XIX. *On the Thermo-electric Series. By* AUGUSTUS MATTHIESSEN, *Ph.D. Communicated by* CHARLES WHEATSTONE, *Esq.*

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BEING enabled by the method described in the Philosophical Magazine (February 1857) to obtain wires of the metals of the alkalies and alkaline earths, I have determined their places, together with most of those of the other metals and some alloys, in the thermo-electric series. The alloys which were experimented with, are those described by ROLLMAN* as giving with other metals stronger thermo-electric currents than those of bismuth or antimony under the same circumstances.

If A, B, C are different metals, and (A, B), (B, C), (C, A) the electromotive powers of thermo-elements formed out of each two of these metals, whose alternate soldering-points are at two different temperatures, then (A, B)+(B, C)+(C, A)=0, and therefore†

$$(A, B)=a-b,$$
$$(B, C)=b-c,$$
$$(C, A)=c-a,$$

where the values of a, b, c not only depend on the two temperatures, but also on the nature of each of the metals A, B, and C. As the "differences" of the same constitute the electromotive powers, the value for any one of these metals may be put $=0$. If the temperatures of the soldering-points of a thermo-element only vary slightly, the electromotive power may be said to be proportional to the difference of the two temperatures, and under the same conditions the quantities a, b, c are also proportional to the difference of the temperatures, and their ratios to each other therefore independent of the same. If now the value of a second metal relative to the above-named value of the first be taken $=1$, the values of the others in relation to these can be deduced, and only depend on the nature of each metal. These values I will call the Thermo-electric Numbers of the metals.

The results obtained are given in Table I., where the thermo-electric number of chemically pure silver is taken $=0$, and that of a certain commercial sort of copper $=1$.

TABLE I.

Bismuth (commercial, pressed wire)	+ 35·81
Bismuth (pure, pressed wire)	+ 32·91
Alloy of 32 parts of bismuth and 1 part of antimony (cast)	+ 29·06
Bismuth (pure, cast)	+ 24·96

* POGGENDORFF's Annalen, lxxxiii. p. 77; lxxxiv. p. 75; lxxxix. p. 90.

† GEHLER, Physikalisches Wörterbuch, B. 9. Ab. 1. S. 776.

Bismuth (crystal, axial)	+24·59
Bismuth (crystal, equatorial)	+17·17
Cobalt No. 1 (a pressed specimen prepared by Professor DUFLOS, and out of the Collection of the Heidelberg Chemical Laboratory)	+ 8·977
Potassium (the same as used for the determination of its electric conducting powers for different temperatures)	+ 5·492
Argentine (wire of commerce, hard drawn)	+ 5·240
Nickel (commercial, free from cobalt, but containing iron, &c.) (from Messrs. EVANS and ATKIN, Birmingham)	+ 5·020
Cobalt No. 2 (from the Collection of the Heidelberg Laboratory)	+ 3·748
Palladium (wire, hard drawn, from DESMOUTIS, CHAPUIS and Co. of Paris)	+ 3·560
Sodium (the same as used for the determination of its electric conducting powers for different temperatures)	+ 3·094
Quicksilver (pure, fused in a glass tube)	+ 2·524
Aluminium (from ROUSSEAU Frères of Paris, wire, hard drawn, analysed by Dr. G. C. CALDWELL, and found to contain Si 2·34, Fe 5·89, and Al 91·77)	+ 1·283
Magnesium (wire, pressed)	+ 1·175
Lead (pure, pressed wire)	+ 1·029
Tin (pure, pressed wire). The difference of the electromotive powers of the elements was here so small that it could not be determined; with the galvanometer, a copper-tin element, when the soldered points had 100° C. difference, gave no appreciable deflection; also the central experiments show as well how very little the electromotive power of a silver-tin thermo-element varies from a silver-copper one	+ 1·000
Copper No. 1 (wire of commerce, annealed, containing small quantities of zinc, tin, lead and nickel)	+ 1·000
Copper No. 2 (wire of commerce, annealed)	+ 0·922
Platinum (wire from DESMOUTIS, CHAPUIS and Co. of Paris)	+ 0·723
Gold (wire, hard drawn, purified by Dr. C. MEYBOOM)	+ 0·613
Iridium (from the Collection of the Heidelberg Chemical Laboratory)	+ 0·163
Antimony (wire, pressed specimens, purified by Dr. W. P. DEXTER and Dr. G. C. CALDWELL)	+ 0·036
Silver (pure, drawn, hard)	0·000
Gas-coke (from the Heidelberg Gas-Manufactory, the hard mass remaining in the retorts)	− 0·057
Zinc (pure, pressed)	− 0·208
Copper (galvanoplastically precipitated)	− 0·244
Cadmium (a pure slip of foil from Professor BÖTTGER)	− 0·332
Antimony (commercial, pressed wire)	− 1·897
Strontium (pressed wire)	− 2·028
Lithium (pressed wire)	− 3·768
Arsenic (a piece, pure)	− 3·828

Calcium (pressed wire)	— 4·260
Iron (pianoforte wire No. 4)	— 5·218
Antimony (axial)	— 6·965
Antimony (equatorial)	— 9·435
Red phosphorus (from Professor SCHRÖTTER, from the Collection of the Heidelberg Chemical Laboratory)	— 9·600
Antimony (purified as above, cast)	— 9·871
An alloy of 12 parts of bismuth, 1 part of tin, cast	— 13·670
An alloy of 2 parts of antimony and 1 part of zinc, cast	— 22·700
Tellurium (from M. ALEXANDER LOEWE of Vienna, purified by M. HOLTZMANN, cast)	—179·80
Selenium (from the Collection of the Heidelberg Chemical Laboratory	—290·00

The electromotive power of a copper No. 1, Argentine thermo-elements, whose soldering-points had the temperatures 7° and 25°, was found by Dr. WILD to be equal to $18·4.10^6$ in the standard given by Professor WEBER, where the unit of length is 1 millimetre, the mass a milligram, and the time a second; and that of the same thermo-element, where the difference of temperature at the soldering-points was 100° C., was found equal to 1·108 compared with that of a DANIELL'S element, the electromotive power of which was taken equal 1000*.

The above series agrees with that found by SEEBECK, with the exception of arsenic, which stands below iron according to his experiments; this however is easily explained, as different sorts of iron give with each other strong thermo-electric currents.

The manner in which the experiments were carried out is the following:—Two thermo-elements, whose warm and cold soldering-points had the same temperatures, were compared with each other; these formed a circuit with the coil of a galvanometer, which surrounded a magnet rod of about a pound weight, to which was fastened a piece of looking-glass, thereby allowing the deflections of the magnet to be observed at a distance by means of a telescope and scale, in the same way as observations are made with the magnetometer. The commutators were brought into the circuit; the one changed the direction of the current in the wire of the multiplier, and the other allowed the currents of the thermo-elements either to pass in a direction so that they strengthened, or so that they opposed each other.

Out of the four observed stationary deflections of the magnet which correspond with the four different possible positions of the commutators, the ratio of the electromotive powers of the two thermo-elements may easily be calculated; for if s_1, s_2, s_3, s_4 be the four observed deflections, and if s_1 and s_4 be the combination of the two warm soldering-points of the two elements, and s_2 and s_3 that of the warm soldering-points of the one with the cold one of the other, that ratio is $=\frac{(s_2-s_3)+(s_1-s_4)}{(s_2-s_3)-(s_1-s_4)}$.

All the solderings of the different metals were placed in two cubical zinc boxes (of about 6 inches the side); these had double sides, the space between them being filled

* POGGENDORFF'S Annalen, vol. ciii. p. 353.

with ashes. The one box was filled with warm water, and the other with water having the temperature of the room; the wires were introduced partly through holes in the covers and partly through holes in the sides, which were made water-tight with india-rubber tubing. In order to prevent any conducting of the electric current through the water, the wires were covered with thin india-rubber tubes, and by means of stirrers a uniformity of temperature was kept up throughout each of the boxes. In consequence of their size and their double sides, the temperature hardly varied during the time an observation was being made. If the electromotive powers of a thermo-element were in exact ratio with the difference of the temperatures, the knowledge of the same would not be necessary with the arrangement described; but as this is not exactly the case, the temperatures were observed by means of thermometers placed in the boxes through the covers. Table II., the arrangement of which will be explained immediately, contains the results of the observations made in the manner above described.

TABLE II.

			Mean.
Silver, *Bismuth* (commercial wires)—5 Silver, Copper.			
$t_1=7°\cdot6$	$t_2=24°\cdot0$	$v=7\cdot163$	7·162
$t_1=7\cdot6$	$t_2=23\cdot0$	$v=7\cdot164$	
$t_1=7\cdot6$	$t_2=22\cdot4$	$v=7\cdot159$	
Silver, *Bismuth* (pure wires)—5 Silver, Copper.			
$t_1=4\cdot2$	$t_2=23\cdot7$	$v=6\cdot585$	6·582
$t_1=4\cdot2$	$t_2=22\cdot6$	$v=6\cdot586$	
$t_1=4\cdot2$	$t_2=21\cdot8$	$v=6\cdot575$	
Silver, *Potassium*—2 Silver, Copper.			
$t_1=4\cdot0$	$t_2=29\cdot3$	$v=2\cdot748$	2·746
$t_1=4\cdot0$	$t_2=27\cdot3$	$v=2\cdot749$	
$t_1=4\cdot0$	$t_2=25\cdot9$	$v=2\cdot742$	
Silver, *Argentine*—2 Silver, Copper.			
$t_1=5\cdot6$	$t_2=32\cdot1$	$v=2\cdot620$	2·620
$t_1=5\cdot6$	$t_2=31\cdot0$	$v=2\cdot621$	
$t_1=5\cdot6$	$t_2=30\cdot0$	$v=2\cdot620$	
Silver, *Palladium*—2 Silver, Copper.			
$t_1=4\cdot4$	$t_2=27\cdot7$	$v=1\cdot783$	1·780
$t_1=4\cdot4$	$t_2=27\cdot2$	$v=1\cdot775$	
$t_1=4\cdot4$	$t_2=26\cdot0$	$v=1\cdot782$	
Silver, *Sodium*—2 Silver, Copper.			
$t_1=4\cdot8$	$t_2=28\cdot9$	$v=1\cdot549$	1·547
$t_1=4\cdot8$	$t_2=27\cdot0$	$v=1\cdot546$	
$t_1=4\cdot8$	$t_2=26\cdot1$	$v=1\cdot550$	
$t_1=4\cdot8$	$t_2=26\cdot0$	$v=1\cdot544$	

TABLE II. (Continued.)

Silver, *Quicksilver*—2 Silver, Copper.

			Mean.
$t_1=$ 7°·2	$t_2=$28°·3	$v=$1·265	1·262
$t_1=$ 7·2	$t_2=$27·8	$v=$1·262	
$t_1=$ 7·2	$t_2=$27·0	$v=$1·259	

2 Silver, Copper—Silver, *Aluminium*.

$t_1=$ 5·0	$t_2=$28·0	$v=$1·559	1·558
$t_1=$ 5·0	$t_2=$26·9	$v=$1·558	
$t_1=$ 5·0	$t_2=$26·0	$v=$1·558	

2 Silver, Copper—Silver, *Magnesium*.

$t_1=$ 6·8	$t_2=$30·1	$v=$1·698	1·702
$t_1=$ 6·8	$t_2=$29·8	$v=$1·704	
$t_1=$ 6·8	$t_2=$27·5	$v=$1·703	

Silver, *Lead*—Silver, Copper.

$t_1=$ 9·0	$t_2=$29·2	$v=$1·031	1·029
$t_1=$ 9·0	$t_2=$28·8	$v=$1·031	
$t_1=$ 9·0	$t_2=$27·4	$v=$1·025	

Silver, Copper—Silver, *Copper* (No. 2).

$t_1=$25·2	$t_2=$42·9	$v=$1·084	1·084
$t_1=$25·2	$t_2=$42·2	$v=$1·083	
$t_1=$25·2	$t_2=$43·9	$v=$1·085	

Silver, Copper—Silver, *Platinum*.

$t_1=$26·2	$t_2=$44·0	$v=$1·385	1·383
$t_1=$26·2	$t_2=$43·8	$v=$1·388	
$t_1=$26·2	$t_2=$42·0	$v=$1·376	

2 Silver, *Gold*—Silver, Copper.

$t_1=$ 4·5	$t_2=$32·4	$v=$1·224	1·226
$t_1=$ 4·5	$t_2=$31·3	$v=$1·222	
$t_1=$ 4·5	$t_2=$30·0	$v=$1·230	
$t_1=$ 4·5	$t_2=$29·0	$v=$1·229	

2 Silver, Copper—2 *Zinc*, Silver.

$t_1=$ 7·0	$t_2=$30·4	$v=$4·822	4·810
$t_1=$ 7·0	$t_2=$29·1	$v=$4·800	
$t_1=$ 7·0	$t_2=$26·6	$v=$4·808	

Silver, Copper—*Cadmium*, Silver.

$t_1=$ 5·4	$t_2=$26·7	$v=$3·002	3·007
$t_1=$ 5·4	$t_2=$25·8	$v=$3·008	
$t_1=$ 5·4	$t_2=$25·2	$v=$3·011	

TABLE II. (Continued.)

2 Silver, Copper—*Antimony* (commercial wire) Silver.

			Mean.
$t_1=$ 8°·0	$t_2=$33°·0	$v=$1·059	
$t_1=$ 8·0	$t_2=$31·2	$v=$1·055	1·054
$t_1=$ 8·0	$t_2=$30·4	$v=$1·052	

Lithium, Silver—2 Silver, Copper.

$t_1=$ 5·2	$t_2=$32·5	$v=$1·888	
$t_1=$ 5·2	$t_2=$31·5	$v=$1·887	1·884
$t_1=$ 5·2	$t_2=$30·0	$v=$1·880	
$t_1=$ 5·2	$t_2=$29·0	$v=$1·881	

Calcium, Silver—2 Silver, Copper.

$t_1=$ 4·3	$t_2=$28·8	$v=$2·132	
$t_1=$ 4·3	$t_2=$28·0	$v=$2·129	2·130
$t_1=$ 4·3	$t_2=$26·9	$v=$2·129	

Iron, Silver—2 Silver, Copper.

$t=$ 6·0	$t_2=$28·8	$v=$2·616	
$t_1=$ 6·0	$t_2=$26·2	$v=$2·608	2·609
$t_1=$ 6·0	$t_2=$29·8	$v=$2·604	

Antimony (pure wire), Argentine—Lead, Argentine.

$t_1=$ 9·5	$t_2=$35·1	$v=$1·234	
$t_1=$ 9·5	$t_2=$33·9	$v=$1·236	1·236
$t_1=$ 9·5	$t_2=$32·9	$v=$1·237	

Copper (galvanoplastic), Copper—Silver, Copper.

$t_1=$26·2	$t_2=$48·0	$v=$1·240	
$t_1=$26·2	$t_2=$46·5	$v=$1·246	1·244
$t_1=$26·2	$t_2=$45·7	$v=$1·247	

Strontium, Argentine—Silver, Argentine.

$t_1=$ 6·0	$t_2=$36·1	$v=$1·383	
$t_1=$ 6·0	$t_2=$34·7	$v=$1·390	1·387
$t_1=$ 6·0	$t_2=$33·1	$v=$1·389	

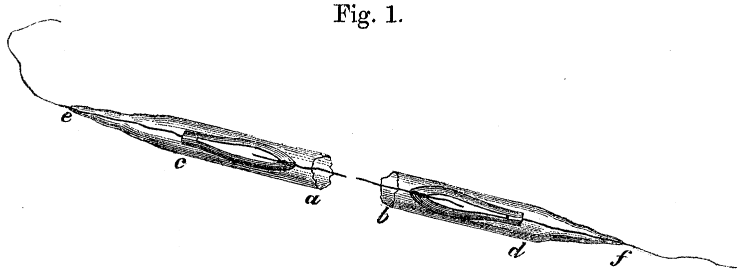
All the temperatures are given in Celsius's degrees. For the first experiment of the series, a thermo-element formed out of commercial bismuth (pressed wire), and silver was compared with a thermo-battery composed of five silver-copper elements. The silver and copper were the same sorts as those whose thermo-electric constants were taken =0 and 1. The temperature (t_1) of the water in the box containing the cold soldering-points was 7°·6, and that of the warm (t_2), 24°·0. The ratio of the electromotive force of the two elements (v) was found =7·163, in two other experiments, 7·164 and 7·157. The mean of these three numbers is 7·162, and therefore the electromotive force of a bismuth-silver element =35·81, that of a silver-copper one, or in other

words, the thermo-electric constant of commercial bismuth (pressed wire), $=35\cdot81$. All the other numbers in the Table have a similar meaning, and the metals, whose thermo-electric numbers are calculated out of them, are written in italics.

The connexion was, in all cases where the metal allowed of it, formed by soldering. Antimony wire, which (as well as that of tellurium) is so brittle that it will hardly bear touching, could of course not be directly soldered, but had to be treated in the following manner. The wire was pressed in a glass tube, in which it was soldered to two thick copper wires with Rose's metal; these, in order to keep them from moving, were made fast in the tube with gypsum.

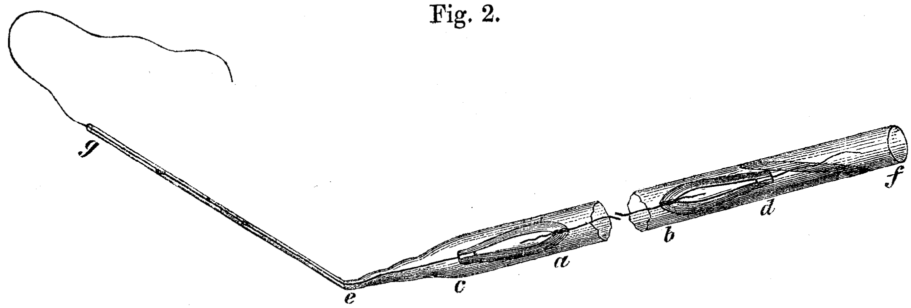
Lithium, calcium, strontium, and magnesium were experimented with in sealed-up glass tubes filled with rock oil, as fig. 1 shows, the ends of the wire being held at *a*

Fig. 1.



and *b* by two steel wire-holders, whose jaws press so strongly together that they flatten out the ends of the wire. At the other end of the wire-holders platinum wires were soldered on, which passed out of the tube at *c* and *d*. The way in which this piece of apparatus was put together is as follows:—a long platinum wire, soldered on to one of the wire-holders, was passed through a glass tube (drawn out and bent as shown in fig. 2) at *f*, so that the end of it came out at *g*, whilst the wire-holder remained outside

Fig. 2.

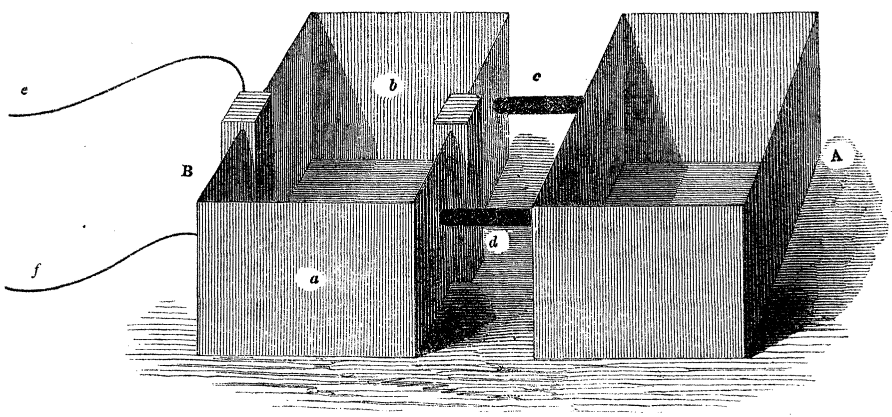


the other end at *f*. The glass tube being then laid in a trough filled with rock oil, the wire, previously pressed in a tube filled with the same liquid, was then taken out of the tube in the trough, the one end of it scraped clean and fastened in the wire-holder, and drawn into the tube by means of the long platinum wire, until only the other end of it remained out; this also having been scraped clean and fastened in the second wire-holder, was drawn into the tube as far as fig. 2 shows. The tube was now lifted out of the trough in an inclined position, so that it almost remained filled with the oil, and sealed up at *g*; at *f* it was then drawn out, the oil boiled to drive out the air, and sealed up

as shown in fig. 1; and lastly, the long end of the glass was melted off at *c*, and the superfluous platinum wire cut off. During the experiments the tube was so placed that the one end found itself in the middle of the one, and the other in the middle of the other box; that filled with warm water was placed higher than the other, in order that the tube might remain in an inclined position, preventing thereby the warming of the other end through currents which would otherwise have arisen in the oil. The connexion was now formed by soldering on the silver or other wires to the platinum ones. To ascertain whether this arrangement would give correct results, a silver-palladium element was compared with two composed of silver-copper; in the one case the palladium wire was fastened in the wire-holders as above described, in the other it was soldered directly to the silver. The ratio of the electromotive power of the two elements was found, when the wire-holders were used, in four observations, 1·779, 1·776, 1·767, 1·777, the mean of which is 1·775, agreeing very well with 1·780, the mean of the results obtained when the wires were soldered together.

The above-described boxes could only be used with metals in form of wire, or rods of a considerable length (at least 8 inches); for experimenting with other metals two smaller boxes were employed, of which fig. 3 is a sketch. A and B are two copper boxes of

Fig. 3.



about 4 inches in height, 4 in width, and 5 long. B consists of two halves, *a* and *b*, insulated from each other by a piece of india-rubber. A was filled with warm, B with cold oil.

If two pieces of different metals, *c* and *d*, are placed between the two boxes, which are pressed against each other by screws, and if the two wires *e* and *f*, soldered to the two halves of B, be connected, a current is formed in the circuit whose electromotive power is equal to that of a thermo-element constructed with the metals *c* and *d*, whose extremities have the temperature of the oil in the boxes. To determine this electromotive power, a circuit was formed with the wires of the multiplier used for the former experiments, the two wires *e* and *f*, and the wires of one or more thermo-elements made of wires whose soldering-points dipped alternately in the oil of each box. The two commutators were again brought into the circuit, and answered the same pur-

pose as before. Where two or more thermo-elements were used, as was generally the case, they were fixed in a piece of wood, as fig. 4 shows, and which needs no explanation. With the same apparatus the difference in the thermo-electric behaviour of the cleavage planes of bismuth and antimony crystals was studied. The bismuth crystals had about 8 millims. the sides; two cleavage planes were made perpendicular to the principal axis, and two parallel to it. As antimony crystals could not be obtained large enough for these experiments, pieces were cut out of commercial antimony, as FRANZ did for his research on the same subject*. These were so experimented with, that in one case the planes perpendicular to the principal axis, in the other those parallel to it, were pressed between the sides of the boxes. The position of the crystals, where the current passes in the direction of the principal axis, is called the axial, the other the equatorial. The results of the observations with the crystals do not agree very well with each other, owing probably to the cleavage planes not being exactly ground at the proper angles, and also to their being placed in a rather oblique position between the boxes. Table III. gives the results obtained with the copper boxes.

Fig. 4.

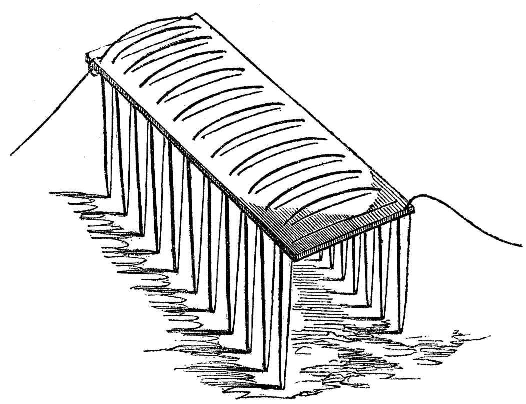


TABLE III.

7 Copper, Argentine—Argentine, *Bismuth* (pure cast).

			Mean.
$t_1=25°\cdot5$	$t_2=47°\cdot0$	$v=1\cdot503$	1·505
$t_1=25\cdot8$	$t_2=40\cdot4$	$v=1\cdot509$	
$t_1=25\cdot5$	$t_2=38\cdot7$	$v=1\cdot504$	

Silver, *Cobalt* (No. 1)—Silver, Argentine.

$t_1=18\cdot7$	$t_2=43\cdot7$	$v=1\cdot722$	1·713
$t_1=18\cdot7$	$t_2=40\cdot0$	$v=1\cdot710$	
$t_1=19\cdot3$	$t_2=36\cdot8$	$v=1\cdot708$	

Silver, Argentine—Silver, *Nickel*.

$t_1=20\cdot5$	$t_2=56\cdot0$	$v=1\cdot040$	1·044
$t_1=20\cdot6$	$t_2=50\cdot2$	$v=1\cdot048$	
$t_1=21\cdot0$	$t_2=44\cdot6$	$v=1\cdot044$	

Silver, Argentine—Silver, *Cobalt* (No. 2).

$t_1=21\cdot2$	$t_2=60\cdot0$	$v=1\cdot389$	1·398
$t_1=21\cdot4$	$t_2=53\cdot0$	$v=1\cdot409$	
$t_1=21\cdot7$	$t_2=47\cdot7$	$v=1\cdot395$	

* POGGENDORFF's Annalen, vol. lxxxiii. p. 374.

Silver, Argentine—*Iridium*, Argentine.

			Mean.
t_1=22°·5	t_2=49°·8	v=1·029	1·032
t_1=22·7	t_2=46·8	v=1·039	
t_1=23·2	t_2=45·3	v=1·027	

Gas-coke, Argentine—Silver, Argentine.

t_1=26·7	t_2=57·5	v=1·010	1·011
t_1=27·2	t_2=56·4	v=1·012	
t_1=27·2	t_2=51·9	v=1·012	

Silver, Argentine—*Arsenic*, Silver.

t_1=23·7	t_2=43·3	v=1·368	1·369
t_1=24·0	t_2=40·5	v=1·372	
t_1=24·4	t_2=36·9	v=1·366	

Antimony (pure cast), Silver—Silver, Argentine.

t_1=22·3	t_2=57·8	v=1·884	1·884
t_1=22·5	t_2=53·5	v=1·882	
t_1=23·1	t_2=48·2	v=1·886	

Tellurium, Silver—19 Copper, Argentine.

t_1=17·0	t_2=36·2	v=2·259	2·232
t_1=17·5	t_2=32·6	v=2·235	
t_1=18·3	t_2=29·7	v=2·215	
t_1=18·5	t_2=37·5	v=2·214	
t_1=18·8	t_2=32·1	v=2·235	
t_1=19·1	t_2=30·6	v=2·228	

Silver, *Bismuth-Antimony*—Silver, Argentine.

t_1=24·6	t_2=58·2	v=5·525	5·546
t_1=24·8	t_2=56·4	v=5·575	
t_1=25·2	t_2=54·1	v=5·538	

Bismuth-Tin, Silver—Silver, Argentine.

t_1=26·2	t_2=56·5	v=2·609	2·608
t_1=26·6	t_2=53·6	v=2·617	
t_1=27·0	t_2=51·0	v=2·598	

Antimony-Zinc, Silver—Silver, Argentine.

t_1=24·3	t_2=51·5	v=4·329	4·333
t_1=24·6	t_2=49·3	v=4·325	
t_1=25·0	t_2=47·5	v=4·345	

5 Silver, Argentine—Silver, *Bismuth* (crystal axial).

t_1=30·0	t_2=45·6	v=1·152	1·154
t_1=30·5	t_2=44·6	v=1·150	
t_1=31·2	t_2=42·8	v=1·160	

5 Silver, Argentine—Silver, *Bismuth* (crystal No. 1, equatorial).

			Mean.
$t_1=31^\circ\cdot2$	$t_2=58^\circ\cdot1$	$v=1\cdot706$	1·702
$t_1=32\cdot5$	$t_2=48\cdot7$	$v=1\cdot700$	
$t_1=32\cdot5$	$t_2=48\cdot1$	$v=1\cdot700$	

5 Silver, Argentine—Silver, *Bismuth* (crystal No. 2, axial).

$t_1=30\cdot0$	$t_2=44\cdot3$	$v=1\cdot073$	1·075
$t_1=30\cdot0$	$t_2=42\cdot7$	$v=1\cdot070$	
$t_1=30\cdot2$	$t_2=41\cdot2$	$v=1\cdot081$	

5 Silver, Argentine—Silver, *Bismuth* (crystal No. 2, equatorial).

$t_1=28\cdot7$	$t_2=39\cdot5$	$v=1\cdot492$	1·499
$t_1=28\cdot7$	$t_2=39\cdot5$	$v=1\cdot494$	
$t_1=29\cdot0$	$t_2=51\cdot0$	$v=1\cdot500$	

Silver, *Bismuth* (crystal No. 3, axial)—5 Silver, Argentine.

$t_1=26\cdot2$	$t_2=45\cdot1$	$v=1\cdot014$	1·012
$t_1=26\cdot3$	$t_2=43\cdot4$	$v=1\cdot012$	
$t_1=27\cdot5$	$t_2=40\cdot8$	$v=1\cdot012$	

5 Silver, Argentine—Silver, *Bismuth* (crystal No. 3, equatorial).

$t_1=28\cdot7$	$t_2=40\cdot0$	$v=1\cdot446$	1·442
$t_1=28\cdot7$	$t_2=39\cdot3$	$v=1\cdot441$	
$t_1=28\cdot7$	$t_2=38\cdot7$	$v=1\cdot438$	

5 Silver, Argentine—Silver, *Bismuth* (crystal No. 4, axial).

$t_1=27\cdot0$	$t_2=50\cdot2$	$v=1\cdot660$	1·661
$t_1=27\cdot4$	$t_2=46\cdot6$	$v=1\cdot662$	

5 Silver, Argentine—Silver, *Bismuth* (crystal No. 4, equatorial).

$t_1=27\cdot6$	$t_2=50\cdot2$	$v=1\cdot243$	1·240
$t_1=27\cdot8$	$t_2=46\cdot6$	$v=1\cdot237$	

2 Silver, Argentine—*Antimony*, No. 1 (axial), Silver.

$t_1=23\cdot8$	$t_2=34\cdot5$	$v=1\cdot485$	1·493
$t_1=23\cdot8$	$t_2=38\cdot0$	$v=1\cdot500$	
$t_1=24\cdot0$	$t_2=35\cdot5$	$v=1\cdot495$	

2 Silver, Argentine—*Antimony*, No. 1 (equatorial), Silver.

$t_1=22\cdot4$	$t_2=39\cdot0$	$v=1\cdot079$	1·090
$t_1=22\cdot4$	$t_2=36\cdot5$	$v=1\cdot090$	
$t_1=22\cdot8$	$t_2=35\cdot7$	$v=1\cdot103$	

2 Silver, Argentine—*Antimony*, No. 2 (axial), Silver.

$t_1=22\cdot6$	$t_2=46\cdot2$	$v=1\cdot521$	1·517
$t_1=22\cdot8$	$t_2=43\cdot4$	$v=1\cdot517$	
$t_1=23\cdot0$	$t_2=44\cdot8$	$v=1\cdot514$	

2 Silver, Argentine—*Antimony*, No. 2 (equatorial), Silver.

			Mean.
$t_1=23°{\cdot}0$	$t_2=42°{\cdot}0$	$v=1{\cdot}314$	
$t_1=23{\cdot}0$	$t_2=40{\cdot}5$	$v=1{\cdot}315$	1·317
$t_1=23{\cdot}2$	$t_2=32{\cdot}2$	$v=1{\cdot}321$	

As tellurium takes such an extraordinary place in the series, it seemed interesting to make a few experiments with a thermo-battery constructed out of tellurium-bismuth; and one composed of eight of these elements, whose soldering-points had but 60° temperature difference, decomposed a solution of sulphate of copper. A thermo-battery, made of 100 pairs of tellurium-bismuth, whose extremities have 100° temperature difference, will give an electromotive power equal to four of DANIELL'S cells. Such a thermo-battery I am at present constructing.

Selenium and red phosphorus conduct electricity, but so badly, that the galvanometer used in all the former experiments could not here be used, and in its stead an astatic multiplier, with 20,000 folds of wires, was employed. As the deflections of the needle were very small, in the calculation the angle of deflection may be said to be proportional to the electromotive forces. Table IV. contains the results obtained with the astatic multiplier and the copper boxes.

TABLE IV.

2 Silver, Argentine—*Red Phosphorus* (only filed, not coppered), Silver.

$v=1{\cdot}08$

2 Silver, Argentine—*Red Phosphorus* (coppered), Silver.

$v=1{\cdot}07$

Selen, Bismuth—19 Copper, Argentine.

$v=3{\cdot}57$ }
$v=3{\cdot}62$ } 36·0

From the values of the thermo-electric numbers of the different metals given in Table I., the ratio of the electromotive power of two elements constructed out of any two of those metals may be calculated. In order, therefore, to ascertain the accuracy of these values, several combinations were made, and their electromotive powers determined. In the following Tables the ratio of the electromotive powers for the different combinations is given.

TABLE V. Experiments made with the large zinc boxes and the multiplier.

	Ratio. Found.	Ratio. Calculated.
Silver, Bismuth (commercial wire)—Silver, Bismuth, Silver, Bismuth (pure wire)	1·097	1·088
Silver, Potassium—Silver, Palladium	1·543	1·542
Silver, Argentine—Silver, Palladium	1·467	1·472

TABLE V. (Continued.)

	Ratio. Found.	Ratio. Calculated.
Silver, Palladium—Silver, Sodium	1·153	1·151
Copper, Potassium—Copper, Sodium	2·149	2·145
Silver, Quicksilver—Silver, Aluminium	1·967	1·967
Silver, Quicksilver—Silver, Magnesium	2·129	2·143
Silver, Lead—Silver, Tin	1·027	1·029
Silver, Copper (No. 2)—Silver, Platinum	1·280	1·275
2 Silver, Gold—Silver, Tin	1·223	1·226
2 Zinc, Silver—Cadmium, Silver	1·245	1·253
Copper (precipitated galvanoplastically), Argentine—Aluminium, Argentine	1·370	1·385
Antimony (pure wire), Argentine—Copper, Argentine	1·228	1·227
Silver, Palladium—Antimony (commercial wire), Silver	1·900	1·876
Strontium, Argentine—Aluminium, Argentine	1·838	1·834
Lithium, Silver—Silver, Palladium	1·056	1·058
Iron, Silver—Calcium, Silver	1·220	1·224

TABLE VI. Experiments with the copper boxes and multiplicator.

Silver, Argentine—Bismuth, alloy of Bismuth, Antimony	1·330	1·278
7 Copper, Argentine—Silver, Bismuth (pure cast)	1·198	1·189
Silver, Argentine—Argentine, Cobalt (No. 1)	1·422	1·403
Silver, Argentine—Cobalt (No. 2), Argentine	3·497	3·510
Silver, Argentine—Copper, Nickel	1·293	1·303
Silver, Argentine—Iridium, Palladium	1·570	1·542
Silver, Argentine—Gas-coke, Palladium	1·479	1·448
Silver, Argentine—Arsenic, Copper	1·104	1·086
Antimony (pure cast), Copper—Silver, Argentine	2·068	2·074
Alloy of Bismuth, Tin, alloy of Antimony, Zinc—Silver, Argentine	1·729	1·723

TABLE VII. Experiments with the copper boxes and the astatic multiplier.

Red Phosphorus (coppered), Copper—2 Silver, Argentine	1·040	1·010
Red Phosphorus (coppered), Argentine—2 Silver, Argentine	1·390	1·410
Selen, Antimony—19 Copper, Argentine	4·370	4·370
Selen, Tellurium—19 Copper, Argentine	2·510	2·610

In conclusion, I may here be allowed to express my thanks to Professor KIRCHHOFF for his valuable advice and assistance whilst carrying out this research, and also to Professor BUNSEN for his kindness in having placed his collection of metals at my disposal.