

system of tie-lines dwindles down to a point and vanishes) is conveniently designated the "limiting point." As a rule this is not the highest point of the curve, but lies on one side or the other, nearer to the base.

Thus, in the annexed diagrams, fig. 26, L represents the limiting point, lying to the *right* of the highest point of the curve in the case of lead-tin-zinc alloys, and to the *left* in that of lead-silver-aluminium alloys, fig. 27.

As regards the two immiscible metals, it is noteworthy that the relative proportion in which they are present at the limiting point is not at all constant, but varies within pretty wide limits according to the nature of the solvent metal.

For the same temperature, and all other things being the same, the substitution of *aluminium* for *zinc* as lighter immiscible metal appears always to *raise* the critical curve—*i.e.* the limits with zinc as lighter metal lie *inside* the corresponding limits with aluminium. Thus the dotted line, No. 2, fig. 27, representing

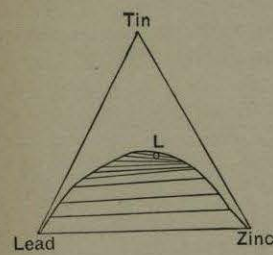


FIG. 26.

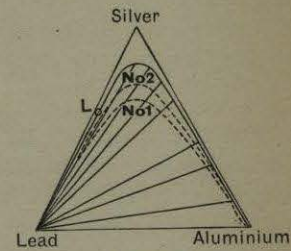


FIG. 27.

Pb, Ag, Al alloys, shows the corresponding curve obtained with Pb, Ag, Zn alloys, omitting bulges. A similar result is noticeable as regards *lead* and *bismuth*, the critical curve with bismuth as heavier immiscible metal always lying *inside* that similarly deduced with lead. On comparing curves obtained with the same immiscible pair at about the same temperature with the solvents *cadmium*, *silver*, *tin*, and *antimony* respectively, it is found that the cadmium and silver curves lie *outside* the tin curve, which again lies outside the antimony curve. Thus the dotted line, No. 1, in the figure representing Pb, Ag, Al alloys, indicates the corresponding curve obtained with Pb, Sn, Al alloys, lying well inside the continuous curve.

The second class of ternary alloys above referred to contains six members—

A.	...	...	B.	...	...	C.
Zn	...	...	Bi	...	...	Pb
Al	...	...	Bi	...	...	Pb
Bi	...	...	Al	...	...	Zn
Pb	...	...	Al	...	...	Zn
Al	...	...	Bi	...	...	Cd
Al	...	...	Pb	...	...	Cd

—the characteristic of this class being that *two* of the three pairs (AB and AC) are "immiscibles," whilst the third pair (BC) consists of metals miscible in all proportions.

When the results of suitable series of observations are plotted with the metal A at the apex of the triangle (fig. 28), and B and C at the ends of the base, the two series of conjugate points trace out *two separate curves* that do not run into one another at a limiting point; one of these curves cuts off a 3-sided figure at the apex of the triangle bounded by the upper parts of the sides and this upper critical curve; the other similarly cuts off a 4-sided figure at the base, bounded by the base, the lower portions of the sides, and this lower critical curve; the area within which all points denote *ideal* alloys only is consequently a 4-sided figure bounded by the middle portions of the sides of the triangle, and the upper and lower critical curves, as indicated in the figure.

No less than 126 quaternary combinations can be formed out of the 9 metals above mentioned. Of these, 55 always form real alloys, whilst 71 give rise to ideal alloys when mixed in proportions inside certain limits. These limits may be delineated by supposing the 4 constituents to be placed at the 4 solid angles of a tetrahedron (preferably regular), when the centre of gravity of the whole is a point indicating the particular mixture used. The conjugate points furnished by a suitable series of ideal alloys map out a "critical surface" inside the tetrahedron.

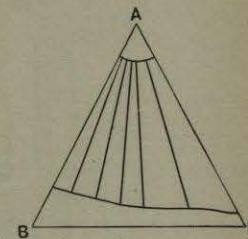


FIG. 28.

Since 6 pairs can be formed from the 4 constituents (AB, AC, AD, BC, BD, CD), 6 classes of quaternary ideal alloys can theoretically exist according as 1, 2, or more of these 6 pairs are "immiscibles."

There are 126 quinary, 84 sexenary, 36 septenary, and 9 octenary combinations that can also be formed from the above 9 metals; making (with those above mentioned and the mixture of the whole 9) 502 different alloys in all. Of these, real alloys (no matter in what proportions the constituents are mixed) are afforded by only 31 quinary, 9 sexenary, and 1 septenary combinations, all the others furnishing ideal alloys when mixed in proportions not outside of certain limits. In all, 320 combinations out of the 502 possible ones can thus yield ideal alloys, whilst the other 182 combinations yield real alloys, no matter in what proportions they are mixed.

Dr Alder Wright's careful experiments also illustrate the similarity in the behaviour of molten alloys and ordinary solutions of salts. This subject has been reviewed by the author and Dr A. Stansfield.<sup>1</sup>

<sup>1</sup> *Sur la Constitution des Alliages Metalliques. Rapport présentés au Congrès International de Physique*, Paris, Gauthier Villars, vol. i., 1900, pp. 306-314.



**Action of Electric Currents on Molten Alloys.**—In tracing the analogies between alloys and saline solutions, it will be well to see what takes place when a current of electricity is passed through an alloy. Take first the case of a fluid alloy through which a current is passed. We have spoken of alloys as solutions; if they be ordinary chemical solutions it has been urged that an electric current of sufficient strength ought to decompose them, and it becomes a most important question to determine whether an ordinary metallic alloy can conduct electrolytically like a salt solution, or whether it conducts as a metal would, that is, without being decomposed.

The question therefore arises—Can a well-marked alloy, or a quasi-compound, be in the slightest degree electrolysed by an exceedingly intense electric current? Some experiments con-

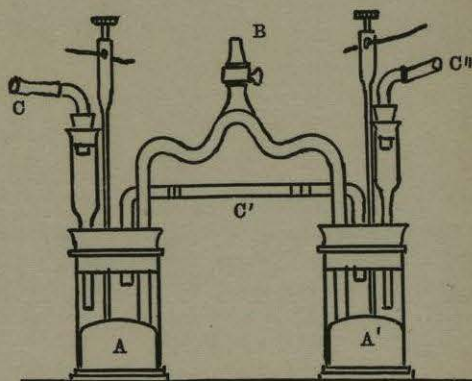


FIG. 29.

ducted by M. Gerardin<sup>1</sup> in 1861 satisfied him that amalgams of sodium and mercury might be decomposed by an electric current, with partial separation of the constituent metals. The experiments were repeated by Dr Obach,<sup>2</sup> who employed the apparatus shown in the diagram (fig. 29). The sodium amalgam is enclosed in the two glass vessels A A', and metallic communication between them is effected by opening the stopcock B and sucking the amalgam into the bent tube. An atmosphere of dry hydrogen is provided by the tubes C C', and the current is transmitted through the amalgam by the battery terminals shown. Subsequent examination of the sodium amalgam proved that no separation had been effected. The composition of the amalgam was unaltered by the passage of the current. He also used a W-shaped tube containing melted alloys, and proved that

<sup>1</sup> *Comptes Rendus*, vol. liii. (1861), p. 727.

<sup>2</sup> *Poggendorff's Ann. der Phys. u. Chemie*, sup. vol. vii. (1876), p. 230.

no decomposition could be observed after the passage of the current.

In 1887, at the request of the Electrolysis Committee of the British Association, the author took up the inquiry,<sup>1</sup> and by employing an intense electric current from secondary cells, showed that no separation took place either in certain alloys of lead and gold, or in alloys of lead and silver, even with so strong a current as 300 amperes. The method employed is indicated by the diagram (fig. 30). The alloy, CD, under examination was placed in cavities cut in a firebrick, shown at E, and the cables from a secondary battery were connected by means of copper holders with wrought-iron terminals, AB. The experiments are given in detail in the *Report of the British Association for 1887*, and it will be sufficient to say here that, as the question at present stands, it would seem that fluid alloys conduct like metals, and not like salt solutions; but if, as Sir O. Lodge suggested, the question as to the possibility of the electrolytic separation of true alloys of metals should be answered in the negative, there must surely remain a group of bodies on the borderland between alloys proper and electrolytes, among which some gradual change from wholly metallic to wholly electrolytic conduction is to be looked for.

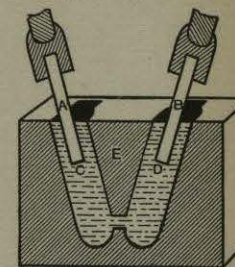


FIG. 30.

#### Conduction of Electricity by Alloys at Varying Temperatures.

—It has long been known that the electrical resistance of alloys increases as the temperature is raised, and decreases as the temperature is lowered, but the want of a simple and accurate pyrometer for many years prevented experiments being carried far in this direction. Le Chatelier,<sup>2</sup> however, has shown by the aid of his pyrometer, to be hereafter described, that in metals which do not undergo any molecular change before fusion, the increase of electrical resistance is proportional to the temperature. Many metals seem, like iron, to undergo sharply defined molecular changes at definite temperatures, and some alloys show progressive changes, all of which are clearly indicated by abrupt or gradual change in resistances.

Dewar and Fleming<sup>3</sup> have examined the electrical resistances of a number of alloys at very low temperatures produced by means of liquid oxygen, and discovered the significant and important fact that although the resistance of alloys is decreased

<sup>1</sup> *Report British Assoc.*, 1887, p. 341.

<sup>2</sup> *Comptes Rendus*, vol. cxi. (1890), p. 454.

<sup>3</sup> *Phil. Mag.*, vol. xxxiv. (1892), p. 326; vol. xxxvi. (1893), p. 271, in which some of the above results are slightly modified. See also *Engineer*, Jan. 27, 1893.



to a certain extent with a lowering of temperature, it is not decreased to the same extent as in the case of pure metals (see p. 66).

Niccolai<sup>1</sup> has recently determined the resistances of a number of alloys at temperatures varying from 400° C. down to -189° C, and from his figures the curves (fig. 31) have been plotted, showing the resistances in absolute magnetic units at different temperatures. Niccolai also showed that annealing and hardening not only altered the absolute value of the resistance, but

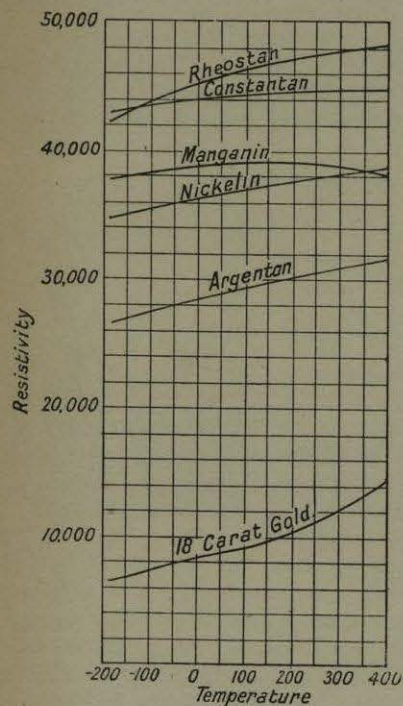


FIG. 31.

also altered the law of the variation of the resistance with temperature.

#### Effect of Composition on the Conductivity of Metallic Alloys.

— The most important work published in this direction was by Matthiessen, 1858-1867, who was the first to discover the connection between the electrical conductivity and the constitution of alloys. He divided alloys into four groups, each of which gives a different type of curve on plotting composition in volume concentrations and conductivity. With certain slight alterations, most of Matthiessen's work still holds good, and Guertler<sup>2</sup> has recently given an excellent résumé of the present position of knowledge on this subject.

The following are the

particulars of the groups of alloys mentioned above. For the constitution of alloys see p. 225.

**Group I.**—To this group belong those alloys of metals which show only a slight solid solubility in one another. In this case the electrical conductivity is a linear function of the volume concentration of the two metals, and therefore the curve obtained is a straight line. Fig. 32 shows several examples of these alloys, and to this group belong the alloys of Sn-Zn, Sn-Pb, Sn-Cd, Pb-Cd, Zn-Cd, etc.

**Group II.**—To this group belong those alloys which form a

<sup>1</sup> *Accad. Lincei Atti*, xvi. p. 185, Aug. 4, 1907.

<sup>2</sup> *Zeitsch. anorg. Chem.*, li., 4, p. 397; also *liv.*, 1, p. 58.

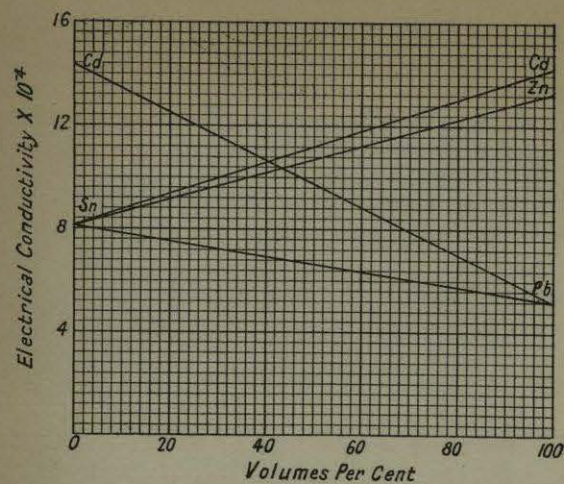


FIG. 32.—Group I., Alloys.

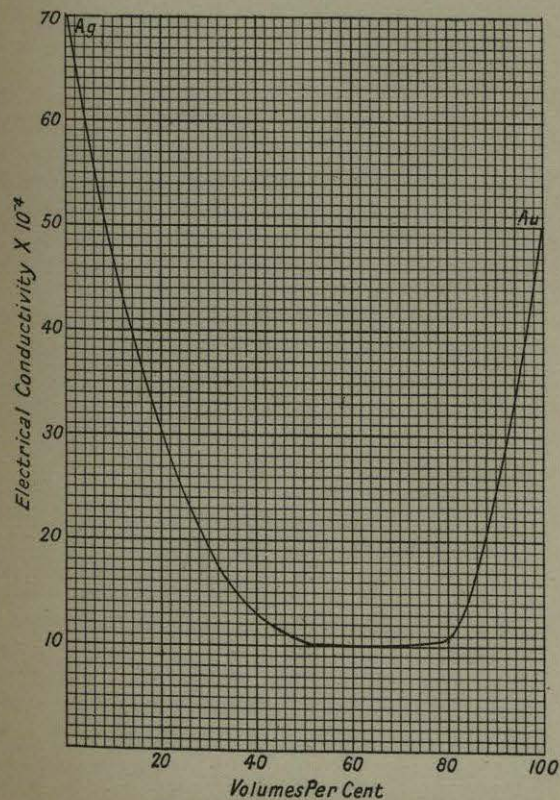


FIG. 33.—Group II., Alloys



continuous series of mixed crystals, or which are completely soluble in the solid state, forming solid solutions.

In this case the curve obtained is U-shaped, the conductivity being greatly reduced by the addition of successive small amounts of each metal in the other, a low minimum being obtained on a smooth curve. This group comprises the Ag-Au, Ni-Cu, Co-Ni alloys, and the curves obtained are illustrated by fig. 33.

*Group III.*—To this group belong the alloys of metals which

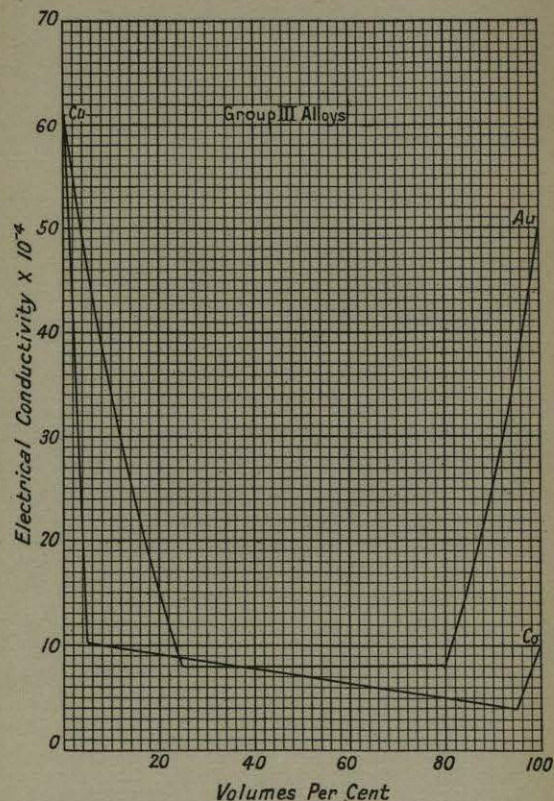


FIG. 34.—Group III., Alloys.

are only partially soluble in the solid state, and which form eutectics (see p. 232) of saturated crystals in the centre of the series.

These alloys give curves which consist of a combination of Groups I. and II., the centre eutectiferous portions give a straight line, and the ends, consisting of solid solutions, show a rapidly decreasing conductivity. To this group belong the alloys Cu-Au, Cu-Ag, Cu-Co, Sn-Bi, Pb-Bi, Au-Bi, etc. Fig. 34 shows the general form of curves obtained.

*Group IV.*—To this group belong the alloys of metals which combine in certain proportions to form true compounds. The curves show maxima or minima points at the places indicated by these compounds. In a series containing  $m$  compounds, the curve may be divided into  $m + 1$  divisions, each of which will be similar to the types given by groups 1, 2, or 3, according to the nature of the constituents. Fig. 35 illustrates this group, and to it belong the alloys Au-Sn, Au-Pb, Sn-Sb, etc.

From published work on the conductivity of alloys, it is found that in no system can the conductivity be higher than that represented by the straight line joining the conductivities of the

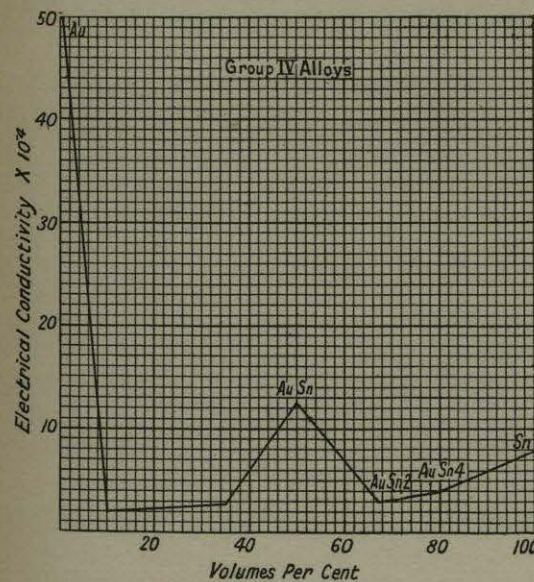


FIG. 35.—Group IV., Alloys.

component metals. Although compounds in alloys do not always show sharp changes of direction in conductivity curves, yet these changes when present always indicate the presence of compounds, sometimes by maximum points, as in the case of  $\text{Cu}_2\text{Sn}$ ,  $\text{AuSn}$ ,  $\text{Cu}_2\text{Sb}$ , etc., or sometimes by minimum points as in  $\text{Cu}_4\text{Sn}$ ,  $\text{Cu}_3\text{Sb}$ ,  $\text{AuSn}_2$ ,  $\text{AuSn}_4$ , etc.

**Influence of Foreign Elements on the Properties of Metals.**—The influence of chemical composition on the mechanical properties of metallic masses is of great importance; this has long been recognised, but it is singular that the subject has been so little investigated. Turn, for instance, to Dr Percy's classical work on Iron and Steel, published in 1864. It fully represents the information which had been gained at that time, yet it con-



tains the results of but few mechanical tests on the materials with which it deals.

The influence of foreign elements is best shown in the case of iron. The properties of this metal are absolutely changed by the presence of a few tenths per cent. of carbon, and the simultaneous presence of other elements greatly complicates these changes.

It seems that metallurgists have only comparatively recently realised that the effect of elements in the presence of each other is very complicated, and that it is absolutely necessary to study the effect of any given element on an absolutely pure mass of the metal to be tested. With regard to iron, the author has shown<sup>1</sup> that the tensile strength of electro-deposited iron, which is as pure as any iron can be, is 2.7 tons per square inch before annealing, and 15.5 tons per square inch after annealing. Even in this case, however, it is doubtful how far the result is influenced by the presence of occluded hydrogen, or by the fact that electrolytic iron is probably an allotropic form of the metal. In studying the effect of carbon, it is very difficult, therefore, to start from pure iron as an absolute basis. One of the most important effects obtained by the addition of carbon to iron is the power of hardening when quenched from a full red heat in water, the hardness thus induced increasing with the percentage of carbon present from .2 per cent. to about 1 per cent. The degree of hardness conferred is also influenced by the temperature from which the metal is quenched and by the rapidity of quenching. The influence of different percentages of carbon on the tensile strength, elongation, and hardness of steels has been studied by many metallurgists, including Howe, Arnold, Harbord, Wahlberg, and others.

Professor Arnold<sup>2</sup> determined the effect of increasing quantities of carbon by means of a set of extremely pure steels containing from .08 to 1.47 per cent. of carbon in the normal condition, that is, heated to 1000° C. and cooled in air, and also in an annealed condition, that is, after heating to 1000° C. for 72 hours and allowing to cool down in the furnace. Fig. 36 is deduced from the results obtained with normal bars, and shows the influence of carbon on the tenacity and ductility of steels. It will be seen that the strength of pure carbon steels will vary from about 19 tons in the case of .08 carbon steel to about 53 tons with 1 per cent. carbon, the actual figure varying with the heat treatment received; with more than 1 per cent. carbon, the steels generally show a decrease in tensile strength. The elongation is found to gradually decrease as the carbon increases from about 45 per cent. in .08 carbon steel to about 3 or 4 per cent. in the case of 1.5 carbon steel.

The important point brought out by these researches was

<sup>1</sup> *Journ. Iron and Steel Inst.*, No. i. (1887), p. 74.

<sup>2</sup> *Proc. Inst. Civil Engineers*, exxiii., 1895-96.

that the saturation point of carbon in steel occurs at about 0.9 per cent. carbon, a point closely associated with many of the important properties of steel.

The effect of carbon on the hardness of steels has been studied by Wahlberg,<sup>1</sup> who shows that the hardness, when quenched in water, gives Brinell number 149 for 0.1 carbon steel and increases to number 627 for 0.92 carbon steel. Unfortunately, the steels used for these tests were not uniform, as they contained varying amounts of silicon and manganese.

The influence of manganese on the properties of steels is of the utmost importance, and the effects produced by its addition vary considerably with the amount added and also with the percentage of carbon present. The general tendency of manganese is to increase the tensile strength and to reduce the ductility. Axle and tyre steels usually contain up to 1 per cent. of manganese,

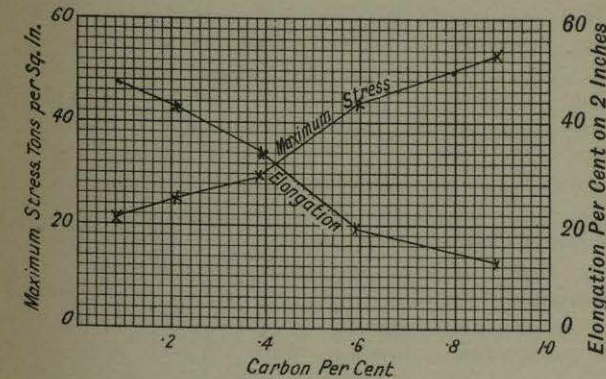


FIG. 33.—Influence of Carbon on the Tenacity and Ductility of Steels.

but in the case of mild steel for boiler plates and for general structural work over 0.6 per cent. begins to be dangerous. The influence of manganese on high carbon tool steels is much more marked, and is usually kept below 0.3 per cent.; when present in greater quantities than this, it is liable to cause fracture on quenching. The foregoing remarks with regard to the action of manganese in the presence of carbon are only true with amounts of manganese not exceeding 2 per cent. Further additions of manganese give remarkable results. Although steel containing from 5.75 to 7 per cent. of manganese, and less than 0.5 per cent. of carbon, is brittle, yet by adding twice this amount of manganese a return in strength is effected; and Hadfield<sup>2</sup> thus obtained the remarkable substance known as manganese steel.

<sup>1</sup> *Journ. Iron and Steel Inst.*, 1901, i. p. 267.

<sup>2</sup> *Ibid.*, 1888, ii. p. 41. This contains an excellent bibliography of the subject.



With from 8 to 20 per cent., a cast bar  $2\frac{1}{2}$  inches square can be bent considerably out of the straight without breaking. The increase in strength continues up to about 15 per cent., when a decrease takes place in actual toughness, though not in transverse strength, and after about 20 per cent. is passed a rapid decrease again takes place. Manganese steel, of the best composition, is free from blowholes, and rolls and forges well; but it is so very hard that it is extremely difficult to work in the cold. Its electrical resistance is thirty times that of copper, and eight times that of wrought iron, and for practical purposes it may be regarded as wholly unmagnetisable.

It is very difficult to estimate the influence of silicon. It is known that the addition of silicon to molten steel is useful, as it prevents the formation of "blowholes" in the solidifying mass. Probably the silicon acts by *increasing* the solubility of gas in iron until the metal has actually set.

In the case of mild steel there is practically no increase in maximum stress or in the elastic limit until over 4 per cent. of silicon is present; when over this amount, however, there is a tendency for silicon to increase the maximum stress and to reduce the extensibility, especially when 1.5 to 2 per cent. is exceeded.

The results of an elaborate series of mechanical tests by R. A. Hadfield<sup>1</sup> on silicon steel in its forged state gave results which showed that silicon, up to 1.5 or 1.75 per cent., added to iron, although increasing the elastic strength and raising the tensile strength, does not impair ductility. After this, however, the further increase of tensile strength noticed is only obtained with a serious loss of ductility. There appears to be no sharp line of demarcation, but when 1.5 to 2 per cent. is exceeded, further slight increases cause great changes in the characteristics of the material. In this respect, therefore, its action rather resembles that of carbon than that of manganese, of which larger amounts are required to effect similar changes.

For many years it had been recognised by metallurgists that silicon added to finished charges had a different effect on the physical properties of steel from that left in the charge, as it sometimes is, at the end of the Bessemer blow; high silicon steel has been regularly made in the open hearth for tyres and axles, and gives excellent results up to .35 per cent. silicon. Bessemer steel, on the other hand, which contains high silicon, left in the metal at the end of the blow, due to the pig-iron blowing too hot, has been found to be quite unreliable, not probably on account of silicon present, but because of the high temperature developed during the process, of which the presence of silicon is only an indication.

C. P. Sandberg<sup>2</sup> has experimented with silicon in rail steels,

<sup>1</sup> *Journ. Iron and Steel Inst.*, 1889, ii. p. 232.

<sup>2</sup> *Trans. Inst. Civil Eng. Conference*, section i. p. 6.

with a view to obtaining soundness and solidity without brittleness, and has found that for rail steel the effect of silicon added is very different from the effect of silicon left in from pig-iron. When silicon is left in, the percentage varies considerably, depending on the heat of the charge. When, however, the silicon has been eliminated from the pig-iron as far as possible, and a known quantity of silicon is added in the form of high-percentage silico-spiegel or ferro-silicon, then the percentage of silicon is easily regulated, and the wearing properties of the steel are found to be greatly improved, this being largely due to the more complete removal of gases and oxide from the steel. Sandberg finds that silicon up to .35 per cent. gives very good results.

It should be borne in mind that larger additions of silicon do not cause a return of strength, which is so remarkable in the case of manganese steel. Silicon steel is, moreover, still magnetic with considerable percentages of silicon, and is in this respect unlike both manganese and nickel steels. Hopkinson states that the electrical resistance of silicon steel is about six or seven times that of pure iron, and Hadfield has shown that the influence of silicon closely resembles that of aluminium.

The presence of silicon also facilitates the separation of graphitic carbon from iron. Prof. Turner<sup>1</sup> of Birmingham University has done excellent work by studying the action of silicon on pig-iron and steel, and his results have been conveniently condensed by F. Gautier,<sup>2</sup> from whose paper the diagram (fig. 37) has been adapted. The maximum result obtained on the series of samples for each kind of resistance has been taken as unity, and the ordinates are expressed as fractions of this maximum. The datum line of the diagram would, however, fall below the limits of the page.

The chief point of interest is that in pig-iron the maximum resistance to traction (tensile strength), to bending, and to crushing is attained with proportions of silicon varying between 1.5 and 2 per cent. Metal containing between 2 and 3 per cent. of silicon appears to be softer than the rest of the series, whilst the maximum resistance to crushing stress is attained with less than 1 per cent. of silicon. It should be added that in the samples rich in silicon the carbon was mainly present in the graphitic state. These also contained about 0.3 per cent. of manganese, and a small quantity, about 0.04 per cent., of sulphur.

Wahlberg<sup>3</sup> gives fully the relative effects of carbon, silicon, and manganese on the *hardness* of steel as shown by Brinell's method.

The influence of sulphur on iron and steel is very marked. This element has the effect of making iron red-short and unworkable at a red heat, and of destroying its welding power. The

<sup>1</sup> *Journ. Chem. Soc.*, 1885, pp. 577 and 902.

<sup>2</sup> *Bull. Soc. de l'Ind. Min.*, vol. iii. (1889), p. 91. See also paper read at the Metallurgical Congress, Paris, 1889.

<sup>3</sup> *Journ. Iron and Steel Inst.*, 1901, i. p. 267.



effect of sulphur on steel is most noticeable during rolling, a small percentage causing the ingots or bars to crack at the edges. The amount of sulphur which may be present without being perceptible during rolling or welding varies with the process by

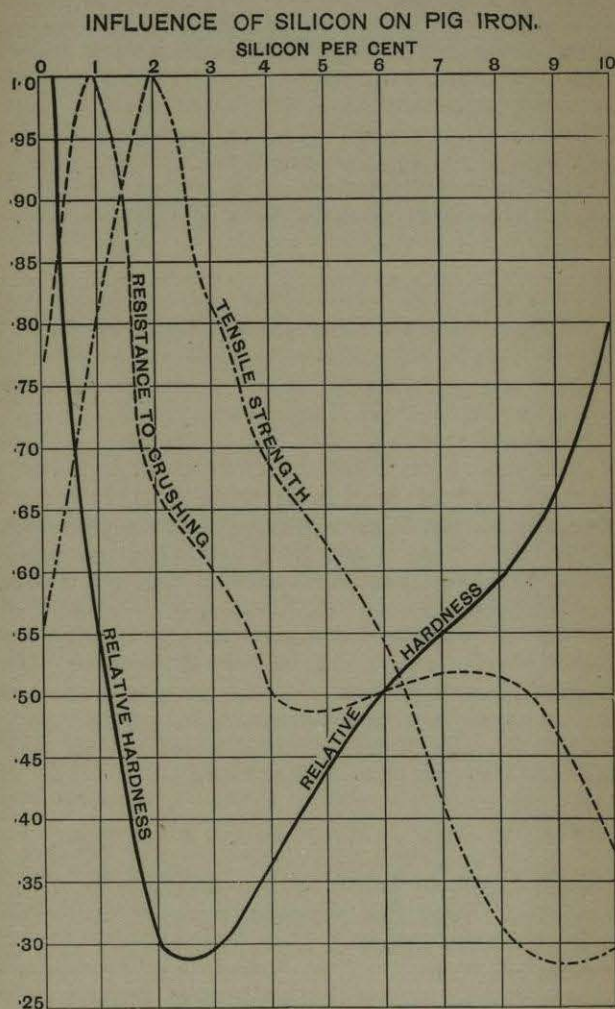


Fig. 37.

which the steel has been made, the amount of manganese and copper present, and the temperature of casting; but for welding and general structural work it should not exceed  $\cdot 06$  per cent., although no signs of red-shortness may be apparent when  $\cdot 1$  is present in certain steels. Manganese counteracts to some extent

the prejudicial action of sulphur, forming with it globules of manganese sulphide, as first shown by Arnold.

Professor Le Chatelier<sup>1</sup> has illustrated this point with some very interesting photomicrographs, which show that sulphur, when present as sulphide of iron, forms a mesh-like structure surrounding the grains of iron, and when manganese is added, these meshes of sulphide are largely broken up, and more or less distributed throughout the mass.

This breaking up of the mesh-work, together with the fact that sulphide of iron has a lower melting-point than the welding temperature of steel, and manganese sulphide has a much higher melting-point than iron sulphide, seem to be a rational explanation of the beneficial effect of manganese in steels containing small amounts of sulphur.

Sulphur is also said to lower the saturation-point of iron for carbon in the molten state, and, like manganese, to prevent to some extent the separation of graphite. Steels containing relatively large percentages of sulphur corrode more rapidly than low sulphur steels.

The influence of phosphorus in steels is most important, and varies considerably with the percentage of carbon present; the higher the carbon, the more prejudicial is the effect of phosphorus, and in the best qualities of crucible tool steels only the very purest materials are used, the phosphorus being frequently under  $\cdot 01$  per cent. The most marked effect of phosphorus is the inducement of cold-shortness and brittleness when subjected to suddenly applied stresses, or, in other words, to "shock." The tensile strength, elongation, etc., appear to be very slightly affected by phosphorus, but there is no doubt that the lower the percentage of this element, the safer will the steel be, and in the case of steel for structural purposes, the limit should be  $\cdot 06$  per cent., while in rails  $\cdot 08$  per cent. may be allowed with safety.

Stead<sup>2</sup> has published very important results on the relation of phosphorus and iron, which should be consulted by the student.

The effect of arsenic in such proportion as is usually present in commercial steels, that is, less than  $0\cdot 1$  per cent., is very little, except with regard to its welding properties. Harbord and Tucker<sup>3</sup> made a series of experiments on the effect of arsenic on mild steel, and came to the conclusion that up to  $\cdot 17$  per cent. it had no effect on the ductility or tenacity of the steel. With  $\cdot 25$  per cent. the steel could not be welded, but even  $1$  per cent. produced no red-shortness at rolling temperatures. Stead<sup>4</sup> has also examined the effect of arsenic on steel, and concluded that between  $\cdot 1$  and  $\cdot 15$  per cent. of arsenic has no effect on the mechanical

<sup>1</sup> *Bulletin de la Société d'Encouragement*, Sept. 1902.

<sup>2</sup> *Journ. Iron and Steel Inst.*, 1900, ii. p. 60.

<sup>3</sup> *Ibid.*, 1888, i. p. 183.

<sup>4</sup> *Ibid.*, 1895, i. p. 108.



properties, but that its influence is just noticeable with 0.2 per cent. The rolling and forging properties are not affected by considerable quantities of arsenic, but welding is much more difficult when comparatively small quantities are present.

To take copper as an example instead of iron, the influence of bismuth is most marked, for although it is easily oxidised, yet it clings to copper with much tenacity, and affects its properties in a most surprising manner. Hampe found that .02 per cent. was sufficient to make the metal distinctly red-short, and cold-shortness begins with .05 per cent. With 0.1 per cent. Bi the copper crumbles under the hammer at a red heat.

According to Keller,<sup>1</sup> a few thousandths per cent. of bismuth render copper unsuitable for electric conductors.

Sulphur often occurs in unrefined copper and renders the metal cold-short; Hampe found, however, that copper with .25 per cent. of sulphur was moderately malleable, but with 0.5 per cent. it became very cold-short, though, curiously, such copper was not red-short.

With regard to the effect of antimony on copper, it has been stated that 0.001 per cent. was very injurious, rendering it unfit for the manufacture of brass wire and sheet. Hampe,<sup>2</sup> however, found that metallic copper containing 0.529 per cent. could be drawn into the finest wire; and Brand<sup>3</sup> states that copper containing 0.5 per cent. of antimony can be worked easily into hollow wire. Extreme red-shortness is caused by 1 per cent. of antimony. Small quantities of antimony seriously affect the electrical properties, reducing the conductivity, and Keller<sup>4</sup> states that a few thousandths per cent. render copper unsuitable for conductors.

Taking gold as an example, it may be stated that very small quantities of lead, bismuth, tin, cadmium, antimony, arsenic, tellurium, or zinc render gold brittle. Lead, bismuth, and tin, when present up to .002 per cent., produce brittleness; and Hatchett states that gold containing .00032 per cent. of antimony is no longer malleable. Although zinc alone renders gold brittle, yet if there be present at the same time silver and copper, then even 5 to 7 per cent. of zinc does not affect the malleability of the metal.

We will next consider one or two typical instances of the effect of metals in varying quantities on each other, forming what are considered to be true alloys.

**Influence of varying Quantities of Metals on each other.**—The effect of the addition of tin to copper, as far as mechanical

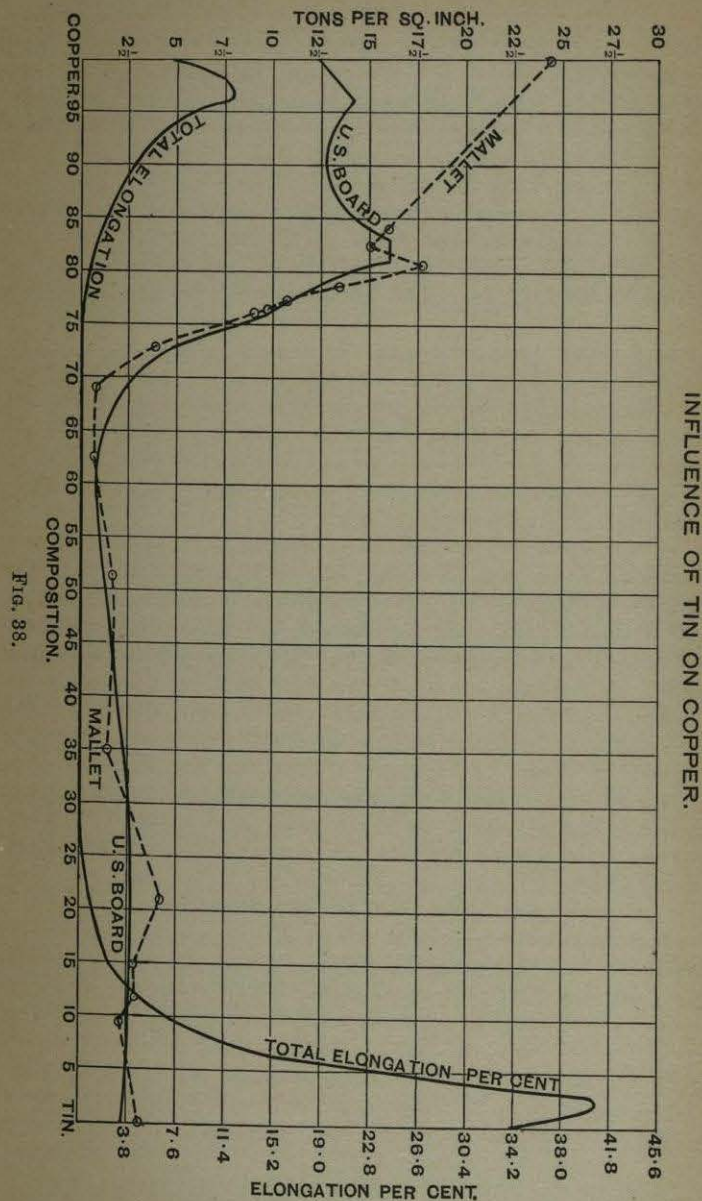
<sup>1</sup> *Mineral Industry*, vol. vii. p. 259.

<sup>2</sup> *Chemiker Ztg.*, 1892, xvi., No. 42.

<sup>3</sup> *Dammer's Chem. Technologie*.

<sup>4</sup> *Trans. Amer. Inst. Min. Eng.*, 1898.

properties are concerned, is shown by the accompanying diagram



(fig. 38), in which the upper curves represent the tensile strengths as determined by Mallet and by a Board of investigators appointed



by the Government of the United States.<sup>1</sup> It may be sufficient to state that the addition of tin to copper rapidly lowers its conductivity for electricity, but, as shown by the results obtained by the U.S. Board, increases its strength, the maximum being attained with about 20 per cent. of tin. An example of the effect of tin on the hardness of copper occurs in the use of bronze for coinage and for metal-work.<sup>2</sup> In the former case the amount of tin is 4 per cent., but if it exceeded 2 per cent. in the latter it would be too hard to give the desired impression. The entire series of copper-tin alloys is very interesting. Two only appear to be homogeneous, and these correspond respectively to the formulæ  $\text{SnCu}_3$  and  $\text{SnCu}_4$ . Notwithstanding the comparatively small difference in their composition, the appearance of the fractured surfaces of these alloys is quite different, the latter being yellowish-grey in colour with a mirror-like fracture, whilst the former is blue with a rough fracture. Having a higher specific gravity than the mean of its constituents, the alloy  $\text{SnCu}_3$  stands out from the rest of the series. Heycock and Neville<sup>3</sup> have shown that a marked difference in properties and microstructure occurs when copper-tin alloys undergo varying thermal treatment.

The influence of aluminium on copper is of great industrial importance, and has been the subject of much research. The Eighth Report to the Alloys Research Committee of the Inst. of Mechanical Engineers<sup>4</sup> contained the results of an elaborate examination of copper aluminium alloys, and should be referred to by the student. Up to 10 per cent. of aluminium there is a gradual increase in the ultimate stress of the alloys, and this point is practically the limit of industrially serviceable alloys, as beyond it there is a rapid fall of ductility and ultimate stress. These alloys may be divided into two classes, the first containing up to 7.35 per cent. Al, with low yield point, moderate ultimate stress, but very good ductility; the second class containing alloys from 7.35 to 10 per cent. Al, with relatively low yield point but good ultimate stress. See fig. 39 for these tests.

The alloys containing from 15 to 90 per cent. of Al do not appear to be of any technical promise. From 15 to 18 per cent. they are very hard, but very brittle. From about 20 to 65 per cent. they diminish in hardness, and are so brittle that they can be powdered with ease in a mortar. Most of them break if dropped on a hard floor. This excessive brittleness ceases at about 67 per cent. Al. Beyond 90 per cent. Al we have another series of useful alloys which really illustrate the influence of

<sup>1</sup> Report on a Preliminary Investigation of the Properties of the Copper-Tin Alloys, Washington, 1879.

<sup>2</sup> Annual Mint Report, 1901.

<sup>3</sup> Phil. Trans. Roy. Soc., 1901.

<sup>4</sup> Proc. Inst. Mech. Eng., 1907, p. 64.

copper on aluminium, but it is found that nothing is to be gained by the addition of more than 4 per cent. of Cu. This

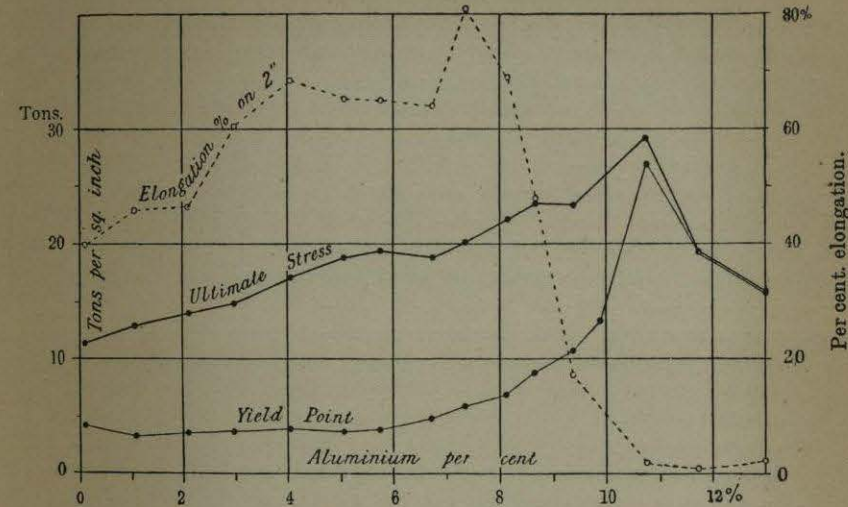


FIG. 39.—Influence of Aluminium on Copper. Tensile Tests on Sand Castings. Slowly cooled from 800° C. (1472° F.).

addition causes a fall of ductility and a rise of tenacity which are fairly steady up to 4 per cent., beyond which there is no

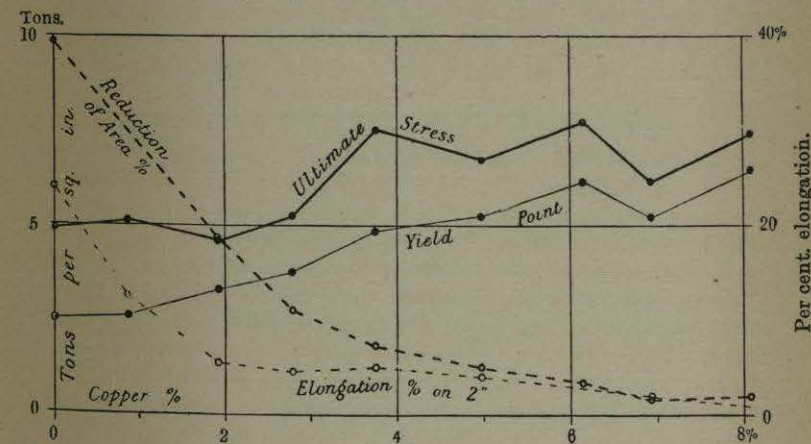


FIG. 40.—Influence of Copper on Aluminium Sand Castings.

increase in tenacity, while the ductility continues to diminish. Fig. 40 will illustrate the general effect of Cu on Al up to 8 per cent.