determined.

Of the bismuth-gold alloys very few could be determined, as bismuth makes gold exceedingly brittle. Gold could not be drawn with 0·25 per cent. of bismuth. With silver-bismuth, however, better results were obtained. The bismuth-antimony alloys were determined, but as no concordant results were obtained, they will not be given; the curve, however, appeared to be similar to those of this class.

On looking at the gold-silver alloys, we find that

$Au\,Ag$ conducts 14·59;
$Au_2\,Ag$ and $Ag_2\,Au$ conduct respectively 16·20 and 16·30;
$Au_4\,Ag$ and $Ag_4\,Au$ conduct respectively 20·91 and 20·94;
$Au_6\,Ag$ and $Ag_6\,Au$ conduct respectively 24·99 and 25·29;

and from these points the difference becomes greater as we approach the pure metals. But as 1 equivalent of gold$=\frac{197}{19·265}=10·226$ volumes, and 1 equivalent of silver $=\frac{108}{10·468}=10·317$ volumes, we may regard the alloy Au Ag as being composed of 1 volume of gold+1 volume of silver; and within the above limits we may add to the alloy Au Ag equal amounts of gold or silver and obtain the same conducting power, showing that gold and silver within these limits, when alloyed with one another, have the same conducting power. The same remarks hold good for some gold and copper alloys.

The curves of the alloys of this class show that there is a rapid decrement on both sides, of which I shall speak shortly.

5. *General Conclusions.*

The question now arises, What are alloys? Are they chemical combinations, or a solution of one metal in another, or mechanical mixtures? And to what is the rapid decrement in the conducting power in many cases due?

To the first of these questions I think we may answer, that most alloys are merely a solution of the one metal in the other; that only in a few cases we may assume chemical combinations, for example, in some of the gold-tin and gold-lead alloys; and we may regard as mechanical mixtures some of the silver-copper and bismuth-zinc alloys. The reasons of the foregoing assumptions are the following:—

1. That if we had to deal with chemical combinations, we should not find in the conducting power of alloys that regularity in the curves which certainly exists; for on looking at those belonging to the different classes, we see at a glance that each class of alloys has a curve of a distinct and separate form. Thus for the first, we have nearly a straight line; for the second, the conducting power always decreases rapidly on the side of the metal belonging to Class B, and then turning, goes almost in a straight line to the side of the metal belonging to Class A. For the third group, we find a rapid decrement on both sides of the curve, and the turning-points united by almost a straight line.

If we now examine the part of the curve where the rapid decrement takes place, we find that in the lead and tin alloys it generally requires twice as much of the former as it does of the latter to reduce a metal belonging to Class B. to a certain conducting power; for instance, to reduce that of silver to 67, it would require 0·9 vol. per cent. of lead, or about 0·5 vol. per cent. of tin; to reduce it to 47·6, there would be required 1·4 vol. per cent. of lead, or about 0·7 vol. per cent. of tin*. Again, to reduce bismuth to 0·261, there is required 1·4 vol. per cent. of lead, or 0·62 vol. per cent. of tin; and to reduce it to the minimum point of the curve, which is, when alloyed with lead, 0·255, and 0·245 when alloyed with tin, it requires 1·76 vol. per cent. of lead and 0·85 vol. per cent. of tin.

2. We cannot explain the reason of the decrement of the conducting powers by assuming that the turning-points of the curves are chemical combinations, for it is not at all probable that there are such as contain only 0·6 per cent. of tin and 99·4 per cent. of bismuth; or 2 per cent. of lead and 98 per cent. of bismuth; or 2·6 per cent. of tin and 9·74 per cent. of silver, &c.

3. That the alloys, at these turning-points, have their calculated specific gravities†.

On Plate V. we find the curves of the alloys belonging to the third class: now here we might be inclined to think that we had to do with chemical combinations. But if we consider, taking the gold-silver curve as a type, that the conducting power of silver is greatly reduced by small per-centages of any metal, and that the same may be said of gold, and if we suppose that this decrement has taken place, and join the two turning-points to which the metals have been reduced, we shall have the gold-silver curve. Take,

* These values were read off from the curves.

† See the specific gravities of lead-bismuth and tin-bismuth alloys in this volume, pp. 162, 165, 166.

for instance, the gold-tin and the silver-tin curves, and connect the two turning-points, and we shall find that the curve so made is exactly similar to that of the gold-silver. Again, look at that of the silver-bismuth, and compare it in the same manner with the tin-silver and tin-bismuth curves, and we obtain similar results.

The gold-bismuth and silver-bismuth curves are exactly similar; the alloys of gold and bismuth conducting less than those of silver and bismuth, as would be expected, as silver is a better conductor than gold.

From the similarity of the curves of alloys, where we may assume, from their chemical behaviour, that we have only a solution of one metal in another, we may always draw approximatively the curve of the alloys of any two metals, if we know to which class they belong. Thus before a single copper-gold alloy had been determined, the curve was almost correctly drawn, and agreed with that which was afterwards found by experiment.

That some alloys are chemical combinations may be deduced from the following facts:—

1. At the turning-points of the curve we generally find the alloys contract or expand.

2. There is no regular form of curve (see those of gold-tin, gold-lead, and silver-copper), so that it cannot be *à priori* even approximatively represented.

3. At the turning-points the alloys contain large per-centages of each metal.

4. At the turning-points of the curves the alloys are different from each other in appearance (crystalline form, &c.).

Now let us for a moment examine the gold-tin curve, it being the only nearly complete one of this class, and starting from the tin side of it, we find a slow decrement in the conducting power to the alloy Sn_5Au; then a slow increment to Sn_2Au, and from this point a slow decrement to $SnAu_2$. For reasons before given, no alloys could be determined between $SnAu_2$ and that containing 2·7 per cent. of tin, from which point the curve goes in a straight line to pure gold. Starting again from the tin side of the curve, we may regard the alloys down to Sn_5Au as a solution of a chemical combination in a metal; from Sn_5Au to Sn_2Au, and from Sn_2Au to $SnAu_2$, as a solution of two chemical combinations in each other, as all of these points are connected with each other by straight lines; and from $SnAu_2$ to the alloy containing 2·7 per cent. of tin, as a solution of a chemical combination in an alloy, and from this point to pure gold as a solution of a small quantity of tin in gold.

Now these turning-points contain, first, Sn_5Au, 60 per cent.; second, Sn_2Au, 37 per cent.; and third, $SnAu_2$, 13 per cent. of tin, which may very well be considered to be chemical combinations. On looking at their specific gravities, we find that Sn_5Au has almost its calculated one, whereas Sn_2Au expands, and $SnAu_2$ contracts more than any other of the gold-tin alloys experimented with.

In their general appearance we see that $SnAu_2$ and Sn_2Au are not at all crystalline, and have a very glassy fracture; but Sn_5Au is exceedingly crystalline, and always shows, on being broken, the cleavage plane of a crystal from one end of the piece to the other.

For the above reasons I think there can be no doubt that the irregularity of the gold-tin curve is due to chemical combination, and that the same may be said of the gold-lead curve.

That some alloys are mechanical mixtures, we know from facts determined by other experimenters; thus, when we fuse 17·73 parts of bismuth and 16·12 parts of zinc together, we find two layers, the upper one consisting of 13·40 parts of zinc, and the lower one 19·40 parts of bismuth alloyed with traces of zinc*; now had we stirred the two metals well together, and cooled rapidly the alloy so obtained, it might be considered as a mechanical mixture.

Again, according to LEVOL†, if we fuse silver and copper together, and allow the alloy to remain quietly in the fused state, we find, on analysing the mass, that different parts contain different per-centages of metal: he found this to be the case with all alloys, excepting that containing 28·11 per cent. of copper, which corresponds to the formula $Ag_3 Cu_4$.

LEVOL regards all alloys of silver and copper as mixtures of $Ag_3 Cu_4$, and either silver or copper; if this were the case, we should have expected to find from that point to pure silver or copper, straight lines; but on examining that curve, starting from the copper side of it, we first see that a rapid decrement takes place, caused by the copper being alloyed with a small quantity of silver. From that alloy containing 90 vols. per cent. to that of 35 vols. per cent. of copper, we have a straight line, and we may regard the intermediate alloys as mixtures or solutions of these two alloys; from the alloy containing 35 vols. per cent. to that with 28 vols. per cent. of copper, we may have a mixture or solution of those alloys: now this last point is the minimum point of the curve, and corresponds almost to LEVOL's $Ag_3 Cu_4$, being an alloy containing 25 per cent. by weight of copper. This, as well as the other lowest points of the curves, must not be considered as actually the lowest, but only as the lowest point found; for in this case we should expect that the alloy containing 28 per cent. of copper would be lower; and from this point to pure silver the alloys may be mixtures, or perhaps solutions of that alloy and silver containing a small quantity of copper. Now it would appear as if at about the point which represents the alloy containing 35 vols. per cent. of copper, there was also one of constant composition, otherwise we should have expected a straight line from the alloy containing 28 vols. per cent. to that containing 90 vols. per cent. of copper.

Of course, from this one curve, we can hardly deduce any conclusions, as we have in all probability to deal with mixtures of chemical compounds, with solutions of the one metal in the other, &c. It only shows that, by the determination of the conducting powers of the alloys, we are able to tell where these are constant or chemical combinations; and when the curves are irregular, we may safely conclude that we have to do with chemical combinations or mechanical mixtures.

That the first group of alloys, their curves being nearly straight lines, are not mix-

* FOURNET, Ann. de Chim. et de Phys., vol. liv. p. 247.

† Journ. de Pharm., vol. xvii. p. 111.

tures but solutions of one metal in the other, may be deduced from the fact of their fusing-points being generally lower than the mean of that of the volumes taken.

Secondly. To what is the rapid decrement of the conducting power due?

The only answer which I can at present give to this question, is that most of the other physical properties of the metal are altered in a like manner; for on looking at the alloys made with the metals of Class A. with one another, we see that most of their other physical properties are not at all altered; for amongst them, for instance, we find no brittle ones; they appear, in fact, to take an equal share of the properties of the metals composing them. But now let us examine the alloys of the second class, and we immediately discover great differences; alloy gold, the most ductile of all metals, with small per-centages of tin, lead, or zinc, and it becomes as brittle as glass. Again, alloy silver with small per-centages of the above metals, and its properties are much altered. Silver, which, when pure, is one of the easiest metals to draw, when alloyed with more than 3 per cent. of tin and 2 per cent. of lead, becomes so brittle, and its tenacity so much impaired, that it cannot be drawn. I do not mean to say it is impossible to do so, but it was tried several times without success. On the other hand, we do not find any marked differences in the ductility, hardness, &c. of tin or lead when alloyed with silver; we may add 10, nay even 20 per cent. of silver to them, and they remain ductile, and may be pressed into wire without any trouble. Of course, with lead and tin alloyed with small quantities of gold, the case is somewhat different, as we have here chemical combinations coming into play; nevertheless, we may add to them 5 per cent. of gold without altering their ductility, &c. to any great extent. Bismuth alloyed with lead or tin becomes more brittle, and in wire its tenacity is impaired; but tin and lead alloyed with large per-centages of bismuth, always retain a considerable amount of ductility, &c.

Again, take the alloys of the third class. Although amongst the gold-silver and the gold-copper alloys we find no brittle ones, yet we know how hard gold, silver, and copper become when we alloy them with small quantities of other metals, and that they lose more in proportion of their ductility, &c., by the addition of small than of large quantities of strange metal.

From these facts, we need not be surprised at the rapid decrement of the conducting powers of the metals belonging to Class B, when alloyed with any other metal; for when we find most of their other physical properties more or less greatly altered by traces of foreign metals, might we not also have expected this result? For where we see no marked change in most of the other physical properties of alloys, as in the first class and in the second, on the one side of the curve, there we have nearly their calculated conducting powers.

It would be very interesting to determine quantitatively some of the other physical properties of the alloys, to see whether in them these properties will decrease in the same marked manner as the conducting powers, when a metal belonging to Class B. is alloyed with any other metal. I intend therefore to commence, especially with this view, with the conducting power for heat, in order to see if the classification of the metals and alloys given in this paper will hold good for any of the other physical properties, as well as in the hope of finding out the cause of the behaviour of the metals of Class B. when alloyed with traces of any other. On looking at the specific gravity of alloys*, we find that they cannot be classified as above, but in all probability the above classification will hold good for their tenacity, hardness, conducting power for heat, &c.

APPENDIX.

On the Electric Conducting Power of Pure Gold.

The values given for the conducting power of pure gold, in my paper "On the Electric Conducting Power of the Metals†," is not quite correct, as the gold from some cause cannot have been chemically pure; although prepared with the greatest care by Dr. Meyboom, yet the wire-drawer in all probability fused it in a crucible which had been previously used; and as only 3 to 4 grms. were purified, a very small amount of impurity would account for the difference which I have lately found. At the time the values appeared very low, compared with those of other experimenters, but it was then thought that the higher ones were due to traces of silver. Experiments, however, have proved, on the contrary, that most of the gold-silver, gold-copper, &c. alloys conduct electricity worse than pure gold; and that, in fact, only those which contain less than 2 per cent. gold in gold-silver alloys, and about 3 per cent. gold in gold-copper alloys, conduct better than pure gold.

Thus chemically-pure gold, prepared by dissolving gold from the refiners in nitrohydrochloric acid, precipitating with algaroth powder, washing alternately with nitric and hydrochloric acids, redissolving in nitrohydrochloric acid, precipitating by sulphurous acid, washing alternately with nitric and hydrochloric acids, and fusing in a muffle with nitrate of potash, gave, compared with a hard drawn silver wire =100 at 0°C.,

I.	II.	III.	Mean.
73·57 at 19°·0	72·10 at 19°·1	72·37 at 19°·8	72·68 at 19°·3.

Another specimen, prepared in the same manner, gave

I.	II.	III.	Mean.
72·80 at 23°·0	73·42 at 23°·8	73·02 at 23°·1	73·08 at 23°·3.

A third specimen, prepared by dissolving gold containing silver in nitrohydrochloric acid, evaporating to dryness with excess of hydrochloric acid, dissolving in about 500 times its weight of water‡ and precipitating with protosulphate of iron, washing out all

* See specific gravities of tin-bismuth and lead-bismuth alloys in this volume, pp. 162, 165, 166.

† Philosophical Transactions, 1858.

‡ It is of the greatest importance, in purifying gold containing silver by this method, that the solution should be made very dilute, so that the chloride of silver dissolved in the chloride of gold may be precipitated before the addition of the protosulphate of iron; otherwise the chloride of silver would fall with the

the iron with boiling hydrochloric acid, and fusing with nitrate of potash and a little borax, gave—

I.	II.	Mean.
73·63 at 13°·5	72·90 at 14°·2	73·27 at 13°·8.

A fourth specimen, prepared exactly as the third, gave—

I.	II.	Mean.
74·20 at 14°·8	73·78 at 15°·5	73·99 at 15°·1.

The so-called proof-gold of the refiners gave—

I.	II.	III.
65·57 at 23°·1	64·25 at 23°·1	65·92 at 23°·1 *.

In conclusion, I give a list of the determinations of gold as found by other experimenters, silver taken =100:—

Riess †.	Lenz †.	Ed. Becquerel ‡.	Harris †.	H. Davy †.	Christie †.
59	58·5	64·9	66·6	67	73

Matthiessen.
55·19 and 73·26 at 17°·8.

On looking over these values, we find that all, except that of Christie, are too low, and the gold-silver alloys which correspond to these numbers are the alloys which contain

99·4 per cent. gold and 0·6 per cent. silver, conducting 59,
99·7 per cent. gold and 0·3 per cent. silver, conducting 66.

Now the proof-gold of the refiners often contains as much as 0·5 per cent. silver, and the value 66 found for it would be that of the alloy 99·7 per cent. gold and 0·3 per cent. silver.

Of course the value given in my paper "On the Thermo-electric Series," for the thermo-electric number of pure gold, cannot be correct, as I used the same gold for those determinations and for those of the conducting power.

I am much indebted to Dr. M. Holzmann for the excellent manner in which he has carried out the greater part of the foregoing determinations.

gold, and be reduced during the process of fusion. The following experiments prove this to be the case; they were carried out in every respect in the same manner, and with the same care as those above, the only difference being in the concentration of the solution.

Thus gold containing silver was dissolved in nitrohydrochloric acid, evaporated to dryness with excess of hydrochloric acid, dissolved in a small quantity of water and precipitated by a concentrated solution of protosulphate of iron, washed alternately by boiling nitric and hydrochloric acids, redissolved in nitrohydrochloric acid, reprecipitated by protosulphate of iron, washed alternately with nitric and hydrochloric acids and fused with nitrate of potash, and then gave

66·57 at 22°·0.

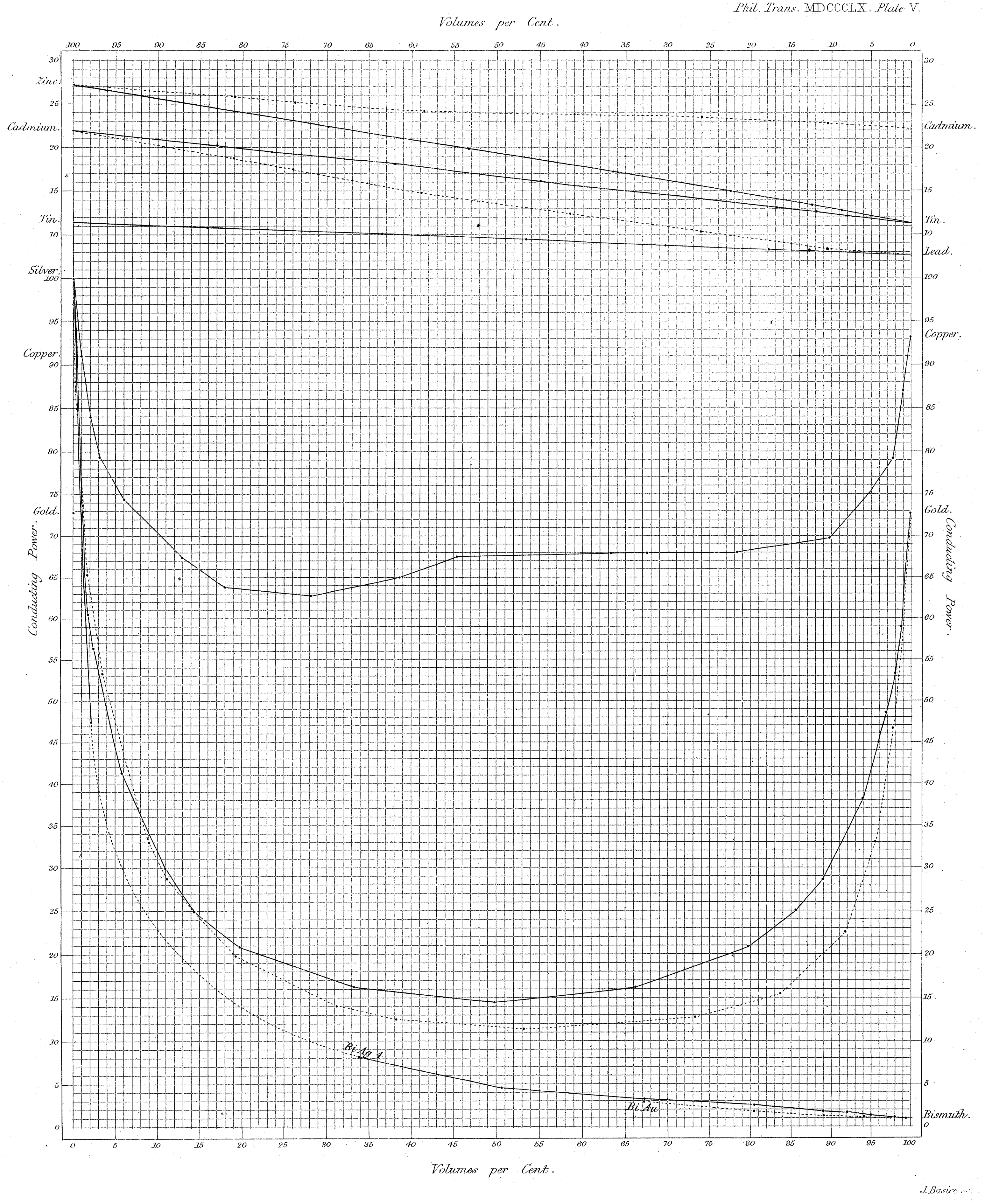
Another specimen, prepared by precipitating a concentrated solution of gold by protosulphate of iron, washing, &c., redissolving and precipitating by sulphurous acid, washing, &c., gave—

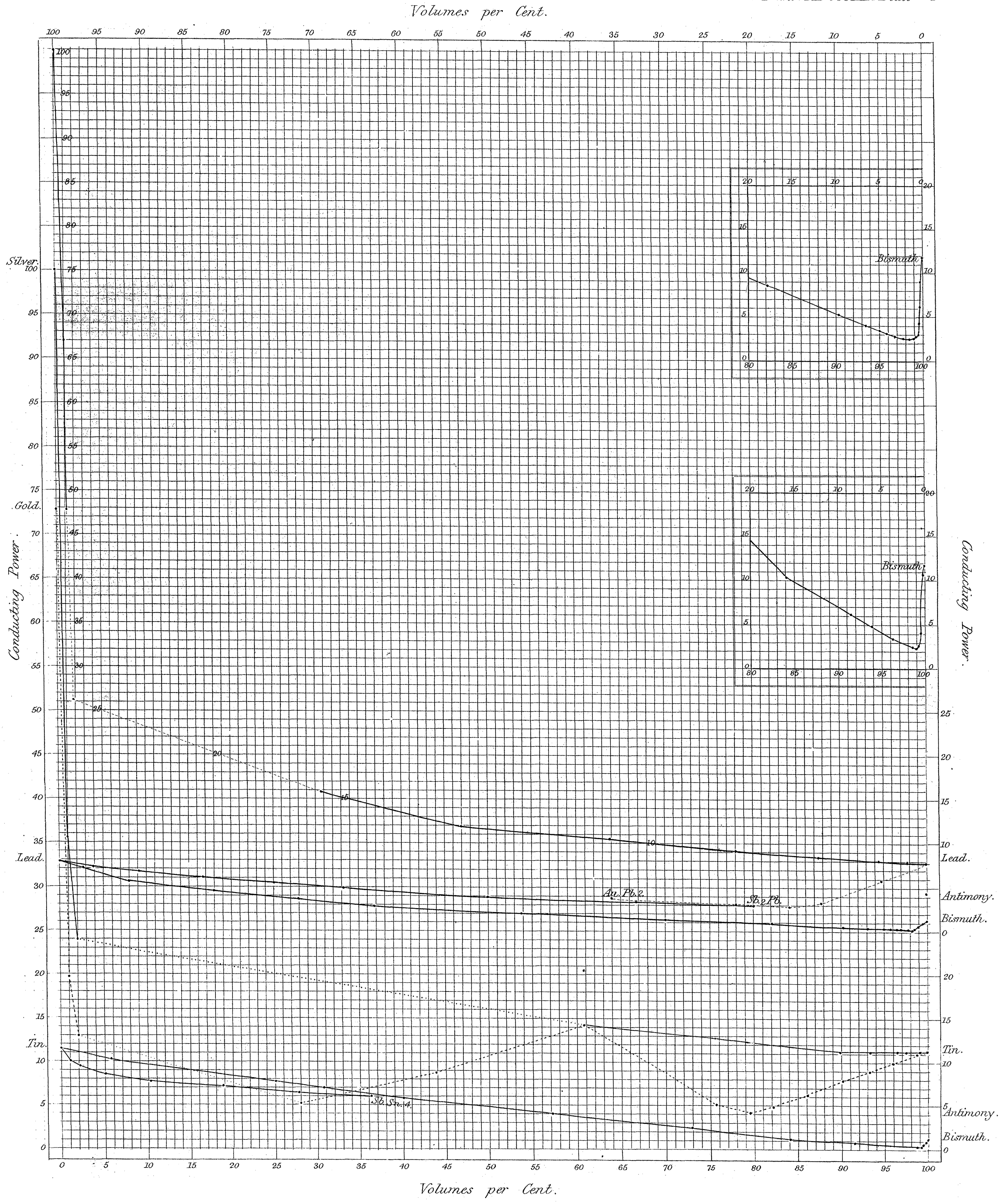
I. 67·87 at 22°·3. II. 67·78 at 22°·3.

* For all the above determinations, hard-drawn wires were used.

† Gmelin, vol. i. p. 289.

‡ Ann. de Chim. et de Phys. iii. 17, 242.


Volumes per Cent.
Zinc.
Cadmium.
Tin.
Lead.
Silver.
Copper.
Gold.
Bismuth.
Conducting Power.
Bi Ag 4
Bi Au
Volumes per Cent.
J. Basire sc.


Volumes per Cent.
Conducting Power.
Silver.
Gold.
Lead.
Tin.
Bismuth
Au. Pb. 2.
Sb. 2 Pb.
Sb. Sn. 4.
Antimony.
Bismuth.
Conducting Power.
Volumes per Cent.

J. Basire sc.