

containing 25 per cent. of nickel requires to be cooled to -50° in order to attain its maximum degree of magnetism.

The magnetic properties of the iron alloys have been studied by Le Chatelier, Osmond, and Mme. Curie, whose original papers should be consulted for further details.

Until recently manganese has been regarded as a non-magnetic metal, but it would seem that it is capable of assuming a magnetic condition when alloyed with other metals. Attention was first called to the fact by Hogg at the meeting of the British Association at Edinburgh in 1892, and his observations have since been confirmed by Heusler and others. The principal magnetic alloys of manganese are those with aluminium, antimony, tin, bismuth, arsenic, and boron.

CHAPTER IV.

THE CONSTITUTION OF ALLOYS.

THE nature and constitution of metals and alloys naturally attracted the attention of the early metallurgists, and Roberts-Austen has pointed out that Achard, Musschenbroek, and Réaumur were all engaged in the study of alloys in the eighteenth century, but it would appear that Boyle was the first to suggest the line of thought which has led to our present views of the constitution of metals and alloys. Discussing the states of matter, he says: "Even such as are solid may respectively have their little atmospheres"; and he adds: "For no man, I think, has yet tried whether glass, and even gold, may not in length of time lose their weight."

Boyle was therefore clearly of the opinion that the solid state of matter was not far removed from, and was in fact usually accompanied by, the liquid or gaseous states, and two hundred years later his belief was proved to be correct by the experiments of Merget and Demarcay.

In 1860 the same suggestion is made by Matthiessen, who, after describing his experiments on the electrical conductivity of alloys, says: "The question now arises, What are alloys? Are they chemical combinations, or a solution of one metal in another, or mechanical mixtures? And to what is the rapid decrement in the conducting power in many cases due? To the first of these questions," he adds, "I think we may answer that most alloys are merely a solution of one metal in the other; that only in a few cases may we assume chemical combinations." Three years later Graham declared his belief that the solid, liquid, and gaseous states probably always co-exist in every solid substance, and he

says: "Liquefaction or solidification may not, therefore, involve the suppression of either the atomic or the molecular movement, but only the restriction of its range." In 1866 he justified this belief by proving that gases were capable of penetrating solid metals. In 1882 Spring produced alloys by compression of the constituent metals, and four years later he declares that "we are led to think that between two molecules of two solid bodies there is a perpetual to-and-fro motion of the atoms." "If," he says, "the two molecules are of the same kind, chemical equilibrium will not be disturbed but if they are different this movement will be revealed by the formation of new substances."

From this time the researches on alloys become more numerous and the development of ideas proceeds more rapidly. In 1889 Heycock and Neville demonstrated the important fact that Raoult's law of the depression of the freezing-point of solvents is in many cases applicable to metals. Roberts-Austen, continuing Graham's work on diffusion, published in 1896 his classical researches on the diffusion of metals, followed by another paper, in which he showed that diffusion took place between metals in the solid state in the same way as in the liquid state, though more slowly. Four years later he was able to prove that gold was capable of diffusing into lead at the ordinary temperature of the atmosphere.

From the foregoing brief historical sketch of the researches into the constitution of alloys it will be seen that the trend of modern research has been to prove that the solid state of matter is closely related to the liquid and gaseous states, and that metals are subject to the same laws which govern the behaviour of liquids and gases. Moreover, just as in the case of inorganic bodies we recognise the existence of elements, compounds, and solutions, so in the case of metals we have pure metals, compounds, and solutions, and it is important to know how these possible constituents may occur in an alloy.

The methods employed in the investigation of the constitution of alloys have already been described, and it only remains to consider the results obtained by their use and the conclusions to be drawn from them. It has already been mentioned that the pyrometer and the microscope have been of the greatest service in determining the constitution of alloys, and we will therefore consider the different types of curve likely to be met with and

the conclusions which may be drawn with the confirmatory evidence of the microscope.

If a temperature record, or a "cooling curve," is taken of a pure metal cooling from a temperature just below its melting-point, the curve obtained is a smooth one without any sign of irregularities, but if a similar curve is taken of the same metal cooling from a temperature *above* its melting-point the result is a curve similar to those shown in fig. 17. At first the cooling proceeds normally and a smooth curve is produced, but as soon as the freezing-point of the metal is reached and it begins to solidify, the temperature remains constant and is represented by a straight line until the latent heat of fusion is given out, when the cooling again continues and the remainder of the curve is normal as before. There is only one irregularity in the curve, and the metal freezes or solidifies as a whole at one definite temperature.¹ In some cases, if the metal is very pure and the cooling takes place slowly and without disturbance, the temperature may descend below the true freezing-point of the metal without solidification taking place. When solidification does occur the temperature rises suddenly to the true freezing-point and remains there until solidification is complete. This super-cooling or surfusion of the metal causes a slight depression in the curve at the beginning of the straight line representing the freezing-point, and is shown in the cooling curve of tin in fig. 17.

A simple curve with only one horizontal break, showing that the metal has solidified as a whole at a definite temperature, is characteristic of pure metals, pure eutectics, and homogeneous solid solutions. Chemical analysis accompanied by a microscopical examination will at once indicate which of the three is under consideration.

A word of explanation is, perhaps, necessary as to the meaning of the expression *solid solution*, as it is frequently applied incorrectly. Consider, first, the case of a liquid solution and the characteristics which define a solution. When a solid substance is dissolved in a liquid the particles of the solid are so intimately mixed with the liquid that they cannot be seen, even with the aid of the microscope, and the solution is clear. If any particles are visible they are capable of being separated by

¹ In this case we assume that no allotropic change takes place. See p. 58.

mechanical means, such as filtration, and they are not in solution. The characteristics of a solution, then, are that the particles of the dissolved substance cannot be detected and cannot be separated by mechanical means. Now the same definition may be applied to solid bodies. In a mass of gold, for example, containing silver, the silver cannot be detected under the highest powers of the microscope, nor is it capable of being separated by mechanical means. The alloy solidifies and crystallises as though it were a pure metal, and the mixture of the two metals is so intimate that there is a strong analogy between it and a liquid solution. Van't Hoff therefore described such a mixture as a solid solution, and the expression is now in general use.

Solid solutions, however, may not always be homogeneous; they may vary in concentration. Thus copper containing a small quantity of tin (not exceeding 8 per cent.) does not separate into two constituents; but it does not solidify at one temperature. As the mass cools down, almost pure copper separates out at first, so that, as solidification proceeds, the portion remaining liquid becomes more concentrated in tin. The only indication of this is found on etching a polished surface, when the unequal action of the etching agent shows itself in shaded bands as seen in photographs 9 and 10.

Most metals are more or less soluble in one another, but the degrees of solubility are very variable. As regards the structure of metals and solid solutions, it may be remarked that they do not crystallise like ordinary liquid solutions, but more closely resemble viscous solutions. Well-defined or idiomorphic crystals are seldom found, while crystallites or the incipient forms of crystals are predominant. On annealing, however, this crystallitic structure is replaced by a well-defined crystalline structure. Photographs 27 and 31 are examples of the crystallitic, and 12, 30, and 34 of the crystalline structure. A curious point to be noted in the crystalline structure is that rolling or hammering produces abundant twinning of the crystals, while in unworked samples cases of twinning are not seen.

The third case of a cooling curve with a single break, viz. that of a pure eutectic, is seldom met with, but will be dealt with immediately. If, now, a cooling curve is taken of a molten metal to which another metal has been added, the curve may be of

three kinds: (1) It may show a single break at a temperature below that of the pure metal, showing that the alloy is a solid solution or a pure eutectic. (2) It may show two breaks, both lower than that of the pure metal, showing that the alloy contains two constituents melting at different temperatures. In most cases, one of the constituents will be found to be a eutectic; but they may both be solid solutions or one of them may be a compound. (3) If the curve shows two breaks, one higher than the melting-point of the pure metal, it may be taken for granted that this break is due to the solidification of a definite compound. The types of curves will be more fully dealt with later, but in the meantime we must define the expressions *eutectic* and *compound*, and consider their microscopical appearance.

The term "eutectic" was first used by Guthrie to indicate the mixture or alloy possessing the lowest freezing-point of a series. This freezing-point is always below that of the mean of the metals of which it is composed. The eutectic structure is composed of the different constituents in juxtaposition, but the structure is always very small and requires a high magnification for its resolution. The constituents of a eutectic may occur in curved plates or laminae, or in globules, and either or both may be simple metals, solid solutions, or compounds. Types of eutectic structures are shown in photographs 6, 7, 8, and 18. They are very characteristic, and cannot easily be mistaken.

The term *compound* or *metallic compound* is applied to those constituents of certain alloys which resemble chemical compounds in their properties. The formation of these compounds is accompanied by an evolution of heat, and they are almost invariably hard and brittle, with melting-points higher than the mean of their constituents. The metals of which they are composed combine, as nearly as can be judged, in atomic proportions; but their composition cannot easily be determined, as they are occasionally soluble in, or themselves dissolve, the metals of which they are composed. They can usually be separated from an alloy by dissolving away the surrounding metal, either with or without the aid of an electric current, but it is impossible to say whether the compound thus separated is pure or not. Metallic compounds can usually be detected under the microscope unless they happen to be soluble in one of the other constituents, as is

sometimes, but not frequently, the case. Occasionally they crystallise out in well-formed crystals exhibiting angles and faces, but more often they simply occur as crystallites. However, the grouping of the crystallites often throws some light on the crystal form. Photograph 2, for example, indicates a very definite arrangement of crystallites, and the compound shown in photograph 4, which has been separated from the alloy by solution, shows a well-formed angle at the extremity of one of the arms. Photograph 5 shows a well-formed crystal of the same compound occurring in the alloy. This is an exceptionally interesting case, as it is not usual to find two metals forming such well-defined compounds. Compounds of metals with the non-metals, however, such as phosphorus, form very well-defined compounds.

Having now considered the possible constituents in an alloy and the types of cooling curve which they produce, the next step is to follow the complete series of alloys formed between any two metals. In order to do this a large number of cooling curves must be taken of alloys varying in composition and their structure examined microscopically. The freezing-points or breaks in the curves are next plotted in the form of a new curve with compositions and temperatures as co-ordinates, so that the freezing-point of any alloy can be seen at a glance. This curve has been described by Gautier, and is now generally known as the "complete freezing-point curve" for that series of alloys.

Le Chatelier has classified binary alloys having normal curves of fusibility under three heads:—

1. Curves consisting of two branches starting from the melting-points of the pure metals and meeting at a point corresponding to the eutectic alloy. A curve of this description is obtained when the two metals are not isomorphous and do not form definite compounds.

The alloys of lead and tin, lead and antimony, and tin and bismuth, belong to this group.

2. Curves consisting of three branches, two starting from the melting-points of the pure metals and a third having a maximum point due to the formation of a definite chemical compound, and crossing the other two in two points corresponding to two eutectics. Examples of this group are found in the alloys of copper and antimony and nickel and tin.

3. A single curve uniting the melting-points of the two pure metals. This is a case of pure isomorphism, which is comparatively rare amongst metals. It is, however, shown in the case of the gold-silver alloys.

The microscopical examination of typical cases of these three curves will illustrate their meaning. As an example of the first curve we will take the alloys of lead and antimony. The freezing-point curve of this series shows a minimum at a point corresponding to 13 per cent. of antimony. If the alloys containing less than 13 per cent. of antimony are examined under the microscope they are found to consist of soft fern-leaf-shaped dendrites of lead surrounded by the eutectic of lead and antimony, the amount of the eutectic increasing as the percentage of antimony increases until the alloy containing 13 per cent. of antimony is reached, when the whole mass is composed of the eutectic. When more than 13 per cent. of antimony is present hard crystals of antimony make their appearance in the eutectic, and these increase as the percentage of antimony increases. Owing to the superior hardness of the antimony crystals they are easily visible by simply polishing and without any etching.

The second type of curve is well represented by the alloys of copper and antimony. In this series there are two eutectics corresponding to the alloys containing 25 and 71 per cent. of

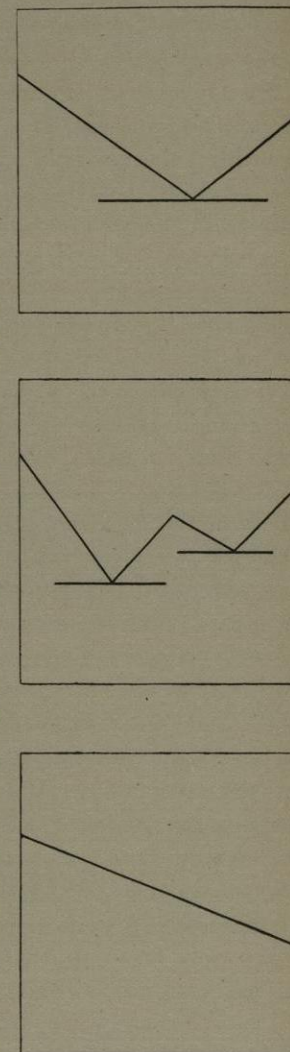


FIG. 19.—Three Curves representing the Constitution of Binary Alloys.

copper, while between these two points the curve rises to a maximum corresponding to 60 per cent. of copper. This is the composition of the definite compound SbCu_2 . Starting with pure antimony, and adding copper in increasing quantities from 0 to 25 per cent., a microscopical examination will reveal crystals of antimony surrounded by a eutectic, the crystals decreasing and the eutectic increasing in quantity until 25 per cent. of copper is reached, when the whole alloy is made up of the eutectic. When more than 25 per cent. of copper is added a new constituent makes its appearance in the form of crystallites having a distinct violet colour. These crystallites increase in quantity until the alloy containing 60 per cent. of copper is reached, which consists entirely of the violet alloy. Between 60 and 70 per cent. the alloys are found to consist of violet grains surrounded by a network of eutectic, and when 70 per cent. is passed dendrites of copper are seen surrounded by the second eutectic.

It will be seen that the alloys which fall under the second group in Le Chatelier's classification, viz. those forming definite chemical compounds, really give the same curves as the alloys of the first group, but duplicated. That is to say, the curve may be divided at the point representing the compound and considering the compound as a separate constituent (which it is), and not as an alloy. The curve is then resolved into two curves of the first group, and represents two freezing-point curves of two series of alloys each formed by a pure metal and a compound.

The third group of alloys is comparatively rare, as very few of the metals are isomorphous. An example, however, is found in the case of the gold-silver alloys. The freezing-point curve consists of a single branch uniting the melting-points of gold and silver, and a microscopical examination fails to show the existence of any eutectic or any definite compound. The properties of the alloys pass gradually from those of gold to those of silver.

These three groups of alloys have been described as having normal curves of fusibility; but in a large number of alloys the curves are more or less complicated. For example, it may happen that one metal is only partially soluble in the other and is at the same time capable of uniting with it in different proportions to form a definite compound. Again, a compound may be partially soluble in the pure metal, or may be isomorphous with one of the

metals. In such cases very complex freezing-point curves are obtained, whose meaning can only be explained by patient and laborious research. The alloys of copper and tin give rise to a complex freezing-point curve, and as these alloys have received more attention than any others, they may be considered as an illustration of the investigations which may be necessary in order to understand the constitution of a series of alloys.

Fig. 20 is the complete series of curves given by Heycock and Neville, and represents not only the results obtained from the cooling curves of the alloys, but also the results of a very thorough microscopical examination. In order to understand the changes which take place in the solid alloys which give rise to breaks in the cooling curves, Heycock and Neville have adopted the plan of quenching the alloys at temperatures above and below the breaks shown by the pyrometer, thus fixing the structure of the alloys at these temperatures, so that they can be examined under the microscope.

The curve ABCDEFGHIK is the freezing-point curve of the alloys, and has been described by Prof. Bakhuis Roozeboom as the *liquidus*, indicating that when the temperature is above this line the alloy is entirely liquid.

The line AblcdefE₂E₃H'H'IK' has similarly been called the *solidus* curve, indicating that at temperatures below this line the alloys are entirely solid. Between these two curves there is a region in which the alloys are partly liquid and partly solid. At these temperatures the alloys consist of a solid relatively rich in copper and a liquid relatively rich in tin.

The lines below the solidus curve indicate changes taking place in the solid alloys, and have been arrived at by a combination of pyrometrical and microscopical examinations.

Heycock and Neville recognise six constituents in the copper-tin alloys. These are—

The constituent α , which is a solid solution of tin and copper, containing not more than 9 per cent. of tin. The portions solidifying first consist of almost pure copper leaving a liquid relatively rich in tin.

The constituents β and γ are also solid solutions of copper and tin, differing from each other in crystalline form. The β crystals

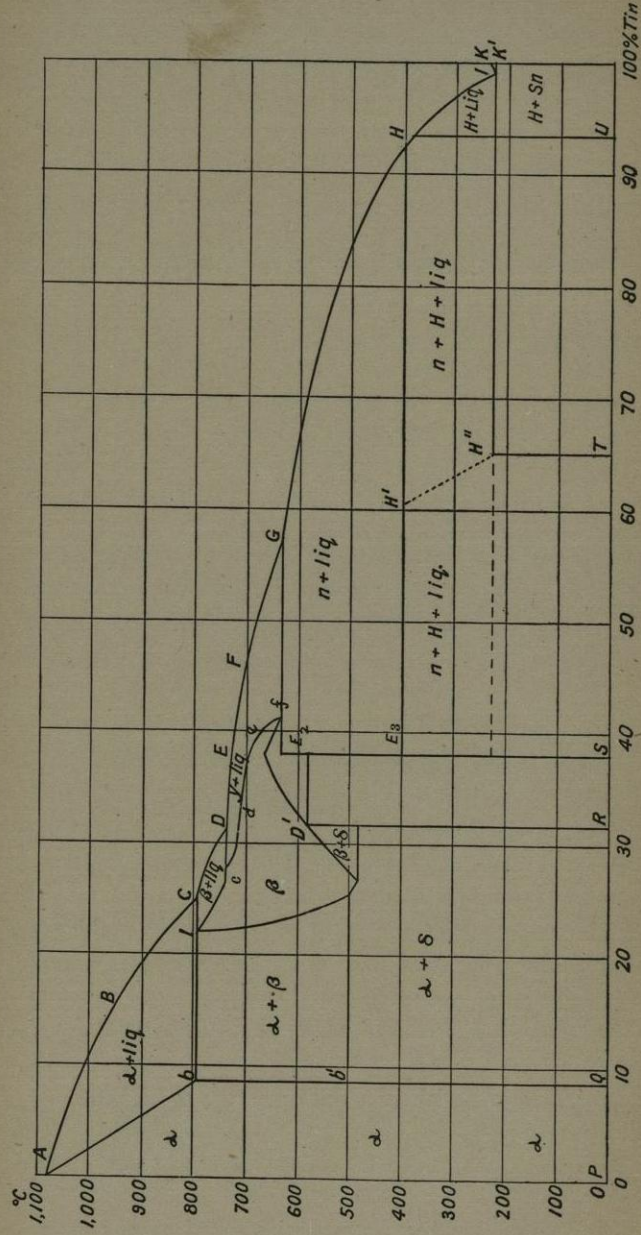


Fig. 20. — Freezing-point Curve of Copper-tin Alloys.

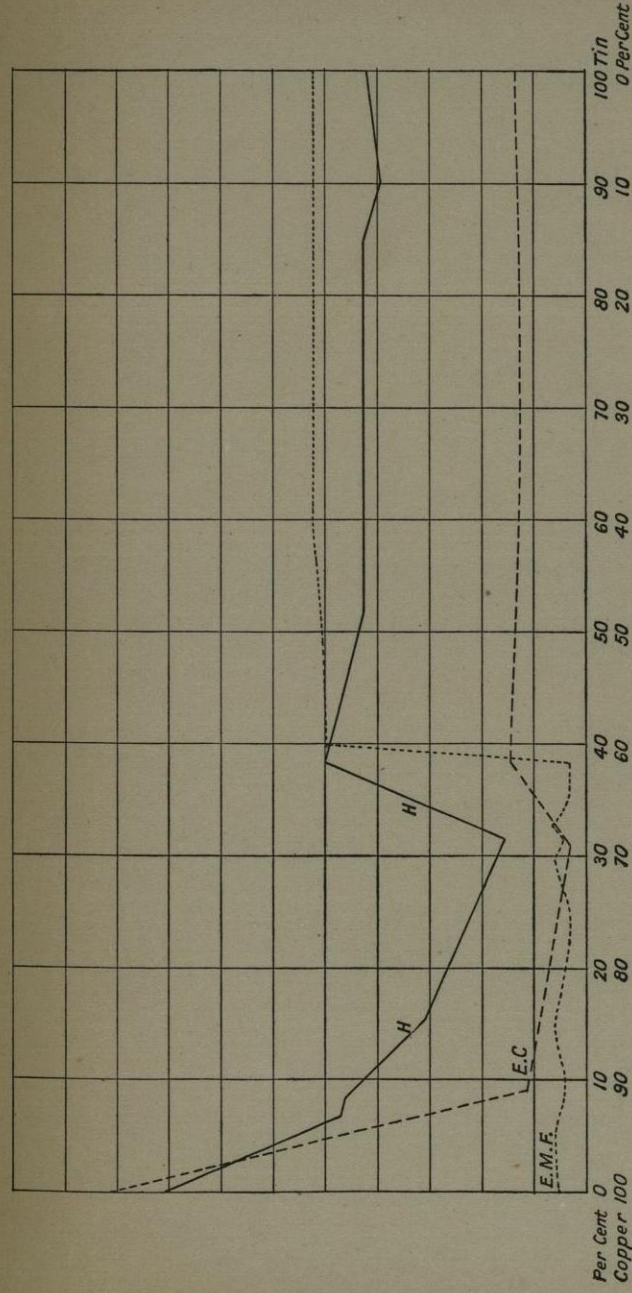


Fig. 21. — Physical Properties of Copper-tin Alloys.

H. Thermal Conductivity.
 E.C. Electrical Conductivity.
 E.M.F. Electromotive Force.

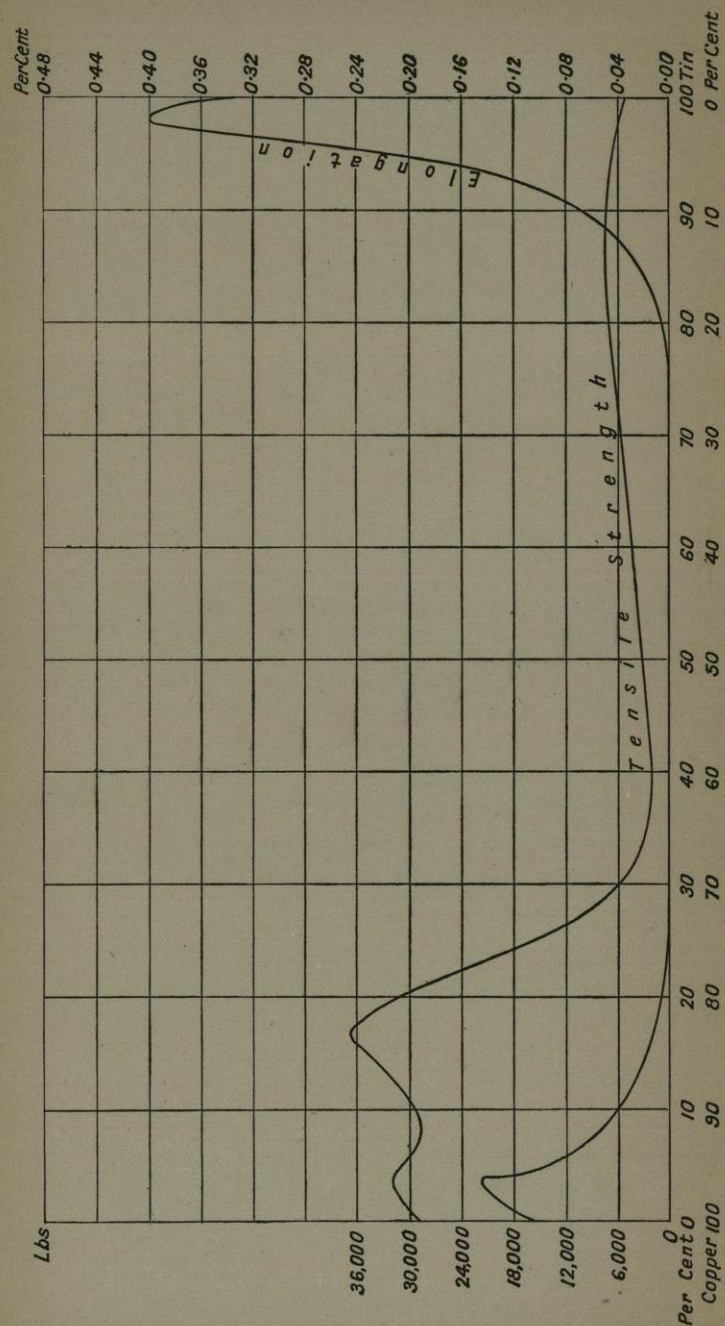


FIG. 22.—Mechanical Properties of Copper-tin Alloys.

contain from 22.5 to 27 per cent. of tin, and the γ crystals from 28 to 37 per cent. of tin.

These constituents may be described as transition constituents, as they are never found in a slowly-cooled alloy. They exist, however, at temperatures above 500° and in alloys quenched above that temperature.

The constituent δ is believed to be the compound Cu_4Sn . It is almost white in colour, and does not crystallise from the liquid alloy; it is only formed when the alloy cools below 500° .

The constituent E is the compound Cu_3Sn . It crystallises in plates, and is easily separated from the alloys.

The constituent H is the compound CuSn . In the slowly-cooled alloys containing from 40 to 90 per cent. of tin, this constituent is found bordering the crystals of Cu_3Sn , whereas in the alloys containing from 93 to 98 per cent. of tin it occurs in the form of hollow crystals, which Heycock and Neville have suggested may be due to the fact that the crystals have formed round nuclei of Cu_3Sn , and that the nuclei have subsequently been re-dissolved.

The temperatures at which these constituents are capable of existing are indicated in the diagram by lines which divide the lower part of the diagram into compartments. It is thus possible to see at a glance the constitution of any particular alloy at any temperature. Consider, for example, an alloy containing 15 per cent. of tin cooling from a molten condition. At 950° crystallites of almost pure copper separate out, and as the temperature falls these become richer and richer in tin until at a temperature just below 800° the constituent β solidifies, and the whole alloy is now solid. When the temperature falls below 500° the constituent β is no longer stable, and the alloy splits up into a mixture of α and δ , in which condition it remains at temperatures below 500° . A glance at the diagram will show that some of the alloys, especially those containing from 23 to 40 per cent. of tin, undergo very remarkable changes during cooling.

The constitution and properties of a series of alloys may be conveniently represented in the form of a chart, of which fig. 23 is a simple case. The curve at the top is the complete freezing-point curve of the lead-tin alloys, while the curve immediately below it shows their constitutional composition. Below this are

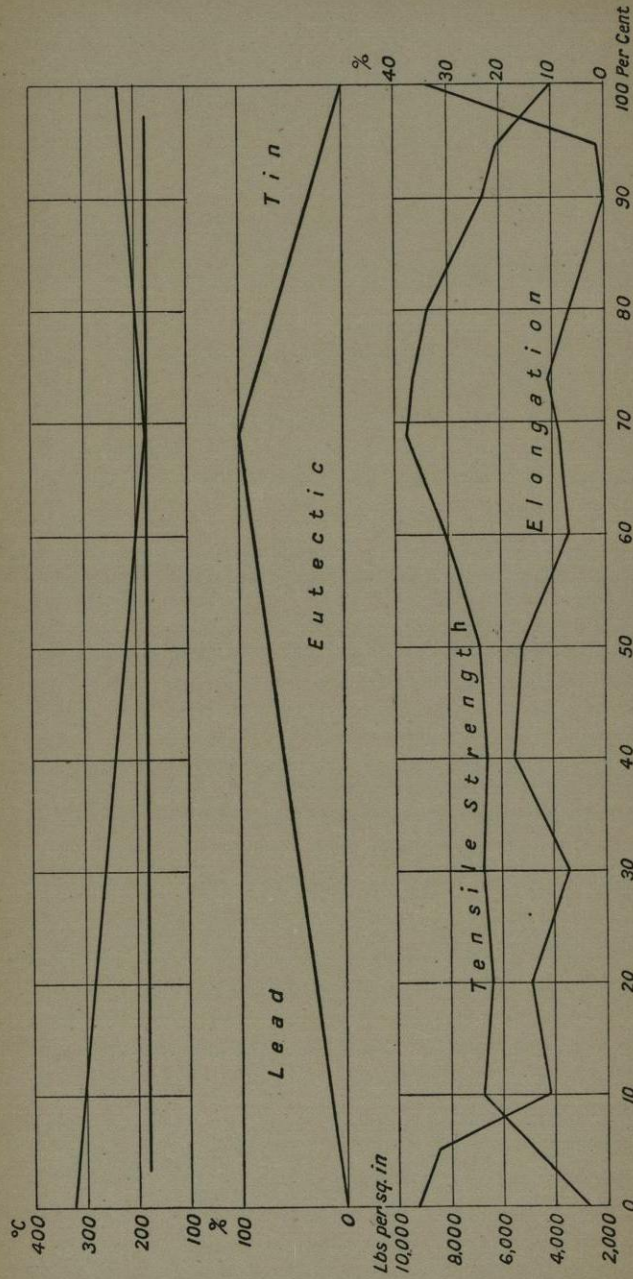


FIG. 23.—Alloy Chart of Lead-tin Alloys, showing—

1. Freezing-point curve.
2. Constitution.
3. Mechanical properties.

plotted the tensile strength and elongation, so that the mechanical properties corresponding to any structure or constitution can be seen at a glance.

The relation between the constitution and the mechanical properties is clearly defined, and the subject is of so much importance in the industrial applications of alloys that it deserves the closest attention. Fortunately the number of constituents which may be present in an alloy is limited to four, namely, pure metals, solid solutions, compounds and eutectics, and it is only necessary to consider the nature and properties of these constituents and their influence on the properties of an alloy.

Pure metals are relatively soft, malleable and ductile, and, when present in an alloy, they tend to impart these qualities to it.

Solid solutions, as already stated, possess similar properties to those of pure metals. They are relatively soft, malleable and ductile, and it may be pointed out that practically all the industrial alloys which are capable of being cold rolled, drawn, and spun, consist of a single solid solution. Brass, bronze containing less than 8 per cent. of tin, malleable phosphor-bronze, coinage-bronze, aluminium-bronze containing less than 7.5 per cent. of aluminium, cupro-manganese, cupro-nickel, German silver, standard gold, magnalium, and some of the nickel and manganese steels, are examples of ductile alloys consisting of a single solid solution. Standard silver may be regarded as an exception to the rule, but the quantity of eutectic in standard silver is very small and the silver-copper eutectic is much more ductile than most eutectics. Alloys consisting of two solid solutions are less ductile, but are still capable of being rolled and worked hot. Muntz metal, manganese-bronze, delta metal, and a number of other "special bronzes" and brasses, are examples of these alloys.

Compounds are harder than the metals of which they are composed, and brittle. They decrease the ductility of the alloy, and tend to lower its tensile strength. On the other hand, they increase the compressive strength of the alloy, a property which is of great importance in the case of bearing and antifriction metals, and at the same time they improve its working qualities as regards turning, filing, etc. The industrial alloys of this class include bronzes containing more than 8 per cent. of tin, cast

phosphor-bronze, all the white metal antifriction alloys, and the aluminium alloys containing copper, nickel, or tin.

Eutectics are brittle, and possess lower melting-points than either of their components. Owing to this difference in melting-point the eutectic portion of an alloy separates between the crystals of the other constituent, forming a network or cement, with the result that the ultimate strength and ductility of the alloy are practically the same as that of the eutectic. It follows that alloys containing eutectics are, with one or two exceptions, unsuited for constructional work. Their principal employment is probably in the form of solders, in which the difference in melting-points of the constituents enables them to be manipulated while in a semi-fluid or pasty condition. The eutectic of iron and carbon known as *pearlite* is an exception to the rule and is unique, as it is formed after the steel is completely solid. The result of this is that the crystals of iron are not surrounded by eutectic, but the eutectic is itself surrounded by free iron; so that the formation of pearlite in steel is rather more comparable, as regards its influence on the mechanical properties, with the formation of compounds in other alloys.

Alloys containing eutectics are sometimes rendered useful by chilling or cooling them rapidly, so that the eutectic is not permitted to solidify between the crystals, but is evenly distributed throughout the mass of metal. Here, again, the eutectic plays the part rather of a compound than that of a normal eutectic.

So far we have only considered alloys of two metals or binary alloys; but when we come to triple alloys the subject is, from a theoretical point of view, considerably more complicated. From a practical point of view, however, the difficulties are not greatly increased, for we find that the alloys contain, as before, only solid solutions, compounds, and eutectics. It is true that a solid solution of three metals may differ in hardness, strength or ductility from a solution containing only two, and it is equally true that a eutectic of three metals has a lower melting-point than a eutectic containing two, but the general characteristics of the constituents are the same. Solid solutions are the ductile constituents; compounds are the hard and brittle constituents; eutectics are hard and brittle and tend to solidify between the grains of the alloy, thus ruining its ductility.

From a theoretical point of view the subject of triple alloys (with the exception of steels) has been practically untouched. The most complete and systematic investigation is due to Charpy, who has chosen the alloys of lead, tin, and bismuth as being the simplest possible series of ternary alloys. The freezing-points of the three series of binary alloys, lead-tin, lead-bismuth, and tin-bismuth, have been determined in addition to those of the ternary series lead-tin-bismuth,

and the results are plotted in the following manner. The composition of the alloys is represented graphically by means of an equilateral triangle ABC (fig. 24). The three vertices A, B and C represent the three constituent metals, and any point on the sides corresponds to a binary alloy of the two metals

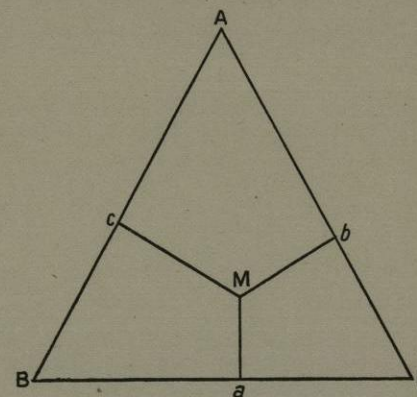


FIG. 24.—Triangular Diagram of Composition.

at the extremities of the line. Ternary alloys are represented by points inside the triangle, and their composition by perpendiculars drawn from the point to the sides. Thus Ma represents the proportion of metal A; Mb the proportion of B, and Mc the proportion of C. Charpy describes his method thus: "In order to represent the variation of a certain property—the fusibility, for instance—a perpendicular is raised from each point to the plane of the triangle, and a distance is measured upon that perpendicular proportional to the temperature of fusibility of the alloy represented by the foot of the perpendicular. The *locus* of these points constitutes the surface of fusibility which corresponds to the curves of fusibility of binary alloys."

Charpy has constructed a model showing the surface of fusibility of the lead-tin-bismuth alloys, and has also plotted the isotherms of the surface of fusibility (fig. 25). In this diagram the surface of fusibility of lead, tin and bismuth alloys is composed of three zones, which, by their intersections, give the lines $E\epsilon$, $E'\epsilon$, and $E''\epsilon$,

the points EE' and E'' corresponding to the three binary eutectics of lead and bismuth, lead and tin, and tin and bismuth respectively. The point ϵ corresponds to the ternary eutectic containing 32 per cent. of lead, 15.5 per cent. of tin and 52.5 per cent. of bismuth, and melts at 96° .

Alloys represented by points in the triangle lying above $E\epsilon E'$ will, on solidification, deposit lead first; and in the same way alloys

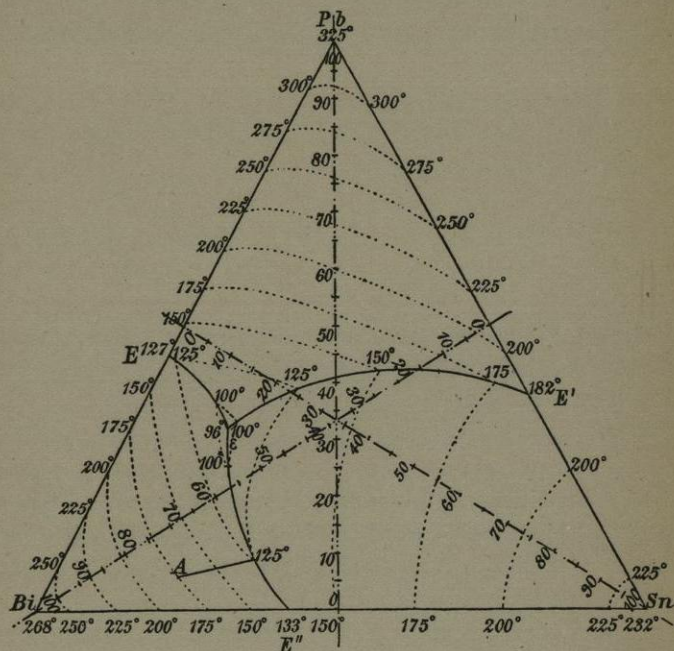


FIG. 25.—Surface of Fusibility of the Alloys of Lead, Tin, and Bismuth.

represented by points lying between $E\epsilon E''$ and Bi and between $E'\epsilon E''$ and Sn will first deposit bismuth and tin respectively.

These results have been fully confirmed by the microscopical examination of the alloys.

Within recent years much has been written upon the constitution of alloys from a theoretical standpoint, and more especially from the point of view of the so-called Phase Rule first enunciated by Willard Gibbs. This rule states that—*it is necessary to assemble at least n different molecular species in order to construct a complete heterogeneous equilibrium consisting of $n+1$ different*

phases. At one particular temperature and pressure only is it possible to have $n+2$ phases in equilibrium. Thus, to take the simplest possible case, the compound H_2O is regarded as a simple molecular species and therefore $n=1$. Now, there are three possible phases in which this compound can exist, viz. ice, water, and water vapour; but according to Gibbs' phase rule only two ($n+1$) phases can remain in equilibrium except at one critical point. Thus a condition of equilibrium extending over a certain range of temperature and pressure may be established between ice and water, water and water vapour, and ice and water vapour, but only at one temperature and pressure (0.0075° and 4.57 mm.) can the three phases occur together.

A more complicated case (which has, however, been thoroughly investigated by Roozeboom) is to be found in the conditions of equilibrium existing between water and sulphur dioxide. Here we have two molecular species ($n=2$) and four possible phases, viz. :—

1. A solid hydrate $SO_2, 7H_2O$.
2. A solution of SO_2 in water.
3. A solution of water in liquid SO_2 .
4. A gas mixture of SO_2 and H_2O .

It has been proved experimentally that only three ($n+1$) of these phases can exist in a condition of equilibrium except at the critical point.

It is evident that the application of the phase rule may be extended to meet the case of alloys with the object of determining the number of possible constituents which can exist in a state of equilibrium in a given system; and this has been done by Roozeboom in the case of the iron carbon alloys. The subject is, however, a complicated one and can hardly be said to have added much to our knowledge of alloys. The student who wishes to follow it up should study the work of physicists (and more especially the masterly researches of Roozeboom) before attempting to deal with the theoretical conclusions of those who are less perfectly acquainted with the subject.

The accompanying glossary of terms, taken, with modifications, from the list drawn up by the Committee appointed by the Iron and Steel Institute to inquire into the nomenclature of metallurgy, contains the more important terms employed by writers on the constitution of alloys.

GLOSSARY OF TERMS.

- Acicular** (Ger. *Nadlig*; Fr. *Aciculaire*).—A term used to describe long needle-like crystals.
- Allotriomorphic** (Ger. *Allotriomorph*; Fr. *Allotriomorphe*).—A term applied to crystals which have taken their shape from their surroundings.
- Allotropic Form or Modification** (Ger. *Allotrope form*; Fr. *Forme Allotropique*).—A term applied to an element which has physical properties and chemical activities different to the normal state of that element.
- Blowholes** (Ger. *Blasenhohlräume, Blasen*; Fr. *Soufflures*).—Small cavities, spherical or ellipsoidal, found in ingots or cast metals. They consist of bubbles of gas which have not been able to escape before the metal became completely solid.
- Cleavage** (Ger. *Spaltbarkeit*; Fr. *Clivage*).—As applied to minerals and metals, is the property possessed by crystals and crystal grains of separating along certain planes. These cleavage planes are usually parallel to one or more of the faces of the crystal forms, but have not necessarily any relation to the faces of the crystal grains.
- Conchoidal** (Ger. *Muschelig*; Fr. *Conchoïdal*).—Having the shape of shell: applied to the concave and convex fractures of some alloys of zinc-copper and tin-copper, glassy slags, etc.
- Critical Points** (Ger. *Kritische Punkte, Haltepunkte*; Fr. *Points critiques*).—The point or zone at which a physical or chemical change takes place, as when, in cooling pure iron and steel from 900° C., an evolution of heat, indicative of a physical change, occurs at the critical points Ar_3 and Ar_2 . When the change is not at one fixed point, but extends over several degrees, the area of change is called a *zone* or *range*.
- Crystallite** (Ger. *Krystallit*; Fr. *Cristallite*).—An arrangement of globulites tending to form a crystal. "Regular aggregates of globulites" (Vogelsang).
- Equilibrium Curve** (Ger. *Gleichgewicht Kurve*; Fr. *Courbe d'équilibre*).—This is a curve showing the relation of temperature and composition of a heterogeneous system, in which the phases present are in equilibrium with each other.

- Etching** (Ger. *Aetzen*; Fr. *Attaque chimique*).—In order to develop the constitutional and crystalline structure of metals and alloys the polished surfaces are subjected to action by suitable reagents, such as nitric acid, iodine, sulphuric and hydrochloric acids, etc. This action is termed etching.
- Eutectic** (Ger. *Eutektisch*; Fr. *Eutectique*).—A term used by Guthrie (1875) to indicate solidified mother-liquor. All eutectics have a freezing-point below that of the mean of their constituents.
- Fibrous** (Ger. *Faserig, Sehnig*; Fr. *Fibreux*).—Composed of fibres or threads. Fractured surfaces of some wrought irons and steels and other metals may falsely indicate fibrous structures. In such cases the fibrous fractured surface is the result of tension, which draws out the crystal grains into threads or fibres.
- Ground-mass** (Ger. *Grundmasse*; Fr. *Masse-fondamentale*).—The ground-mass of a rock is the matrix in which crystals are embedded. Similarly in metallography the term may be used for the mass which is in preponderating quantity.
- Hysteresis** (Ger. *Hysteresis*; Fr. *Hystérésis*—Ewing).—Retardation of magnetisation (magnetic hysteresis). The persistency with which certain bodies tend to retain a previous condition. Prof. Ewing uses the word in the more general sense of a dissipation of energy occurring in any cycle of operations.
- Idiomorphic** (Ger. *Idiomorph*; Fr. *Idiomorphe*).—Crystals which have developed their external forms freely.
- Isomorphous** (Ger. *Isomorph*; Fr. *Isomorphe*).—A term applied to crystals exhibiting similarity in form.
- Lamella** (Ger. *Plättchen, Blättchen*; Fr. *Lamelle*).—A term used in microscopic petrography for a thin plate. Plates of graphite in grey pig iron, and the plates of cementite in pearlite, are lamellæ.
- Lamina** (Ger. *Blättchen*; Fr. *Lame*).—A thin leaf-like plate.
- Margarite** (Ger. *Margarit*; Fr. *Margarite*).—The name given by Vogelsang (*Die Krystalliten*, p. 19) to the linear arrangement, like strings of beads, assumed by globulites. Osmond and others have used the term to describe the same arrangement of crystallites in metals and alloys.

Mixed Crystals (Ger. *Mischkrystalle*; Fr. *Cristaux mêlés*).—A term used for two or more substances which are capable of crystallising together to a greater or less extent, but which are not isomorphous. Mixed crystals are not, as a rule, homogeneous. The term is very frequently incorrectly used.

Mother-liquor (Ger. *Mutterlauge*; Fr. *Liqueur-mère*).—During the process of congelation of any system consisting of several substances in a state of solution, a portion of the solution remains in a fluid state after the separating out of solid crystals; this liquor is termed "mother-liquor." In systems consisting of two constituents with a eutectic point, the composition of this liquor approximates, as congelation proceeds, to that of the eutectic mixture, and quite attains to this composition before the whole mass passes into the solid state.

Orientation (Ger. *Orientirung*; Fr. *Orientation*).—The relative direction of the axes of crystals, or of the axes of elasticity in two or more crystals, or the relative position of these axes with regard to a certain surface or line; for instance, the polished surface or a cleavage plane, etc.

Osmotic Pressure (Ger. *Osmotischer Druck*; Fr. *Pression osmotique*).—When two liquids are separated by the intervention of a porous diaphragm, a flow of liquid takes place from one side to the other, or sometimes an unequal flow of the two liquids in opposite directions. This phenomenon is termed "osmose," and the pressure exerted by a dissolved substance in its solution is termed its osmotic pressure.

Pipe (Ger. *Lunker, Schwundungshohlraum*; Fr. *Retassure*).—A pipe is the cavity formed in the central upper part of the ingot.

Polymorphism (Ger. *Polymorphismus*; Fr. *Polymorphisme*).—The property possessed by some substances of assuming more than two forms of molecular structure.

Recalescence (Ger. *Recalescenz*; Fr. *Recalescence*—Barrett).—A term used to express the phenomenon of the evolution of internal heat, which occurs when iron and steel cool through the critical zones or ranges.

Scoriæ (Ger. *Schlackenartiger Körper*; Fr. *Scories*).—Cinder or slags from metallurgical processes.

Segregation (Ger. *Ausscheidung, Sagerung*; Fr. *Ségrégation*).—

A term applied to the more fusible parts of metals and alloys which are last to freeze, and are driven into certain local centres by the metal which first crystallises. Segregates are generally found near the centre of the castings, and are most pronounced in very large masses.

Slip-bands (Ewing and Rosenhain).—A microscopic appearance in smooth surfaces of metals after straining, caused by slips along the cleavage or gliding planes of the crystalline grains.

Surfusion (Ger. *Ueberschmelzung*; Fr. *Surfusion*).—A transitory liquid state at temperatures below the normal freezing-point.

Twinned (Ger. *Verzwilligt, Zwillingsbildung*; Fr. *Hémitrope, Maclé*).—A crystal is twinned when two portions of the same individual, or two different individuals, are related to one another according to a definite law.