XVIII. *On the Relative Power of Metals and Alloys to conduct Heat.*—Part I. *By*

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Metals and their alloys being now so extensively employed in arts and manufactures, and for instruments of precision, we have thought that it would be interesting, in a scientific or commercial point of view, if we were to examine their conductibility carefully and completely.

To enable us to determine with accuracy the conducting power of all the ordinary metals, and of seventy of their alloys and thirty of their amalgams, we had to find out a new method of determining the conducting power of metals; for the process followed by M. Despretz could only give results to be relied upon for a few of the best conductors, such as silver, gold, and copper. Further, his process, which consists in having a long and thick bar of metal, so as to allow holes to be drilled, in which mercury and the bulb of a thermometer are inserted, would have required a large quantity of each metal in a state of purity, the labour of obtaining which, even comparatively pure, is well known. Also from the fact of mercury being employed, we should have been unable to ascertain the conducting power of such important alloys as brass and bronzes, and could not have applied the process to amalgams.

The method which we have followed gives such consistent results, that we have not only been able to determine the influence exercised on the conducting power of metals by the addition of 1 or 2 per cent. of another metal, but also to appreciate the difference of conductibility of two alloys made of the same metals, and only differing by a few per cent. in the relative proportions of the metals composing them. At the same time the conditions theoretically required in order to obtain results independent of everything but the nature of the substances, are not very rigorously fulfilled, so that the term conducting power, as used by us, must be understood in a somewhat qualified sense, and as having relation to our method of determining it. We believe, however, that the ratios of the conducting powers, as determined by our method, do not differ from those of the real conducting powers.

Before describing the process followed and examining the results obtained, it is necessary to state that we have made a great number of experiments with the hope of solving the important chemical question, Are alloys simple mixtures of metals, or are they definite compounds? With this view we have operated on a large number of alloys and

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amalgams, convinced that if the chemical nature of alloys and amalgams is still enveloped in darkness, it is because they have been prepared with impure or commercial metals, and not made in equivalent quantities. The consequence has been, that as metals have only a slight affinity for each other, and as the definite compounds which they have a tendency to form were mixed with an excess of one of the metals employed, the alloys produced have presented properties which could lead to no information as to their nature. These difficulties have been increased by the fact, that in many alloys, such as those of copper and tin, or copper and zinc, the metals have a tendency, when allowed to cool slowly, to form several crystallizable compounds, differing in their composition in the various parts of the alloys; the less fusible being on the exterior, and those more so in the interior of the mass. The impurities existing in commercial metals are often so large as considerably to modify the properties of their alloys; for we have found in our researches that if 1 per cent. of a metal be added to 99 of another, it alters its conducting power most materially. To avoid these causes of error, we have composed our alloys of pure metals and employed definite proportions.

The apparatus which we used is composed of a deal box (Plate XXVII.), A, 105 millims. in width, 165 millims. in length, and 220 millims. in height; with a cover, and painted white externally and internally. Inside this box are two vulcanized india-rubber square vessels, the sides of which are 15 millims. thick. The larger vessel, B, measures internally 52 millims. on the side and 125 millims. deep, and is capable of containing 336 cub. cent. of water. The smaller vessel, C, is 27 millims. on the side and 125 millims. deep, and has a capacity of 90 cub. cent.

These vessels are painted white and surrounded with wadding; and still further to prevent any radiation of heat, a deal board, D, is placed between the two vessels. So little heat is radiated from the vessel B, when it contains 200 cub. cent. of water at 90°, to the smaller vessel C, containing 50 cub. cent. at 16°, that in a quarter of an hour, the time required for our experiments, the water in the latter vessel did not rise one-tenth of a degree Centigrade. Therefore all sensible radiation and conduction was avoided, and the rise of temperature in this vessel, during the experiment, must have been entirely due to the heat conducted by the square bar of metal (G) used. This bar is 6 centims. long and 1 centim. square, and is so arranged in the experiment, that 1 cub. cent. is in the vessel B, 1 cub. cent. in the vessel C; 3 cub. cent. are covered by the sides of the boxes through which it passes; and the last 1 cub. cent., marked H, is covered with a piece of vulcanized india-rubber tubing, and the whole made secure from any leakage by lining the sides of the holes, through which the bar passes, with a varnish made of caoutchouc dissolved in benzine. This bar is placed 54 millims. from the bottom of B, and 12 millims. from the bottom of C.

When we desire to make an experiment, the vessels are put in water so as to equalize their temperature; they are then carefully wiped and placed in the wooden box, surrounded with wadding, and 50 cub. cent. of water, at the temperature of the room, poured into the vessel C; the two boxes are then covered with vulcanized india-rubber lids, each perforated with two holes; the vessels are covered with wadding, and the lid of the box shut. Through one of the holes in the vessel C is introduced a very sensitive thermometer, graduated in tenths of a degree; in the other hole is a small whalebone rod, E, having at its extremity a piece of vulcanized rubber to agitate thoroughly the water in the vessel during the experiment, and render it of a uniform temperature. When the water in the vessel C has attained a fixed temperature (which is generally within one degree of that of the room), a thermometer is introduced into the vessel B, and 200 cub. cent. of boiling water poured in by means of a funnel, which communicates with a tube F; the temperature of the liquid falls to 86° or 88°, but is again raised within three minutes to 90°, by a small jet of steam, generated in a flask, the water in which is kept boiling during the whole of the experiment. A few experiments soon enable the operator to keep up a constant temperature of 90° in the vessel B during the quarter of an hour which the experiment requires. Immediately on the boiling water being poured into the vessel B, the operator looks attentively at the scale of the thermometer in vessel C, and as soon as he perceives the column of mercury rising, he carefully marks the second and minute dials of his watch, and makes similar marks fifteen minutes further on. During this time the operator agitates the liquid in vessel C with the agitator E, and every five minutes marks down the rise of temperature. The water in the vessel B has a uniform temperature, owing to the agitation produced in it by the small jet of steam which arrives almost close to the bottom.

The following figures will show how insignificant was the radiation from the large vessel B, containing 200 cub. cent. of water at 90° C., to the smaller vessel C, containing 50 cub. cent. of water at natural temperature, when the two vessels were not connected by a metallic bar, though placed in their usual position in the apparatus, for in fifteen minutes the temperature of the water in the smaller vessel C only increased 0·05 of a degree, and in half an hour only 0°·7.

	Temperature of the water in the vessel C.
	17°·20
After 15 minutes	17·25
After 30 minutes	17·90

Therefore the entire increase of temperature in the vessel C, in our experiment, must have been due to the heat conducted by the bar.

It was found that it required twenty-four hours before the temperature of the water in the vessels of the apparatus was in equilibrium with that of the surrounding atmosphere, when 200 cub. cent. of boiling water was poured into the vessel B, and the apparatus left to cool. It might be objected that in our experiments we neglected to take into account the heat absorbed by the sides of the vessel C; but we found, from a great number of experiments, that whether we took into consideration, or not, the amount of heat absorbed, it did not affect in any degree the relative conductibility of the metals and their alloys; but it must be borne in mind that it was not the absolute quantity of heat communicated to the bar in vessel B which was determined in vessel C, but the relative facility of conduction by various metals, all circumstances being the same. The best proofs that we can give of the accuracy of the process are—1st, that the series of alloys which conduct heat in the ratio of the equivalents of the metals composing them would not have shown such a coincidence between the observed and theoretical results if our process had presented any serious defects. 2nd, that we have been able to determine with accuracy the marked influence exercised by the addition of 1 per cent. of a metal to another metal. 3rd, it will be seen further on in the paper, that we have determined with precision, that in copper bars, having different conducting surfaces, the observed result agrees with the calculated one.

The process followed to ascertain the amount of heat absorbed by the vessel C, consisted in putting into the vessel, cooled down to the natural temperature, 50 cub. cent. of water, having the temperature which the water had when the last experiment was completed, and noticing how much heat was absorbed from the water during the quarter hour. For example—

	Mean conductibility.	Mean absorption.	Total.
Zinc cast vertically . . .	20·03	8·80	28·83
Antimony cast vertically .	6·12	2·50	8·62

but as $20·03 : 6·12 :: 28·83 : x = 8·80$, the relative conducting power of antimony.

Therefore it is quite clear that the addition of the heat absorbed by the vessel C, to the heat of the water in the same, would have complicated our results without any advantage.

We shall only give two examples here to show how very regularly the apparatus works, and how accurately it indicates the different degrees of conducting power of two metals. The increase of temperature, in the successive five minutes, is in the same ratio whether the conductors be good or bad.

Name of the metals.	Temperature of the room.	Temperature of the 50 cub. cent. of water before beginning.	Temperature of the 50 cub. cent. of water after each 5 minutes.			Constant temperature of the 200 cub. cent. of water.	Conductibility found.	Mean.
Pure Copper...	20°	21°	34°·4	42°·7	48°·0	90°	27·0	27·05
	20	20	33·6	41·8	47·1	90	27·1	
Lead	18	18·2	22·0	25·1	27·4	90	9·2	9·17
	18	18·3	22·1	25·0	27·45	90	9·15	

In fact, it is owing to the facility of appreciating within two-tenths of a degree, in two successive essays, the conducting power of a metal or alloy, that we have been able to determine the precise conducting power of so large a number of alloys and amalgams, and even these researches have required more than a year's constant labour and attention.

The metals which we used were purified by the following processes:—

Gold.—About 140 grammes of nearly pure gold were dissolved in aqua regia, and the liquid evaporated to dryness. The residue was dissolved and filtered, and to the filtrate a solution of protosulphate of iron was added. The gold thus precipitated was washed with hydrochloric acid, and fused with a little borax and nitre.

Silver.—Pure chloride was reduced by fusing with pure carbonate of potash.

Copper was obtained by reducing pure oxide of copper by a current of pure hydrogen, or by depositing it from a solution of pure salt at a pole of a galvanic battery.

Tin.—Well-crystallized protochloride of tin was recrystallized, and when quite pure, was reduced by being fused with a mixture of bicarbonate of soda and lamp-black.

Bismuth.—Pulverized bismuth was dissolved in strong nitric acid, the liquor filtered through asbestos, and mixed with twenty times its bulk of water. The subnitrate thus obtained was washed, dried, and reduced with lamp-black.

Antimony.—This metal was pulverized and fused with a mixture of pure nitrate and carbonate of soda; the antimoniate of soda so produced was washed with boiling water until the filtrate was no longer alkaline. The insoluble mass was dried and reduced with lamp-black.

Lead.—Nitrate of lead was recrystallized, and when pure, the salt was dried and calcined. The oxide of lead so prepared was reduced by lamp-black.

Zinc.—Vieille Montagne zinc was redistilled twice.

Cadmium.—This metal was obtained pure by dissolving in hydrochloric acid, and passing sulphuretted hydrogen into the liquor. The sulphuret of cadmium was well washed with a solution of sulphuretted hydrogen and dissolved in hydrochloric acid; carbonate of ammonia was added, and the precipitate was washed, dried, mixed with lamp-black, and the cadmium distilled.

The platinum, aluminium, iron and sodium which we used, were only commercially pure.

As the determination of the power of metals to conduct is of great importance, we shall give here a detailed record of the results obtained:—

Name of the metals.	Temperature of the 50 cub. cent. of water before beginning.	Temperature of the 50 cub. cent. after 15 minutes.	Conductibility found.	Mean.	Conductibility. Silver=1000.
Silver $\frac{1000}{1000}$	19°·8 19·7	51°·6 51·7	31·8 32·0	31·9	1000
Gold $\frac{1000}{1000}$	14 13·6	45·4 44·8	31·40 31·20	31·30	981
Gold $\frac{991}{1000}$	20·3 20·3 20·0	47·3 47·0 46·7	27·0 26·7 26·7	26·80	840
Copper (rolled)	19·5 20·0 21·0 20·5	46·3 47·1 48·0 47·45	26·8 27·1 27·0 26·95	26·95	845
Copper (cast)	21·30 21·45	47·2 47·3	25·90 25·83	25·87	811
Mercury	15·0 16·6	36·7 38·1	21·7 21·5	21·60	677
Aluminium	18·2 17·7	39·3 39·0	21·1 21·3	21·20	665

TABLE (continued).

Name of the metals.	Temperature of the 50 cub. cent. of water before beginning.	Temperature of the 50 cub. cent. after 15 minutes.	Conductibility found.	Mean.	Conductibility. Silver=1000.
Zinc (rolled)	18°·4 19·9 18·5	39°·0 40·2 38·9	20·6 20·3 20·4	20·45	641
Zinc (cast vertically)	19·6 19·2 14·0	39·8 39·1 35·0	20·2 19·9 20·0	20·03	628
Zinc (cast horizontally)	20·6 20·8	40·0 40·2	19·4 19·4	19·40	608
Cadmium	18·0 16·5	36·5 34·8	18·5 18·3	18·40	577
Malleable iron	18·70 19·05	32·6 33·0	13·9 13·90	13·92	436
Tin	20·5 21·2	34·0 34·6	13·55 13·4	13·45	422
Steel	15·2 15·5	27·8 28·2	12·6 12·7	12·65	397
Platinum	15 14	27·1 26·2	12·1 12·2	12·15	380
Sodium	14·2 14·1	25·9 25·7	11·7 11·6	11·65	365
Cast iron	14·9 15·6	26·4 27·0	11·50 11·40	11·45	359
Lead	20·5 18·3	29·70 27·45	9·20 9·15	9·17	287
Antimony (cast horizontally)	14·6 14·3	21·5 21·1	6·9 6·8	6·85	215
Antimony (cast vertically)	19·2 18·9	25·30 25·05	6·10 6·15	6·12	192
Bismuth	19·0 18·3	21·00 20·20	2·00 1·90	1·95	61

From the details given in describing the apparatus used in our experiments and the methods followed, it will be easy to perceive that for the solid metals we always employed square bars, 1 c. m. square and 6 c. m. long. These bars were always cast of a larger size than required, and were filed down to the exact dimensions. For mercury and sodium we were obliged to have recourse to other methods of operating. We employed a very thin sheet-iron box, the internal dimensions of which were exactly those of the square metallic bars which we usually employed. To admit the mercury, there was in the middle of one of the longitudinal surfaces, a small hole 4 millims. in diameter, and when full of mercury the hole was stopped with a little thick caoutchouc varnish. The box was then weighed, by which it was easy to ascertain if it was quite full. It was then introduced into the two vulcanized india-rubber boxes, and the conducting power of the mercury and box determined. By subtracting the special conducting power of the box (which had previously been ascertained) from the total conducting power of the box and mercury, the difference was the conducting power of the mercury as given above. We operated in the same way with sodium, with this difference, that we melted the sodium under benzine, and whilst fluid filled the box with it. Of course we cannot pretend that the figures which we give in these two instances represent their exact conducting power, but they are at all events very near the truth. We endeavoured to ascertain the conducting power of potassium in the same way, but failed, owing to the tendency which potassium has to granulate when melted under benzine.

We think it our duty to state, that we are aware of the respective works of M. LANGBERG and of MM. WIEDEMANN and FRANZ, but that we have not followed their thermo-electrical process, as we deemed our method capable of giving more direct and reliable results. We have, however, great pleasure in confirming their results with reference to the superior conducting power of silver to that of gold, though the order of conductibility of the other metals as determined by our process is different from theirs.

In determining the conducting power of metals great attention must be paid to their physical state, as their conductibility is modified by their molecular condition.

Influence of Molecular Condition.

We found that the conducting power of several metals was different when they were rolled out into bars, or when cast. Thus, for example,—

	Conductibility found.	Conductibility. Silver = 1000.
Rolled copper . . .	26·95	845
Cast copper	25·87	811.

It is probable that the reason why rolled metal conducts heat better than the same metal when simply cast, is that the molecules composing the rolled metal are in closer contact than those composing the cast metal, owing to the process of rolling; and it is worthy of observation, that this view agrees with Mr. J. P. JOULE's theory, that heat travels in bodies by the vibration of matter, and not by the fluid called caloric, travelling between the interstices of the molecules.

Influence of Crystallization.

The influence of the molecular arrangement is clearly illustrated in the following examples, where it is seen that the conducting power of zinc, antimony, and bismuth is modified according to the axes of crystallization. Thus the conducting power of zinc is different if the sample for experiment is cast horizontally or vertically; for example,

	Conductibility found.	Conductibility. Silver = 1000.
Zinc cast vertically . .	20·03	628
Zinc cast horizontally .	19·40	608

If these two square bars be broken and examined, they present a very great difference. The one cast vertically has four axes of crystallization, all starting from the centre and proceeding towards each angle of the bar, as shown in Plate XXVII. The one cast horizontally has one centre line or axis of crystallization, which divides the square bar into three parts.

The results obtained with antimony are the following:—

	Conductibility found.	Conductibility. Silver = 1000.
Antimony cast vertically . .	6·12	192
Antimony cast horizontally .	6·85	215

We shall refer to the extraordinary influence exercised by crystallization on conduction of heat when we examine some of the alloys.

Influence of small amounts of impurities on the Conducting Power of Metals.

We have thought that it would be useful to ascertain the influence which 1 per cent. of a metal exercises when added to another, and these are the curious results obtained with gold and silver:—

	Found.	Conductibility. Silver =1000.
Pure gold	31·31	981
Gold with 1 per cent. of silver . . .	26·80	840

Therefore the addition of 1 per cent. of silver, the best conductor, to gold, diminishes its conducting power nearly 20 per cent.

We have observed much more marked examples of the diminution of conductibility of a metal by the addition of 1 per cent. of another metal, for example, whilst the conducting power of pure mercury is 21·60, it is only 13·15 when amalgamated with 1·25 per cent. of tin. Professor W. THOMSON having lately discovered that a small quantity of various metals added to copper greatly modifies the conduction of electricity by this metal, we deemed it advisable to try if the conduction of heat by copper would also be altered if we were to alloy it with 1 per cent. of various other metals. We were fortunate enough to obtain results which coincide with his, namely, that some metals increase the conduction of heat by copper, whilst others diminish it.

We have also examined the influence which carbon exercises on the conductibility of iron, and we hope that the results observed will prove useful in a commercial point of view; for as seen by the figures obtained, the difference is about equal to 18 per cent. The following are the results:—

	Found.	Conductibility. Silver=1000.
Malleable iron *	13·92	436
Steel	12·65	397
Cast iron	11·45	359

* The iron was manufactured from the same cast iron as that used in this experiment, and both were identical to those used by Mr. JOULE in his thermo-electrical experiments. Their composition was as follows:—

	Analysis of cast iron.	Wrought iron.
Carbon	2·275	0·296
Silicium	2·720	0·120
Phosphorus	0·645	0·139
Sulphur	0·301	0·134
Manganese and aluminium .	traces	
Iron	94·059	99·311
	100·000	100·000

We also thought that it would be interesting to ascertain what would be the influence of another non-metallic substance on a metal, and we accordingly made the following series:—

	Found.	Mean.	Conductibility. Silver=1000.
Cast copper	......	25·87	811
Copper with 1 per cent. of arsenic ...	18·1, 18·3	18·20	570
Copper with 0·5 per cent. of arsenic	21·3, 21·4	21·35	669
Copper with 0·25 per cent. of arsenic	24·7, 24·5	24·60	771

These results confirm the influence of a non-metallic body on the conductibility of a metal. It is interesting to observe that the influence of arsenic on the conduction of heat on copper is in ratio with the increased quantity of arsenic.

We have also examined a great number of alloys with the hope of throwing some light on their chemical composition, and we trust that the facts which we are about to describe will not only tend to illustrate this point, but will also be of interest from the new and various results observed.

We have also made a great variety of experiments with the view of ascertaining if there be a general law in connexion with the conduction of heat by alloys, and although we could not trace any general rule, still we observed several useful facts.

The conduction of heat by alloys may be considered under three general heads:—

1. Alloys which conduct heat in ratio with the relative equivalents of the metals composing them.

2. Alloys in which there is an excess of equivalents of the worse conducting metal over the number of equivalents of the better conductor, such as alloys composed of 1Cu and 2Sn; 1Cu and 3Sn; 1Cu and 4Sn, &c., and which present the curious and unexpected rule that they conduct heat as if they did not contain a particle of the better conductor; the conducting power of such alloys being the same as if the square bar which we were examining was entirely composed of the worse conducting metal. A not less remarkable fact is that the alloys of a series such as those of 2 equivalents of bismuth and 1 of lead, 3Bi and 1Pb, 4Bi and 1Pb, 5Bi and 1Pb, all conduct the same, viz. about 1·9, the various increasing quantities of lead exercising no influence on the conductibility of the alloys. The results obtained with this class of alloys are most important to engineers; for it will be seen in the case of the alloys of brass and bronze, that no increase is gained in the conductibility of an alloy by increasing the quantity of a good conductor; nay, in many cases it would be a decided loss, unless a sufficient quantity of the better conducting metal be employed to bring the alloy under the third head.

3. Alloys composed of the same metals as the last class, but in which the number of equivalents of the better conducting metal is greater than the number of equivalents of

the worse conductor; for example, alloys composed of 1Sn 2Cu; 1Sn 3Cu; 1Sn 4Cu: in this case each alloy has its own arbitrary conducting power; the conductibility of such an alloy gradually increases and tends towards the conducting power of the better conductor of the two metals composing the alloy.

Before describing the experiments which relate to these three classes of alloys, we deem it advisable to state, that from the numerous assays which we have made, we are led to believe that the conduction of heat by alloys is greatly modified by the crystalline system to which each of the metals composing them belongs, or by the peculiar crystalline form of its own crystals; for we have observed that some of the crystallized alloys of copper and tin, and copper and zinc, have a special conducting power of their own; for example,—

		Found.	Calculated.	Silver=1000. Found.	Silver=1000. Calculated.
Tin ... 1 equivalent ... Copper, 3 equivalents ...	38·21 61·79 100·00	15·75	21·37	494	670
Tin ... 1 equivalent ... Copper, 4 equivalents ...	31·73 68·27 100·00	4·96	21·88	155	686

Whilst the alloys which present little or no crystallization have a conductivity which is in ratio to the equivalent quantities of the metals composing them; for example,—

		Found.	Calculated.	Silver=1000. Found.	Silver=1000. Calculated.
Lead ... 1 equivalent ... Tin ... 3 equivalents ...	36·99 63·01 100·00	11·96	11·86	375	372
Lead ... 1 equivalent ... Tin ... 4 equivalents ...	30·56 69·44 100·00	12·17	12·14	381	381

The method which we have followed to calculate the theoretical conducting power of our alloys is the following:—

Multiply the per-centage quantity of each metal by the respective conducting power of that metal, add the results together and divide by 100; for example, in the alloy Pb 3Sn,

$$\begin{array}{lr} \text{Pb } 36{\cdot}99 \times 9{\cdot}17 = & 339{\cdot}19 \\ \text{3Sn } 63{\cdot}01 \times 13{\cdot}45 & 847{\cdot}48 \\ \hline & 100)1186{\cdot}67 \\ \hline & 11{\cdot}86 \end{array}$$

11·86 the theoretical conducting power of the alloy.

We have also taken care always to cool the alloys rapidly, so as to render their mass of a more uniform composition, and prevent, especially in copper and tin alloys, the formation of various crystalline compounds having different compositions.

The description of the physical appearance of these alloys will be given in a paper on their hardness.

The first class of alloys which we shall describe, are those which conduct heat in the ratio of the conductibility of the metals composing them. This class is represented by the alloys of tin and lead, and tin and zinc.

Formula of the alloys and per-centage.	Found (Mean).	Calculated.	Silver = 1000.	
			Found.	Calculated.
5Sn = 73·97 1Pb = 26·03	12·28	12·30	385	386
4Sn = 69·44 1Pb = 30·56	12·17	12·14	381	381
3Sn = 63·01 1Pb = 36·99	11·96	11·86	375	372
2Sn = 53·18 1Pb = 46·82	11·16	11·16	350	350
1Sn = 36·22 1Pb = 63·78	10·52	10·72	230	236
1Sn = 22·11 2Pb = 77·89	10·00	10·11	313	317
1Sn = 15·91 3Pb = 84·09	9·91	9·85	311	309
1Sn = 12·44 4Pb = 87·56	9·60	9·69	301	304
1Sn = 10·20 5Pb = 89·80	9·55	9·60	299	301

Tin and Zinc.

Formula of the alloys, and per-centage.	Temperature of the 50 cub. cent. before beginning.	Temperature of the 50 cub. cent. after 15 minutes, from 5 to 5 minutes.	Conductibility found.	Mean.	Calculated.	Silver = 1000.	
						Found.	Calculated.
5Zn = 73·43 1Sn = 26·57	17°·0 17·0	24°·9 30°·3 34°·2 24·7 30·2 34·3	17·2 17·3	17·25	18·25	541	572
4Zn = 68·86 1Sn = 31·14	16·4 16·0	24·3 30·5 34·7 24·1 30·0 34·3	18·3 18·3	18·3	17·99	574	564
3Zn = 62·43 1Sn = 37·57	17·6 16·7	25·3 30·5 34·4 24·5 29·9 33·7	16·8 17·0	16·9	17·57	530	551
2Zn = 53·11 1Sn = 46·89	18·5 17·5	26·4 31·5 35·2 24·9 30·3 34·1	16·7 16·6	16·65	16·95	522	532
1Zn = 35·61 1Sn = 64·39	18·1 17·4	25·5 30·5 34·1 24·6 29·8 33·4	16·0 16·0	16·00	15·80	501	495
1Zn = 21·65 2Sn = 78·35	17·1 16·6	23 8 28·7 32·3 23·3 28·2 21·7	15·2 15·1	15·15	14·90	475	467
1Zn = 15·55 3Sn = 84·45	17·5 17·6	24·3 28·9 32·2 24·4 28·9 32·1	14·7 14·5	14·6	14·39	458	451
1Zn = 12·14 4Sn = 87·86	17·3 17·5	23·8 28·7 32·0 23·8 28·8 32·0	14·7 14·5	14·6	14·25	457	447
1Zn = 9·95 5Sn = 90·05	17·1 17·0	23·6 28·4 31·7 23·4 28·2 31·5	14·6 14·5	14·55	14·10	456	442

The above two series of alloys are the only ones which conducted heat as above stated; and from experiments which will be described further on, we believe that the metals composing these alloys are simply mixed and not combined together.

Alloys containing an excess of the worse conducting Metal.

The study of this class of alloys being most interesting, we have made many experiments in order to discover why the presence of one metal completely annihilates the conducting power of the other, especially when the latter is the better conductor of the two.

The following series will illustrate the above statement.

Lead and Antimony.

Formula of the alloys and per-centage.	Found (Mean).	Calculated.	Silver = 1000.	
			Found.	Calculated.
1Pb = 61·61, 1Sb = 38·39	6·05	8·00	190	251
1Pb = 47·60, 2Sb = 52·40	5·90	7·57	185	237
1Pb = 34·86, 3Sb = 65·14	5·85	7·18	184	225
1Pb = 28·63, 4Sb = 71·37	5·70	6·99	179	219
1Pb = 24·30, 5Sb = 75·70	5·70	6·85	179	215

It will be perceived, on looking over the results obtained, that all these alloys conduct heat almost as if the square bars examined were composed of pure antimony, the conducting power of which is 6·12; for if lead, which has a conducting power of 9·17, had influenced the passage of heat through the bars, the conducting power of the alloys would have been much higher, as shown by the column of theoretical conductibility.

The same results were obtained with the following series composed of bismuth and antimony:—

Antimony and Bismuth.

Formula of the alloys and per-centage.	Found (Mean).	Calculated.	Silver = 1000.	
			Found.	Calculated.
1Sb = 37·74, 1Bi = 62·26	1·97	3·52	62	110
1Sb = 23·26, 2Bi = 76·74	1·87	2·92	59	91
1Sb = 16·81, 3Bi = 83·19	1·90	2·64	59	83
1Sb = 13·17, 4Bi = 86·83	1·50	2·47	47	77
1Sb = 10·82, 5Bi = 89·18	1·55	2·39	48	75

We now describe the most important series of this class of alloys, namely, that consisting of those composed of tin and copper.

Copper and Tin.

Formula of the alloys and per-centage.	Temperature of the 50 cub. cent. before beginning.	Temperature of the 50 cub. cent. after 15 minutes.	Conductibility found.	Mean.	Calculated.	Silver = 1000. Found.	Silver = 1000. Calculated.
Cu=34·98, Sn=65·02	20·8°, 19·8	34·0°, 33·1	13·2, 13·3	13·25	17·80	415	558
Cu=21·21, 2Sn=78·79	19·4, 19·5	33·2, 33·2	13·8, 13·7	13·75	16·08	431	504
Cu=15·21, 3Sn=84·79	19·2, 19·45	32·80, 32·85	13·6, 13·4	13·50	15·33	423	481
Cu=11·86, 4Sn=88·14	18·9, 19·0	31·7, 32·1	12·8, 13·1	12·95	14·92	406	468
Cu= 9·73, 5Sn=90·27	19·4, 19·7	32·0, 32·4	12·6, 12·7	12·65	14·65	396	459

It is very interesting to observe, that although these alloys contain such different quantities of copper, viz. from 9·73 to 34·98, and this of a good conductor of heat, still no influence is exercised by it on the conductibility of the alloys, for they all give the same results as if the square bar experimented upon were composed of pure tin. Another fact, which increases the importance of the bronze alloys, is the difference which they present in their conductibility when they contain an excess of copper, not only with regard to the above series, but also between each alloy, all of which have a conducting power of their own.

Copper and Tin.

Formula of the alloys and per-centage.	Temperature of the 50 cub. cent. before beginning.	Temperature of the 50 cub. cent. after 15 minutes.	Conductibility found.	Mean.	Calculated.	Silver = 1000. Found.	Silver = 1000. Calculated.
Sn=38·21, 3Cu=61·79	21°, 20·6	36·7°, 36·4	15·7, 15·8	15·75	21·37	494	670
Sn=31·73, 4Cu=68·27	18·2, 18·0, 19·3, 18·4	23·1, 23·1, 24·25, 23·30	4·9, 5·1, 4·95, 4·90	4·96	21·88	155	686
Sn=27·10, 5Cu=72·90	17·7, 18·7, 17·9	24·2, 25·3, 24·5	6·5, 6·6, 6·6	6·6	22·50	207	705

The results obtained with Sn 4Cu were so extraordinary, that the bar first prepared was remelted and cast, from a fear that there might be in the mass some vacant space or hole impeding conduction; but as it yielded the same results when submitted to experiment, we decided to make a new bar, weighing most carefully the metals to be used and also the bar when cast; the loss being only 0·5 per cent., we were satisfied that the bar was sound, and still it gave the same figures as the bar first experimented with;

and therefore we concluded that an alloy of tin and copper containing 68 per cent. of the latter metal, has a conducting power five times less than it should have according to theory. From the above results it is highly probable that these alloys of tin and copper, and especially the three last, are definite chemical compounds; for if they were mixtures, they would conduct heat in ratio to the equivalents of the metals composing them, and would not each have a peculiar and different conductibility. These views are substantiated by experiments which we have made with square bars composed of sectional parts of copper and tin. These bars were made by a very skilful optician of this town, Mr. DANCER, and the parts soldered together with tin solder in so thin a layer, that it did not occupy a space of 0·25 millim. in the five junctions.

The first two bars we employed were of the usual dimensions, and composed of cubes of copper and tin, each 1 cub. cent., arranged in the following order:—

Bar No. 1 (see Plate XXVII.), 2 cubes of tin, 2 cubes of copper and 2 cubes of tin. Bar No. 2 (see Plate XXVII.), 2 cubes of copper, 2 cubes of tin and 2 cubes of copper. The results arrived at were—

	Found (Mean).	Calculated.	Silver =1000.	
			Found.	Calculated.
Bar No. 1	17·25	18·12	541	568
Bar No. 2	18·35	22·23	575	696

Therefore these two bars conduct heat nearly as the theoretical results indicate; the slight difference of 1 or 2 degrees between the obtained and calculated figures being probably due to the influence of the tin solder existing between each cube, and to the cubes not being perfect in all their dimensions. Still, what different results these bars give, as compared with alloys having nearly the same per-centage of tin and copper! for we have

			Obtained.	Calculated.	Silver =1000.	
					Found.	Calculated.
Bar No. 1. Tin	62·39	Conductibility	17·25	18·12	541	568
Copper...	37·21					
	100·00					
Alloy:— 1 equivalent of Tin......	65·02	Conductibility	13·25	17·80	415	558
1 equivalent of Copper	34·98					
	100·00					
Bar No. 2. Tin	29·33	Conductibility	18·35	22·23	575	696
Copper...	70·67					
	100·00					
Alloy:— 1 equivalent of Tin......	31·73	Conductibility	4·96	21·88	155	686
4 equivalents of Copper	68·27					
	100·00					

These results appear to us perfectly to substantiate our views, viz. that these alloys are definite chemical compounds, and not a mixture of metals; for if they were the latter they would conduct heat as the bars, and would not have a conductibility of their own. We deemed it advisable to have a third bar made, in which the cubes of copper and tin alternated, and these are the results obtained (see Plate XXVII.):—

	Found.	Mean.	Calculated.	Silver = 1000.	
				Found.	Calculated.
Bar No. 3	18·1 18·3	18·2	20·22	570	634

The composition of this bar is intermediate between that of the alloys Sn 2Cu and Sn 3Cu, which contain in 100 parts:—

		Obtained.	Calculated.	Silver = 1000.	
				Found.	Calculated.
1 equivalent of Tin ...... 51·83 2 equivalents of Copper 48·17 100·00	Conductibility	13·65	19·87	428	623
1 equivalent of Tin ...... 38·21 3 equivalents of Copper 61·79 100·00	Conductibility	15·75	21·37	494	670
Whilst the bar is composed of— Tin .... 45·36 Copper ... 54·64 100·00					
And conducts as a mixture, or		18·20	20·22	570	634

Notwithstanding these facts, we were not prepared for the curious results which we obtained with the following bar, composed of two longitudinal bars of tin soldered to two of copper and placed in juxtaposition (see Plate XXVII. bar No. 4); for although it contained in 100 parts the same weight of tin and copper as the last bar, it conducted heat at quite a different rate; in fact, its conductibility was the same as if the bar was entirely composed of pure copper, and did not contain half its bulk of tin.

	Found.	Mean.	Calculated.	Silver = 1000.	
				Found.	Calculated.
Bar No. 4	26·5 26·4	26·45	20·22	829	634

These interesting results were confirmed by having similar bars made of copper and zinc, and copper and lead.

	Found.	Mean.	Calculated.	Silver = 1000.	
				Found.	Calculated.
Bar No. 5. Copper = 56·12, Zinc = 43·88	26·8, 26·9	26·85	23·33	842	731
Bar No. 6. Copper = 43·42, Lead = 56·58	23·0, 23·1	23·05	16·42	723	515

We wished to ascertain if the extent of surface of the copper in contact with the other metal exercised any influence. We therefore had a bar made in which there was the same relative weight of tin and copper, but in which the surface of the two metals in contact was only one half of that of the bar No. 4. This was effected by soldering together one bar of copper, 1 centim. wide and 5 millims. thick, to a similar one of tin (see Plate XXVII. bar No. 7); and although the results leave some doubt whether the surfaces have an action, still the figures are sufficiently different to deserve serious consideration.

	Found.	Mean.	Calculated.	Silver = 1000.	
				Found.	Calculated.
Bar No. 7	24·2	24·15	20·22	757	634
Bar No. 4	24·1	26·45	20·22	829	634

The conductibility of these bars, and especially of Nos. 4 and 6, being equal to that of rolled copper, with which they had been made, we wished to see what would ensue, if bars of the same copper, and having the same diameter or surface as that of the copper in the above bars, were subjected to experiment. These are the results:—

Bar No. 8. Square copper bar of 7 millims. square, or one half the bulk of the bar usually employed.

Found.	Mean.	Calculated.	Silver = 1000.	
			Found.	Calculated.
19·1, 19·1	19·1	17·73	599	591

Bar No. 9*. Bar of rolled copper, 5 millims. thick and 1 centim. wide.

Found.	Mean.	Calculated.	Silver = 1000.	
			Found.	Calculated.
19·4, 19·3	19·35	18·86	606	591

* The surfaces in the vessels B and C of bar 9 being to our standard bar of copper $5:3\cdot5::26\cdot95:x=18\cdot86$.

Therefore there cannot remain a doubt that the presence of tin, zinc, or lead in the bars exercise a marked action on the conductibility of the copper; for we have—

1 centim. square bar of rolled copper	26·95
7 millims. square bar of rolled copper	19·12
5 millims. thick, 1 centim. wide } bar of rolled copper	19·35
1 centim. square bar of rolled copper and tin	26·45
1 centim. square bar of rolled copper and zinc . . .	26·85
1 centim. square bar of rolled copper and lead * . . .	23·05

Alloys in which there is an excess of the good Conductor.

Having already described the peculiar properties presented by four of the bronze alloys, viz. those of Sn 2Cu, Sn 3Cu, Sn 4Cu and Sn 5Cu, we should have nothing more to add to them, if we did not wish to illustrate the extraordinary influence which tin exercises on the conductibility of copper, and also to show that when there is a great excess of a good conductor in an alloy, it overcomes the resistance of the bad conductor, and in consequence the conductibility of such alloys increases with the proportion of the good conductor.

	Obtained.	Calculated.	Silver=1000.	
			Obtained.	Calculated.
Sn =27·10, 5Cu=72·90	6·60	22·50	207	705
Sn =15·68, 10Cu=84·32	9·80	23·90	307	749
Sn =11·03, 15Cu=88·97	12·82	24·50	402	768
Sn = 8·51, 20Cu=91·49	14·85	24·81	465	778
Sn = 6·83, 25Cu=93·17	15·15	25·02	475	784

Alloys of Bismuth and Antimony.

These alloys also show a gradually higher degree of conductibility as the number of equivalents of antimony increases in the compound.

	Obtained.	Calculated.	Silver=1000.	
			Obtained.	Calculated.
Bi =62·26, Sb=37·74	1·97	3·52	62	110
Bi =45·21, 2Sb=54·79	2·45	4·23	76	132
Bi =35·48, 3Sb=64·52	2·55	4·63	80	145
Bi =29·20, 4Sb=70·80	3·05	4·90	96	153
Bi =24·81, 5Sb=75·19	3·45	5·08	108	159

* A metal having a very low conducting power.

Alloys of Antimony and Lead.

Owing no doubt to the slight difference of the conductibility of these two metals,

Antimony being . . 6·12
Lead . . . . 9·17

the influence of excess of equivalents of lead over those of antimony is not so striking in this series as in the preceding one. The following are the results observed:—

	Found.	Calculated.	Silver=1000. Found.	Silver=1000. Calculated.
Sb=38·39, 2Pb=61·61	6·05	8·00	190	251
Sb=23·68, 4Pb=76·32	6·50	8·44	204	265
Sb=17·20, 6Pb=82·80	7·05	8·64	221	271
Sb=13·48, 8Pb=86·52	7·00	8·75	219	274
Sb=11·08, 10Pb=88·92	7·35	8·83	230	276

Alloys of Zinc and Copper.

The reason why we have kept these alloys all together, and have not divided them so as to bring them under the last two divisions, is, that they have a tendency to come entirely under the last division. We say a tendency, for they do not offer the distinctive degrees of conductibility that the alloys of copper and tin or bismuth and antimony present; but this may be due to the conducting powers of copper and zinc being within a few degrees of one another,

Cast Copper being . 25·87
Cast Zinc . . . . . 20·03.

Conductibility of Copper and Zinc Alloys.

	Obtained.	Calculated.	Silver=1000. Obtained.	Silver=1000. Calculated.
Cu=49·32, Zn=50·68	21·95	22·92	688	718
Cu=32·74, 2Zn=67·26	13·65	21·91	428	687
Cu=24·64, 3Zn=75·36	16·95	21·44	531	672
Cu=19·57, 4Zn=80·43	18·80	21·14	589	663
Cu=16·30, 5Zn=83·70	19·00	20·95	595	657

It is probable that Cu 2Zn and Cu 3Zn are definite compounds, for not only have they a special conducting power of their own far below that of the metals composing them, but also they are perfectly crystallized. The most splendid of all the brass alloys is the alloy CuZn, which is of a beautiful gold colour and crystallizes in prisms, often 3 centims. long. These crystals are also interesting on account of their extraordinary elasticity. It is surprising that so cheap an alloy has not been employed in commerce, for no commercial brass contains more than 30 to 35 per cent. of zinc, whilst the above one contains 50·68 of this metal. The only explanation that we can give of this fact is, that if copper be alloyed with more than 50 per cent. of zinc, the alloys formed do not possess the colour of brass, but become white as zinc, and therefore the manufacturers have never tried to unite these metals in the exact proportions given above. We say exact, for it is remarkable that a variation of a few per cent. in the relative proportions of the two metals no longer yields the beautiful alloy which we have noticed, but only a white and comparatively useless one.

Alloys with excess of Copper.

	Found.	Calculated.	Silver=1000.	
			Found.	Calculated.
Zn=33·94, 2Cu=66·06	19·80	23·80	621	748
Zn=25·52, 3Cu=74·48	20·35	24·37	638	764
Zn=20·44, 4Cu=79·56	21·25	24·67	666	770
Zn=17·05, 5Cu=62·95	22·80	24·87	715	780

We also made a bar 1 centim. cub. square of zinc and copper, placing a cube of each metal alternately, as in No. 3 bar of tin and copper, and the result obtained is similar; for we have—

	Found.	Calculated.	Silver=1000.	
			Found.	Calculated.
Bar 10....................	22·5	23·33	705	731

The facts presented by a bar 1 centim. square, and composed of two longitudinal bars of copper and zinc, have been described under the bar No. 5.

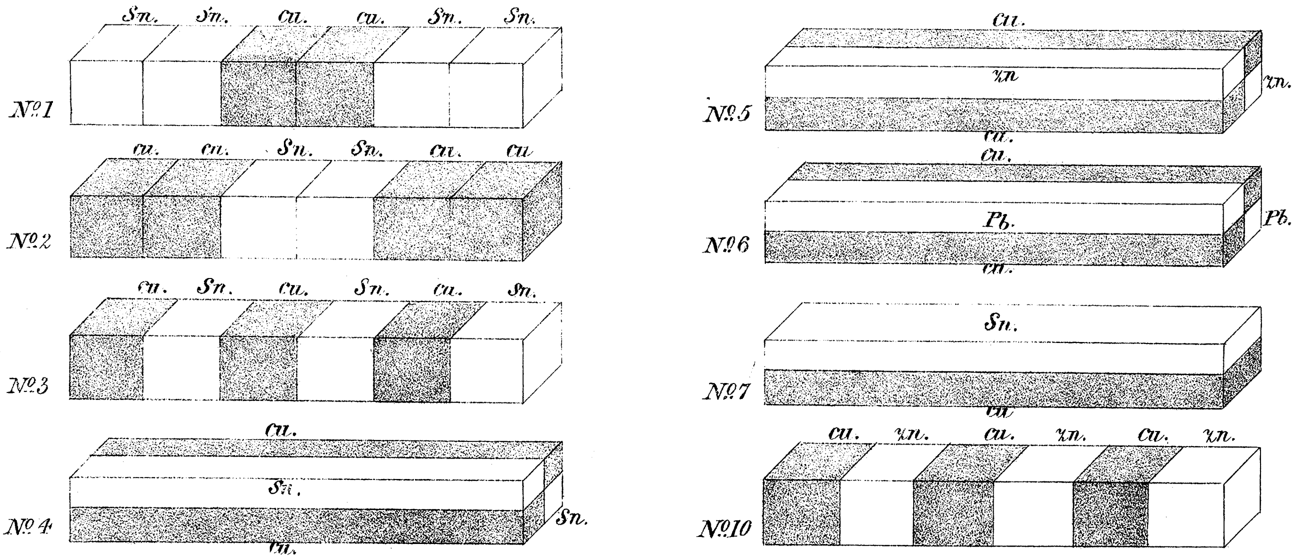
We also thought that it might be useful if we were to analyse the following commercial alloys, and determine their respective conducting powers.

		Found.	Calculated.	Silver = 1000. Found.	Silver = 1000. Calculated.
"Yellow brass" ...	Cu=64·0, Zn=56·0	17·80	22·73	558	712
"Pumps and pipes"	Cu=80·0, Sn= 5·0, Zn= 7·5, Pb= 7·5	13·60	22·57	426	707
"Mud plugs"	Cu=80·0, Sn=10·0, Zn=10·0	12·60	24·00	394	754
"Large bearings" ...	Cu=82·05, Sn=12·82, Zn= 5·13	11·00	23·97	345	751

It is extraordinary to find what a low conducting power these alloys possess; for with the exception of the alloy named "Yellow brass," they do not conduct heat better than wrought and cast iron. This is due to the impurities of the metals employed, and shows the advantage that there will be in substituting for them some of the much cheaper alloys above described.

We hope that the results contained in this paper will prove interesting to the members of the Royal Society, and deserve their approbation.

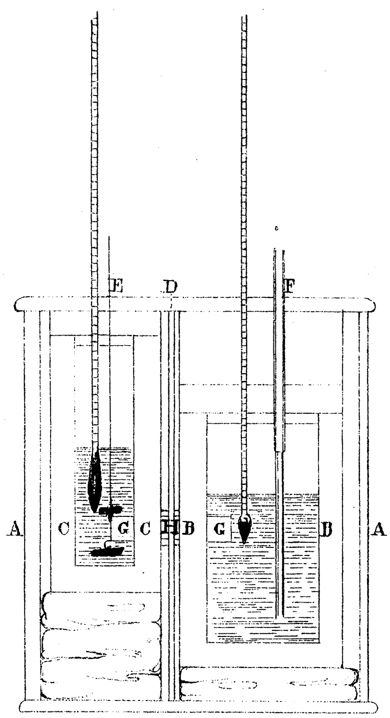
We shall shortly have the honour to forward Part II. of this paper "On Amalgams."



Setion of Zinc bar cast vertically

Section of Zinc bar cast horizontally

see page 355.



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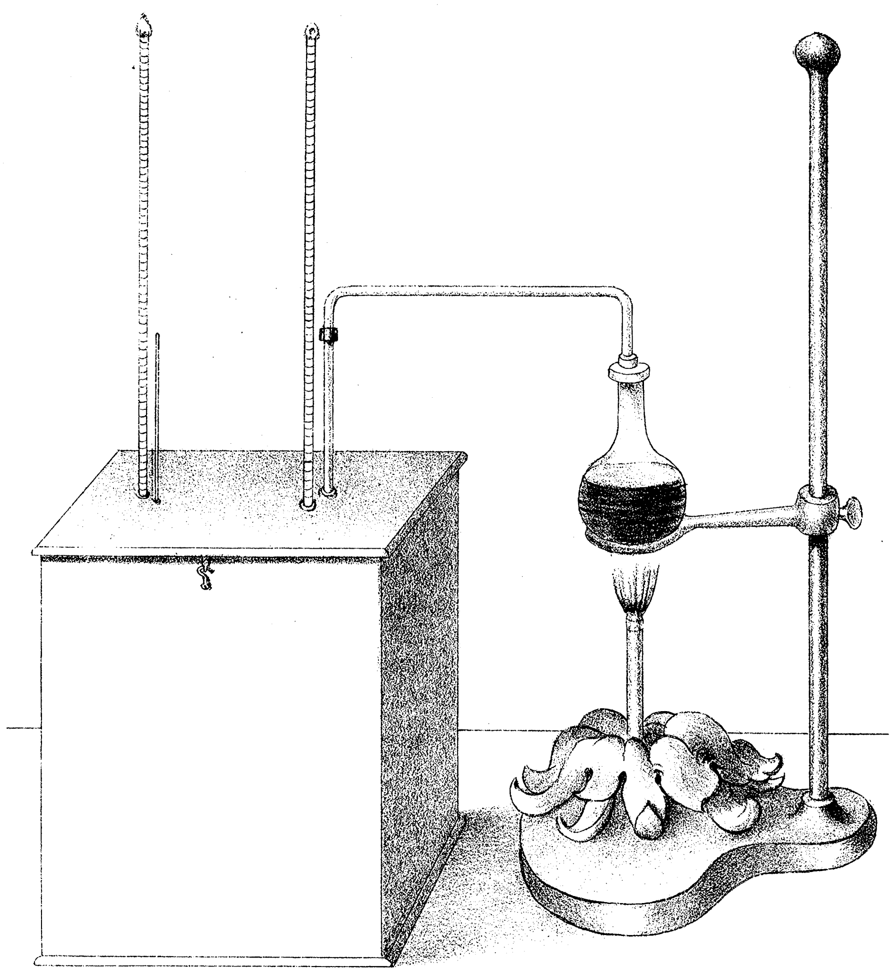

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