

XIX.—*On Alloys.*

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IN the following pages, my object, besides drawing attention to the general nature and properties of alloys, is to show reasons deduced from experiments, for my adoption of certain views on the subject, which may be summed up in a few words, thus:—

I. That, according to certain physical properties, the metals may be divided into two classes:—

Class A. Those metals which impart to their alloys their physical properties in the proportion in which they themselves exist in the alloy.

Class B. Those metals which do not impart to their alloys their physical properties in the proportion in which they themselves exist in the alloy.

The metals belonging to class A are lead, tin, zinc, and cadmium, and those belonging to class B, in all probability, all the rest.

II. That the alloys may be divided into three groups:—

a. Those made of the metals belonging to class A with one another.

b. Those made of the metals belonging to class A with those of class B.

c. Those made of the metals belonging to class B with one another.

III. That in nearly all cases the two-metal alloys may be considered as solidified solutions of the one metal in the other.

Under the term solidified solution I mean a solution of two

substances which has been allowed to solidify, as for instance, if a mixture of ether and alcohol were made, and sufficient cold could be produced to solidify it, we should produce a solidified solution of these two substances in one another. Again, if the chlorides of potassium and sodium, say in equal parts, be melted together and allowed to solidify, the solid thus produced is a solidified solution of the chlorides of potassium and sodium in one another. Glass is also a good example of a solidified solution; to produce it, different silicates are fused together and allowed to solidify. There is, however, an important point in the definition of the term solidified solution which must not be overlooked, namely, that the components are most intimately mixed together; in fact they are homogeneously diffused in one another, and to that extent that, even under the most powerful microscope, it would not be possible to distinguish the components of a solidified solution. As examples of this fact, glass may be quoted, which presents under high magnifying power a homogeneous mass; the silver and gold in the gold-silver alloys cannot be distinguished by the same test from one another.

Such then is a brief outline of what I consider alloys generally to be, and I will now proceed to explain why I have adopted these views; but before entering on the subject, I would state that what I am about to say regards only two-metal alloys made from pure metals. I make this remark, as some of the facts I am about to advance do not agree with those generally accepted.

A most useful piece of apparatus in making alloys for experimental purposes on a small scale is the common clay tobacco pipe, the bowl serving for a crucible, and the stem as a means of passing a gas (hydrogen) through it to mix the melted metals, to prevent oxidation, and afterwards as a form to cast the alloy in, by sucking the contents of the bowl into the stem, by means of an india-rubber tube. This form of apparatus might be made in any size in fire-clay, and would be of great service in experimenting with copper and its alloys.

If to a melted metal, a solid one be added, certain phenomena will be observed which may be classed under the following heads:

I. The solid metal dissolves quickly in the melted one, with evolution of heat, notwithstanding the fact that a cold piece of metal is put into the fused one, and also that a certain amount

of heat is rendered latent by the liquefaction of the solid metal ; as examples : gold and just melted tin ; sodium and mercury.

II. The solid metal dissolves quickly without evolution of heat ; as example : lead and just melted tin.

III. The solid metal dissolves slowly ; as example : copper and just melted tin.

IV. Only a partial alloy is formed : or in other words, each metal dissolves to only a limited extent in the other, in the same manner as ether and water, for water will only dissolve a certain amount of ether, and ether a certain amount of water. Now supposing these solutions were well shaken up together and submitted to an intense cold, sufficient to solidify them, the solid mass so produced would not be a solidified solution of ether and water, but a mixture of solidified solutions of ether in water, and water in ether : for no doubt under a high magnifying power the components of the mixture could be distinguished one from the other. Perfectly analogous cases are found with alloys, as examples :

I. Lead and zinc : lead will only dissolve 1·6 per cent. zinc, zinc only 1·2 per cent. lead.

II. Bismuth and zinc : bismuth will only dissolve 8·14 per cent. zinc, and zinc 2·4 per cent. bismuth.

These facts may be easily proved by fusing lead or bismuth in a crucible and adding zinc to the melted metal, when, after the addition of a certain quantity, the zinc alloy being specifically lighter, will float on the surface ; or better still, if, say equal parts of the metals be taken, fused, mixed thoroughly, and cast into a mould imbedded in red hot sand and allowed to cool slowly, the separation of the two alloys will be perfect. If on the contrary equal parts of the two metals be fused together, well mixed and cooled suddenly, such an alloy would be analogous to the case of ether and water, a mixture of solidified solution of zinc in lead or bismuth, and of bismuth or lead in zinc.

The physical properties of alloys may be divided into three classes :—

I. Those which in all cases are imparted to the alloy approximately in the ratio in which they are possessed by the component metals.

II. Those which in all cases are not imparted to the alloy in the ratio in which they are possessed by the component metals.

III. Those which in some cases are and in others are not imparted to the alloy in the ratio in which they are possessed by the component metals.

From the last class I shall endeavour to deduce the chemical nature of alloys; it will however be necessary to say a few words regarding the other two classes.

As types of the first class, specific gravity, specific heat, and expansion due to heat, may be taken.

a. Specific Gravity.—With regard to this property it is too well known that the specific gravities of the metals take part in that of their alloys approximately in the ratio of their relative volumes, to need any further comment; but for the sake of illustration I give the following tables, the first containing the values found for the specific gravity of alloys of two metals belonging to class A, and the second those of two metals belonging to class B.

TABLE I.

	Obs. specific gravity.	T.	Cal. specific gravity.
Sn	7.295	12.8	—
Sn ₆ Pb	7.927	15.2	7.948
Sn ₄ Pb	8.188	16.0	8.203
Sn ₂ Pb	8.779	17.2	8.781
Sn Pb	9.460	15.5	9.474
Sn Pb ₂	10.080	14.8	10.136
Sn Pb ₄	10.590	14.3	10.645
Sn Pb ₆	10.815	15.6	10.857
Pb	11.376	13.5	—

TABLE II.

	Obs. specific gravity.	T.	Cal. specific gravity.
Ag	10.468	13.2	—
Ag ₆ Au	11.760	13.1	11.715
Ag ₄ Au	12.257	14.7	12.215
Ag ₂ Au	13.432	14.3	13.383
Ag Au	14.870	13.0	14.847
Ag Au ₂	16.354	13.0	16.315
Ag Au ₄	17.540	12.3	17.493
Ag Au ₆	18.041	13.1	17.998
Au	19.265	12.8	—

(Phil. Trans., 1860, p. 177.)

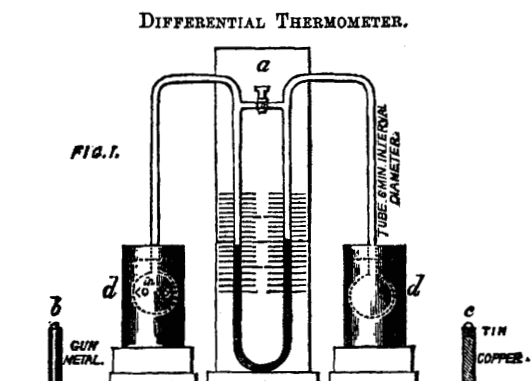
b. Specific Heat.—In the few cases in which experiments have been made on the specific heat of alloys, it appears that the specific heats of the metals take part in that of their alloys in the ratio of their relative weights, as shown in table III.

TABLE III.

	Obs. specific heat.	Cal. specific heat.
PbSn	0·04073	0·04039
PbSn ₂	0·04506	0·04461
PbSb.....	0·03880	0·03883
BiSn.....	0·04000	0·03987
BiSn ₂	0·04504	0·04415

(Watts' Dict. Chem., iii., p. 33.)

This may easily be shown with the help of an inverted differential thermometer (figure 1), the construction of which



needs no explanation. The stop-cock *a*, has been found most useful in adjusting the level of the liquid in the bent tube. If an alloy be made (say gun-metal) and cast in a mould, and if, on the other hand, a piece of copper be cast in the same mould and turned down, so that its weight corresponds to the weight of copper in the alloy; and if the amount of tin corresponding to the quantity of tin in the alloy be cast round the top of the copper, two castings will be produced (*b* and *c* figure 1) of equal weights, the one being an alloy, the other its components. These may now be heated in boiling water for a short time and then placed in the cylinders (*d d*), into which equal weights or bulks of water of the same temperature have been poured and

if, after about a minute's immersion, during which time the castings have been kept in motion, the air-thermometer be placed in the water, no difference in the level of the liquid will be observed, indicating that the specific heats of the two castings are the same. On the contrary, if equal weights (about 500 grms.) of two metals having different specific heats be taken, for instance lead and zinc, and if the same process be followed out, a very marked difference will be observed in the indication of the thermometer (about 60 mm. difference in the levels of the liquid in the bent tube). If, however, weights of any two metals be taken, corresponding to their combining numbers, no difference in the heights of the columns will be observed.

This modification of the differential air-thermometer is a simple means of illustrating many experiments on heat, as for instance, latent heat, influence of sources of heat and of salts on the boiling points of liquids, showing that the temperature of steam is not altered by the addition of salt to the water (the practical application of this well known fact is seen in fixing the boiling point of a thermometer), &c.

c. Expansion due to Heat.—That this property also follows the law, namely, that the expansion due to heat of the metals takes part in that of their alloys, approximately in the ratio of their relative volumes, is proved by the results given in table IV.

TABLE IV.

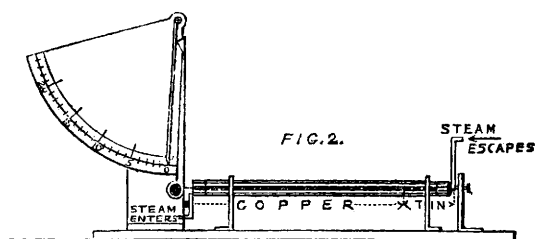
Alloy.	Volumes per cent.	Observed volume at 0° = 1 v. at 100°.	Calculated volume at 0° = 1 v. at 100°.
Sn ₄ Pb ..	22·28 Pb	1·007188	1·007225
Pb ₄ Sn ..	82·09 Pb	1·008419	1·008129
CdPb ..	58·49 Pb	1·009138	1·008847
Sn ₄ Zn ..	87·46 Sn	1·007184	1·007144
Sn ₆ Zn ..	91·28 Sn	1·007058	1·007066
Bi ₈₈ Sn ..	0·85 Sn	1·004064	1·003972
BiSn ..	42·81 Sn	1·005098	1·005207
Bi ₄₈ Pb ..	1·76 Pb	1·004086	1·004026
BiPb ..	46·26 Pb	1·008621	1·006007
Cu + Zn (71 p. c. Cu)	33·85 Zn	1·005719	1·006328
AuSn ..	60·85 Sn	1·004233	1·005919
Au ₄ Sn ₇ ..	73·14 Sn	1·004428	1·006223

TABLE IV (*continued*).

Ag ₄ Au.....	19·86 Au	1·005166	1·005549
AgAu	49·79 Au	1·004916	1·005123
AgAu ₄	79·86 Au	1·004300	1·004693
Ag + Pt (66·6 p. c. Ag) ..	19·65 Pt	1·004568	1·005207
Au + Cu (66·6 p. c. Au) ..	48·06 Au	1·004657	1·004716
Ag + Cu (36·1 p. c. Ag) ..	28·31 Ag	1·005436	1·005233
Ag + Cu (71·6 p. c. Ag) ..	73·13 Ag	1·005713	1·005607

A simple mode of showing this is to take a bar of gun-metal and place it as shown (fig. 2.) in a glass tube, fitted at the ends with glass tubes, in such a manner that steam can be blown through it. If now a comparative experiment be made in this manner, first with a bar of gun-metal, and then with a bar made of its components, by soldering together the proper lengths of copper and tin, as shown in the figure, it will be found that the index indicating the expansion, will show in both cases the same readings.

APPARATUS TO SHOW EXPANSION BY HEAT.



II. As types of the second class of physical properties, namely, those which in all cases are not imparted to the alloy in the ratio in which they are possessed by the component metals, the fusing points and crystalline form may be chosen for discussion.

a. Fusing Points.—It has been often stated that the fact of the fusion point of an alloy being lower than the mean fusion points of the component metals, is an indication of chemical combination. But on carefully looking into what is known on the subject, it will be found that all mixtures have a lower fusion point than the mean of the substances forming the mixture. So, for instance, salt water solidifies below zero; chloride of potassium and chloride of sodium fuse at a lower tem-

perature than the mean of the relative volumes of the components, so likewise do mixtures of chloride of potassium with chloride of calcium or strontium, &c. As a practical example of this fact, the fluxes used by metallurgists may be quoted; so also the solder used by various metal-washers; and when decomposing a silicate, we prefer to fuse it with a mixture of the carbonates of potassium and sodium, rather than with either of them alone.

Taking the most simple of these cases, the mixture of the chlorides of potassium and sodium, I may say that nobody has, as yet, asserted in this case, that chemical combination exists between these salts on account of the existence of a lower fusion point than the mean fusing point of the component salts. This property, being a general property of all mixtures (some of the amalgams I believe only excepted), we must arrive at the conclusion, that the fact that alloys fuse more readily than the mean fusing points of the component metals, is by no means an indication of chemical combination.

This fact, I think, admits of explanation as follows:—

It is generally admitted that matter in the solid state exhibits excess of attraction over repulsion, whilst in the liquid state these forces are balanced, and in the gaseous state repulsion predominates over attraction. Let us assume that similar particles of matter attract each other more powerfully than dissimilar ones. It will then follow that the attraction subsisting between the particles of a mixture will be sooner overcome by repulsion than in the case of a homogeneous body: hence mixtures should fuse more readily than their constituents.

b. Crystalline Form.—Various observers have deduced that certain alloys are chemical combinations, owing to their crystallising in definite forms; this has also been often done in the case of carbon-iron alloys; in fact, numerous chemical combinations between these two elements, have been said to be discovered in this manner. It may, however, be asserted, that definite crystalline forms, with alloys, are not necessarily chemical combinations.

Cooke was, I believe, the first to point out this, for he proved that all the alloys of antimony and zinc containing from 43 to 64 per cent. of zinc, crystallise in the same form, but differently from the other alloys of these two metals. With the

gold-tin alloys, it has been shown that well defined crystals are not limited to definite proportions of the two metals, but are common to all alloys of these metals containing from 27 to 43 per cent. gold.

The crystals of these alloys have never the same composition as the mother-liquor from which they were crystallised, but contain always more gold, as is shown by the results contained in table V.

TABLE V.

Composition of alloy.	Amount of gold per cent. in first crop of crystals.	Amount of gold per cent. in	Amount of gold per cent. in mother-liquor.
41·8 Au } 58·2 Sn }	43·6	2nd crop. 43·6	40·8
40·5 Au } 59·5 Sn }	42·9	6th crop. 38·7	
37·5 Au } 62·5 Sn }	39·7	4th crop. 37·6	32·9
35·0 Au } 65·0 Sn }	37·5	4th crop. 32·6	30·6
32·5 Au } 67·5 Sn }	36·8	4th crop. 35·2	28·7
30·0 Au } 70·0 Sn }	33·8	6th crop. 31·5	25·3
25·0 Au } 75·0 Sn }	27·4	20·1

Storer has also shown that all the copper-zinc alloys crystallise in the same form, so that crystals of any composition can be obtained.

In considering this property, we must bear in mind the influence of traces of foreign matter on the crystallisation of all substances. Thus many pure metals may be made to crystallise more readily, if a trace of another metal be added; for instance, antimony to which a trace of tin is added

crystallises much more readily, and in much larger crystals than the pure metal. With lead the case is reversed, for in this case, the purer the lead the larger the crystals. With salts we find analogous behaviour; so, for instance, chloride of ammonium when dissolved in pure water crystallises in small crystals, but when a small quantity of tarry matter is added to the solution, it crystallises readily in large cubes; common salt crystallises from water, as is well known, in cubes; from urine, or from water containing urea, in octohedrons.

The fact that two metals are capable of alloying with each other and producing definite crystalline forms, in other proportions than those of their combining weights, ought always to be borne in mind, when discussing the chemical nature of a metallic compound.

III. As types of the third class of physical properties, namely of those which in some cases are, and in others are not, imparted to the alloy in the ratio in which they are possessed by the component metals, the conducting power for heat and electricity, sound, elasticity, and tenacity, may be taken.

a. Conducting Power for Electricity.—The values obtained for the conducting powers of alloys prove that this property belongs to this class.

Table VI contains the values employed in calculation.

TABLE VI.

Metal. All hard-drawn.	Atomic weight.	Specific gravity.	Specific conducting power of metre length and millimetre diameter, in terms of the BA unit.
Silver	108	10·5	47·5
Copper	63·5	8·9	47·5
Gold	197	19·3	37·1
Zinc	65	7·1	13·8
Cadmium . .	112	8·6	11·3
Tin	116	7·3	5·9
Lead	207	11·4	4·0
Iron	—	—	8·0

Tables 7, 8, and 9 contain a few examples of each group of alloys. Table 7, those of class A with one another. Table 8, those of class A with class B. Table 9, those of class B with one another.

TABLE VII.

Alloy.	Specific conducting power of metre length and millimetre diameter, in terms of the BA unit.		
	Volumes per cent.	Observed.	Calculated.
Sn ₄ Pb	83·9 tin	5·7	5·6
Sn ₄ Cd	83·1 „	6·9	6·8
Sn ₂ Zn	77·7 „	7·9	7·6
PbSn	53·4 lead	4·8	4·9
ZnCd ₂	26·1 zinc	12·2	12·0
SnCd ₄	23·5 tin	10·3	10·0
CdPb ₆	10·6 cadmium	4·3	4·7

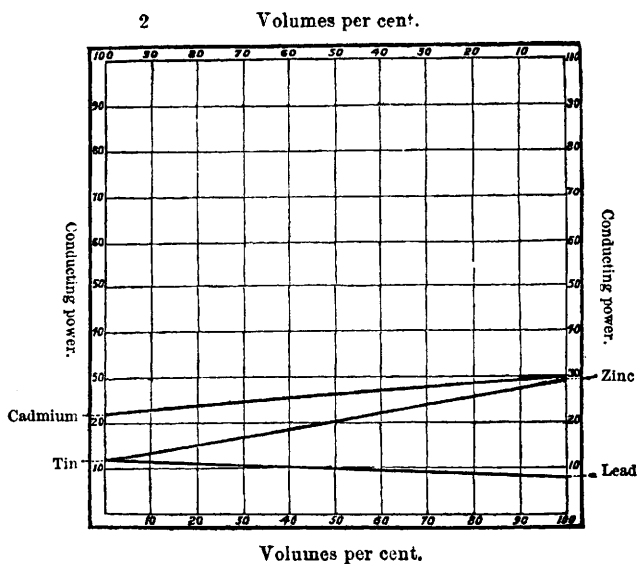
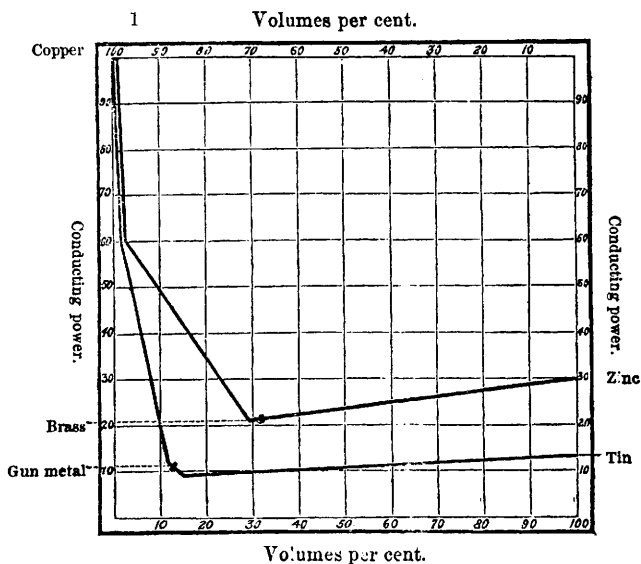
TABLE VIII.

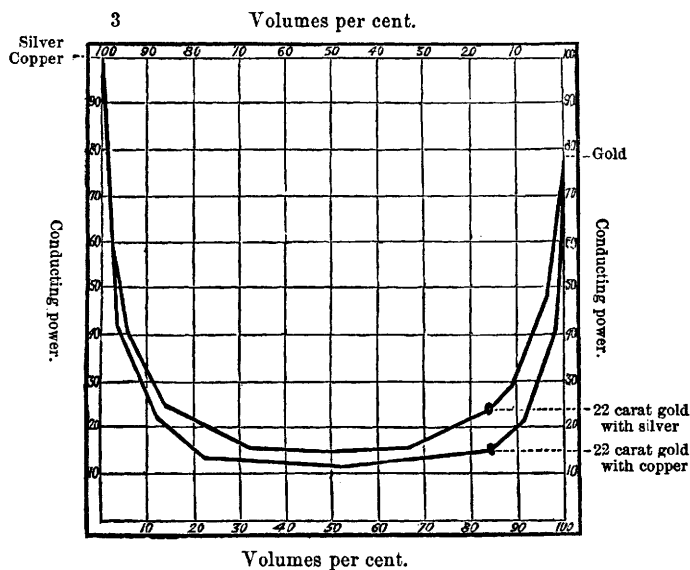
All hard-drawn.			
Copper-tin	93·6 tin	5·7	8·5
„	83·6 „	6·0	12·7
„	14·9 „	4·2	41·3
„	11·6 „	5·9	42·7
„	6·0 „	9·4	45·0
„	1·4 „	29·7	46·9
Copper-zinc	42·1 zinc	10·4	33·3
„	29·4 „	10·3	37·6
„	23·6 „	13·4	39·6
„	10·9 „	22·1	43·9
„	5·0 „	28·7	45·8

TABLE IX.

All hard-drawn.			
Gold-silver . . .	79·9 gold	10·1	39·2
„	52·1 „	7·1	42·1
„	19·9 „	10·3	45·4
Gold-copper . . .	98·4 „	26·7	37·3
„	81·7 „	7·6	39·0
„	19·2 „	9·8	45·5
„	0·7 „	40·0	47·4
Steel	—	6·3	—

The accompanying curves, 1, 2, and 3, represent graphically the values obtained for the conducting powers of some alloys of each group, the conducting power of silver being taken, for convenience sake, to equal 100.



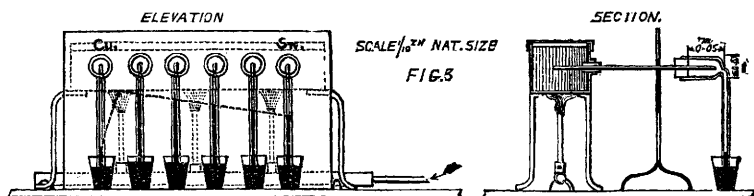


From these it will be seen at a glance that the alloys belonging to metals of the class A conduct electricity in the ratio of the relative volumes of the component metals, whilst the others do not. It will be as well to draw attention at once to the marked change which takes place in this property, when a metal belonging to class B is alloyed, either with one of its own class, or with one belonging to class A; and also to the fact, that when a metal belonging to class A is alloyed with one of class B., no such change takes place. This behaviour is observed with all the physical properties belonging to this class.

b. Conducting Power for Heat. — Wiedemann and Franz have shown experimentally, that the conducting powers for heat and electricity for metals and alloys are identical. The conducting power for heat may be conveniently shown with the help of the apparatus represented in fig. 3. If bars of copper, copper-tin alloys of various compositions, and tin be made and fitted in the box, as shown in the figure, with small air-thermometers at their ends, and boiling water be poured into the box (which may be kept boiling with lamps underneath), the depressions in the columns of liquid in the air-

thermometers will approximately show the ratio between the conducting powers of these bars. An additional advantage of this modification of the apparatus is that the differences of the

APPARATUS TO SHew CONDUCTIVITY OF METALS AND THEIR ALLOYS FOR HEAT.



indications of the thermometers remain constant for some time. The curve formed by the tops of the columns would represent, in fact, the resistance-curves for electricity.

It is obvious, by taking series of the other two groups of alloys, the indications of the thermometers would give the resistance-curves corresponding to those alloys.

This method gives us, therefore, a simple and striking means of showing the sudden or gradual alteration in conductivity in the three groups of alloys.

It is scarcely necessary to mention that screens must be placed between the box and the air-thermometers, to prevent the thermometers being heated by radiation.

c. Sound.—If bars of copper, tin, zinc, or lead, suspended by a string, be struck, they all emit a dead sound; if, on the contrary, bars of copper-tin (gun-metal) or copper-zinc (brass) be struck, they will emit a clear ringing note, showing the marked effect of alloying a metal of class B with one of class A. Conversely, if we strike bars of tin-copper (containing 12 p. c. copper), or tin-lead (containing 20 p. c. lead), they will emit a dead sound, showing, as in the cases of conduction of heat and electricity, no marked change when metals of class A are alloyed with one another, or with one belonging to class B. The same effects will be produced when bars of wrought iron and steel are struck, the first emitting only a slight sound, the second a clear ringing note.

d. Elasticity.—When a weight is hung to spirals of hard drawn wires of the same diameter, both in wire and coil, different effects will be produced (diameter of wire No. 23 wire-gauge, diameter of coil about 7 mm. weight used 500 grms.)

The copper, silver, gold, and platinum spirals will be almost lengthened to a straight wire.

The tin, zinc, copper-tin (12 p. c. copper) and tin-lead spirals will be almost lengthened to straight wires, with only 50 grms.

The copper-tin (gun-metal), brass, platinum-silver (33 p. c. platinum), and gold-copper (22 carat) spirals will be only lengthened to a small extent with 500 grms.

The iron spiral may be made to lengthen with 500 grms. weight, especially on shaking the spiral; but that of steel does not lengthen at all under the same conditions.

Here then, again, we see the marked change in this property, when a class B metal is alloyed with one of its own class or with one of class A, as well as the absence of any marked change when a class A metal is alloyed either with one of its own class, or with one of class B.

e. Tenacity.—With the help of a draw-bench and spring-balance, wires may be broken, to show in a rough way their relative tenacity. The values in the following table must be considered as only approximative, but they will nevertheless show the fact, that as soon as a metal belonging to class B is alloyed with another, its tenacity is greatly increased.

All hard-drawn wires, gauge No. 23; for convenience sake double wires were used in the experiments.

TABLE X.

	Breaking strain for double wire.
Copper.....	25—30 lbs.
Tin	under 7 "
Copper-tin (12 p. c. tin) ..	80—90 "
Tin-copper (12 p. c. copper)	about 7 "
Lead	under 7 "
Tin-lead	" 7 "
Gold.....	20—25 lbs.
Gold-copper	70—75 "
Silver	45—50 "
Platinum.....	45—50 "
Silver-platinum	75—80 "
Iron	80—90 "
Steel	above 200 lbs.

The foregoing experiments tend to prove that the physical

properties belonging to this class follow the law; that as soon as a metal belonging to class B is alloyed with one of class A, or with one of its own class, a very marked change in the physical properties takes place, they no longer being equal to the mean of the relative weights or volumes of the component metals. That the curves representing their numerical values, would have analogous forms, is proved, not only by the foregoing data, but also by the fact that the turning points of the electric conducting power curves represent approximately the composition of technically used alloys, such alloys being used on account of some special physical property.

Thus, gun-metal (10 p. c. tin) is marked on the copper-tin curve, its turning point corresponding to 12.5 p. c. tin.

Brass containing 28 p. c. zinc is marked on the copper-zinc curve, the turning point of which corresponds to 25 p. c. zinc.

22 carat gold alloyed with silver is marked on the silver-gold curve, and the same alloyed with copper on the copper-gold curve.

When the Electrical Standard Committee appointed by the British Association arranged their unit-coil, they chose the alloy containing 33 p. c. platinum, on account of its being the turning point of the silver-platinum curve, and from its possessing certain electrical properties which rendered it eminently fit for the purpose. It was afterwards found that this alloy had been in use for many years on account of its high elasticity as a dental alloy.

The question now arises what are the alloys at the turning points of these curves? Are they chemical combinations, or are they not, and if not, what are they?

If they are chemical combinations, then we should have to accept the following formulæ:—

The alloy composed of 87.5 copper and 12.5 tin	
would correspond to about.....	Cu_{13}Sn
The alloy composed of 75 copper and 25 zinc to	Cu_3Zn
The alloy composed of 22 gold and 2 silver to ..	Au_6Ag
The alloy composed of 22.1 gold and 2 copper to	$\text{Au}_{17}\text{Cu}_2$
The alloy composed of 66.6 silver and 33.3 platinum to	$\text{Ag}_{17}\text{Pt}_2$
The alloy composed of 99.3 bismuth and 0.7 tin to	Bi_{99}Sn
The alloy composed of 98.0 bismuth and 2.0 lead to	Bi_{48}Pb

The above alloys represent the turning points of the electric conducting power curves expressed in weights. Now it has just been pointed out that the curves which would numerically represent the third group of physical properties would have analogous, but not identically the same form: hence it follows that the turning points of these curves may vary several per cent. in their composition. Are then these also chemical combinations? I think however that the idea of the existence of chemical combinations at these points must be given up, owing to such abnormal combinations as the above, which must then exist, and also owing to the immense number of them having nearly the same composition as the curves representing each of the physical properties of the third group, having in all probability slightly different turning points; and if in the one case they be chemical combinations, why should they not be in the other?

The great similarity in the forms of the curves representing the electric conducting powers of alloys speaks also against the turning points being chemical combinations:—for with the first group of alloys they are nearly straight lines; with the second there is a rapid decrement on the side beginning with the metal belonging to class B; and then it turns and goes in a straight line to the metal belonging to class A. The letter L would represent the typical form of these curves; and with the third there is a rapid decrement on both sides of the curve, the turning points being connected with each other by nearly straight lines; the letter U would represent the typical form of this class of curves.

Having thus shown the probability of the non-existence of chemical combinations at these points, the next step is to indicate the probable cause of the marked changes in the physical properties of a class B metal when entering into an alloy. The experiments detailed tend to show that the third group of physical properties of the metal belonging to class B, when it enters into an alloy with one of its own class or with one of class A, undergo a change, and this change is brought about by a small quantity of the other metal, the quantity of metal required for the completion of this change being dependent on the metal employed; in other words, the class B metal enters into an alloy in an allotropic condition, which modification possesses other physical properties than the original metal:

further, when a metal belonging to class A enters into an alloy, it retains in the alloy its original physical properties.

If the turning points of the curves be now examined from the above point of view, the following facts may be deduced. Taking the copper-tin, copper-zinc, bismuth-tin, and bismuth-lead turning points as examples, table 11 contains the numerical data for these alloys.

TABLE XI.

Composition of Alloy.				Conducting power of alloy in terms of the B.A. unit for metre length and millimetre diameter.
Copper	·851	Tin	·149	4·19
„	·706	Zinc ..	·294	10·33
Bismuth ..	·9905	Tin	·0885	0·117
„ ..	·982	Lead ..	·018	0·122

From the above hypothesis the metals, lead, tin, and zinc enter into alloys with their normal physical properties: hence the part these metals take in the conducting power of the above alloys may be calculated, and will be found, for tin in the first alloy, to be equal to $0·88$ for $5·88 \times ·149 = 0·88$.

For zinc in the second alloy, it will be found equal to 4·06

For tin in the third alloy, it will be found equal to . . . 0·056

For lead in the fourth alloy, it will be found equal to . . . 0·071

the conducting powers of these metals being in terms of the B.A. unit, equal to tin 5·88, lead 3·96, and zinc 13·80.

With the first alloy the conducting power for allotropic copper may be found by subtracting the value found for the tin in the alloy from the conducting power of the alloy itself, the value then for the ·851 of copper will be found.

Thus, $4·19 - 0·88 = 3·31$, this last value representing ·851 allotropic copper; or a wire of a metre length and millimetre diameter of allotropic copper will have a conducting power equal to 3·89.

From the copper-zinc alloy the value of ·706 copper will be found equal to 6·27; or 1 metre, &c., copper has a conducting power equal to 8·89.

From the bismuth-tin alloy the value of ·990 bismuth will be found equal to 0·0670; or 1 metre, &c., bismuth has a conducting power equal to 0·0677.

From the bismuth-lead alloy the value of .982 bismuth will be found equal to 0.050; or 1 metre, &c., bismuth has a conducting power equal to 0.0520.

The conducting power of the allotropic copper when alloyed with tin is found to be 3.89, and when with zinc 8.89.

Now, at first sight there seems no connection between these numbers, but when they are divided by the conducting powers of tin and lead respectively, the quotient will be nearly the same:—

$$\frac{3.89}{5.88} = 0.662, \text{ and } \frac{8.89}{13.8} = 0.644.$$

If the values deduced for the conducting powers of bismuth be divided in like manner by those of tin and lead, the same result will be obtained, thus:—

$$\frac{0.0677}{5.88} = 0.00115, \text{ and } \frac{0.0520}{3.96} = 0.00130.$$

These values agree together as well as can be expected, considering that the turning points have not been absolutely determined, and that a small percentage difference will account for the differences between them.

It may, therefore, be supposed, although it has been only proved in these two cases, that when copper or bismuth enters into an alloy, their conducting powers alter as follows:—

The conducting power of copper will be = $0.65 \times$ the c.p. of the metal alloying it; and that of bismuth = $0.00123 \times$ the c.p. of the metal alloying it.

What the above empirical deduction means I am at a loss, at present, to understand, but the data I am at present acquiring will no doubt throw some light on the subject.

From the above point of view, most of the alloys made of metals of class A, with one another, may be regarded as:—

Solidified solutions of the one metal in the other.

Those made of class A with those of class B (say equal parts) as:—

Solidified solutions of the allotropic condition of the class B metal and the class A metal in one another.

And those of class B (say equal parts) with one another as:—

Solidified solutions of the allotropic conditions of the one metal in that of the other.

In the description of the foregoing experiments in connection with the third class of physical properties, it will be seen that

I have always made a comparison between iron and steel. This has been done to show that the carbon-iron alloys behave in an analogous manner to other alloys, which cannot be looked upon as chemical combinations. Now, although many are of opinion that because the carbon in some sorts of cast-iron can, under certain conditions, be evolved as carburetted hydrogen, there exists between these two elements chemical combinations, it is more than probable, that the carbon, when in the fine state of division in which it must exist in such specimens, if they be solidified solutions, may possess properties which do not belong to it in its denser form. It seems almost inconceivable that chemical combination between two elements should simply be dependent on the various rates of cooling, for it is possible to produce, with some specimens, so-called chemical combination of carbon and iron (white iron), or the mechanical mixture of carbon and iron (grey iron), merely by cooling the molten mass quickly or slowly. The analogy of cast-iron and steel with other alloys, indicates the non-existence of chemical combinations between carbon and iron.*

There seems to be but little doubt that between certain metals there may exist chemical combinations, as between gold and lead, or zinc, or tin; and in the cases of some of the amalgams, the existence of chemical combinations is indicated:

1. By the fact that a large amount of heat is set free when they are alloyed with one another.
2. By the fact that the alloys do not possess the typical properties of the groups to which they belong.

At present so little is known with regard to the chemical, as well as the physical behaviour of these alloys, that until they have been better studied, it is unnecessary to enter more fully into the subject.

Before concluding I cannot but thank Mr. Bassett for his valuable assistance in carrying out and arranging the above detailed experiments, especially those with the differential air-thermometer, as well as those with the method for showing conduction for heat; to him is due, as much as to myself, any credit in employing the modifications described, as we worked them out and arranged them conjointly.

* See Reports on the Chemical Nature of Alloys and of Cast-iron (Brit. Assoc. Rep. 1863 and 1866).