

ered as indeformable and as constant in strength. This implies that a complete representation of the facts of paramagnetism and of the exchange of energy between magnets and currents is obtained on the hypothesis that the magnets consist of similar currents rigidly obeying the ordinary laws of electrodynamics. As regards paramagnetism, Curie has shown that paramagnetic susceptibility is inversely proportional to the absolute temperature. The author fully explains this law. The molecules whose magnetic axis is parallel to the field acquire a greater kinetic energy than the others, leading to an increase of temperature proportional to the increase of moment. To reduce this a quantity of heat $dQ = H dM$ must be abstracted. Since

$\frac{dQ}{T}$ is an exact differential, we have Curie's law

$$M = k \frac{H}{T}$$

if the magnetization is proportional to the field.—P. Langevin, *Journal de Physique*, October, 1905.

SOLUTIONS OF SOLIDS AND SOLID SOLUTIONS.*

By J. H. STANSBIE, B.Sc., F.I.C.

THE general question of solution has always been of importance to the metallurgist, and is becoming more so on account of the fresh information concerning the nature of solutions which is constantly coming to hand. The practical metallurgist has so many difficulties to overcome in the melting, casting, and manipulation of metals and alloys generally, that information which seems to have but a remote bearing upon his work may prove useful, and he cannot afford to let it pass.

Solids and liquids are recognized by their general properties, and it is certain that whatever matter is, a solid body of appreciable size is made up of parts, and that there are causes within the body which determine the relative positions of these parts, and also their mean distance apart. This may be explained by assuming that internal friction prevents the separation of the parts, or that there is a constantly acting pressure which is directed toward the interior of the solid. The idea of internal friction is supported by the viscosity of the malleable metals, which enables them to flow under the hammer. But in order that this change in form may take place, work must be done upon the metal, and in this respect the viscous solid differs from the true liquid, which can alter its form without expenditure of work, if allowed to do so. It will be well to keep this viscosity of metals in mind, and to remember that for the majority of metals there is a temperature at which the metal offers the least resistance to work done on it while still preserving the solid state.

Also, it may be noted that the work put on to a solid during its change of form may all be converted into heat, or part of it may be stored up in the body itself. The latter is the case with metals which harden when they are worked, and the fraction of the energy thus stored up is given out again during annealing. Thus the system "hard metal" contains more energy than the system "soft metal."

Generally speaking, the particles of a solid are under restraint, and their separate motions are confined to excessively small spaces; but in a liquid there seems to be nothing to quite hinder its particles from wandering anywhere within the boundaries of its volume. There is, however, a cause which determines the mean distance of these particles, and so determines the volume of the liquid. It is well known that an enormous pressure is required to reduce the volume of a solid or liquid when it is a true volume pressure—that is, directed from all parts toward the center of the body; although the density of a metal may be increased by working.

Now we may regard any solid or liquid body as a self-contained system which will conserve itself as long as neither matter nor energy crosses its boundary, although the relations between its matter and energy may undergo readjustment. But if energy enters or leaves such a material system, important changes may take place. The changes we have to consider refer to the solid and liquid states.

Solids may be divided into two classes—amorphous and crystalline. Amorphous means without form, in the sense of without crystalline form. Amorphous solids seem to come more into a line with liquids. They certainly resemble ordinary liquids in viscosity, although their viscosity is much greater than that of water. There is a tendency to wander on the part of the individual particles; but whether it takes place at ordinary temperatures, even to a limited extent, is an open question. Although Ewing and Rosenhain and Stead have observed the gradual absorption of one solid body by another, such solids have the same properties in all directions; that is, the forces at work within them are evenly distributed, and wandering is thus probable; for any slight disturbance of the equilibrium in any part would tend to set up motion in that part. This inclines us to the belief that metals which become plastic on heating lose their crystalline character when in the plastic state, and those that harden on working also tend to become amorphous. In a crystalline solid, however, there is no haphazard arrangement of the particles. The form of the ultimate particles or molecules seems to condition the regular arrangement, and the regular, though not always uniform, distribution of the internal forces.

Now if we agree that an amorphous solid resembles

a liquid, it must also resemble a liquid solution; and if it resembles a liquid solution, it must also resemble a solid solution. May it be said, then, that a solid solution is amorphous?

But it is possible for an amorphous solid to crystallize under proper conditions; it is also possible for a solid solution to crystallize. Is it still a solid solution after the crystallization has taken place? The answer to this is, that mixed crystals are regarded as solid solutions. What is the solution of a solid? If a solid combines with a liquid to form a homogeneous mass—that is, a mass of uniform concentration, which is still liquid—the whole mass is called a solution of the solid, and the components of the solution are known as the solvent and the solute. In such a mass there is a complete merging of the components without regard to that fixed ratio between them which is so characteristic of a true chemical merging. In the process of solution the solid disappears from sight, even when aided by the most powerful microscope, and the most careful analysis fails to detect any difference in composition of different parts of the solution.

From what has been said already it will be understood that a kind of internal pressure is acting toward the interior of a solid, so as to keep its mass intact without aid from outside. You may call this attraction, cohesion, tenacity, or give it any name you please, but the fact remains that an expenditure of energy is necessary to separate its particles.

In the liquid state the body is in a more unstable condition, for in many cases its exposed surface loses some of its matter under certain conditions; but even this depends upon the readiness with which the liquid becomes gas. But as it loses matter it also loses internal energy.

Now, in the case of liquids a small portion of their internal energy seems to concentrate itself very near to the boundaries of the body. This is known as superficial energy, and its amount depends upon the area of its surface, and the bodies with which it is in contact. It appears to act in a very thin stratum, and is known as surface tension. This surface energy always tends to a minimum, and seems to act as a kind of pressure toward the interior when it is allowed full play. This is seen in the case of rain drops, which are masses of water occupying volumes with the smallest possible areas under the conditions. Here the surface tension causes the boundary layer to act like an elastic skin, and to draw the matter into its volume of smallest area.

A homogeneous solid or liquid is said to be in a definite phase, and it is immaterial how many components there may be in the mass as long as it is homogeneous. Another idea of a phase is that it is a mass of uniform concentration, and when it consists of more than one component they are mechanically or physically separable.

A system consisting of one or more phases is said to be in true equilibrium when it remains constant under constant conditions of temperature, pressure, and concentration, and when a very small change in one of these variables causes a correspondingly small change in the system.

Now turn to a system consisting of a solid and a liquid which will dissolve it. If there is an excess of the solid, the point of saturation for a definite temperature cannot be exceeded, however long the solid and liquid phases are in contact with each other. The two variables here are the temperature and concentration.

Let us consider for a moment what is happening here. We know that the solid phase is passing into a liquid phase; and we know further that it is a purely physical or mechanical action, and that heat is being absorbed. Now it is purely a surface action. The particles of the solid are in contact with the particles on the surface of the liquid, and their proximity assists in some way, it may be by surface tension, the internal energy of the solid, which is always directed outward, and some of the solid particles find themselves in the liquid. But these particles still have a tendency toward their own, and although they have become migrating bodies, they sometimes migrate back, and an interchange may take place between the particles of the solid in the liquid, and those in the solid itself. This goes on till the point of saturation is reached, and then the rate of exchange of particles is the same in all directions, and we have a system consisting of a solid phase and a liquid phase in equilibrium. The solid phase consists of one component, and the liquid phase of two components, the liquid and the solid dissolved in it.

The rate at which a given solid dissolves in a given liquid depends upon a number of circumstances. Sometimes it is very rapid, and sometimes very slow. Also the rate at which the solid particles will diffuse through the mass of the solvent may vary considerably.

It may be remarked that the idea of interchange or dynamic equilibrium between the solid and liquid phases after saturation has been reached appears to be opposed to that of uniform concentration; but it may be said that this exchange takes place only in the surface layers, and is of a constantly counter-balancing character. The necessity of the idea is shown by the fact that large crystals in a saturated solution may grow on one face and dwindle on another to exactly the same amount, the total mass of the crystal keeping constant. This is probably due to slight differences in the concentration of the layers in contact with the faces, which causes a difference in the surface energy on the faces. But as these differences may be excessively small, the general concentration may be regarded as uniform. The general principle contained in

this statement is of importance in connection with solid solutions. There is also the view that the crystals may have different solubilities in different directions.

The equilibrium of the system solid solution is at once disturbed by an increase or decrease in its temperature. The general effect of an increase in temperature is to cause more of the solute to pass into the solvent, and a decrease to bring about the opposite effect. But this is not uniformly true, for the solubility of some solids increases with the temperature up to a certain point, and decreases with a further increase in temperature.

A solid in solution possesses a definite pressure, which is called its solution pressure; this is no doubt largely instrumental in bringing about diffusion of the solid through the bulk of the liquid after dissolution. It is well known that a salt in solution raises the boiling point of the liquid, and this means simply that a given rise in temperature causes a smaller increase in the vapor pressure of the solvent when a solute is present than when it is absent. Also, the freezing point of the solution of a solid is lowered by the presence of the solid; the lowest temperature being obtained for a definite concentration, which, in the case of salts and water, gives the composition of the cryohydrate, and in the case of alloys, the eutectic mixture.

In many cases solutions can be cooled below their point of saturation without any of the solute separating in the solid state; but the system is in unstable equilibrium, and a small portion of the solid dropped into the solution causes partial solidification, with development of heat, to take place at once.

What is a solid solution? A solid mass containing two or more components of uniform concentration. In other words, it is a homogeneous mass containing constituents which are physically and mechanically separable as far as solidity permits. Here we have the possibility of variations in concentration with variations in temperature; also of conditions under which certain components are in equilibrium. But it is very evident that the investigations of such conditions are much more complicated than with solutions of solids. All changes in solid solutions must be necessarily slow.

The clear glasses are probably the best examples of solid solutions, for their composition may vary by infinitesimals from specimen to specimen. The readiness with which molten silicates dissolve either silica or basic oxides is well known, and also that the components may or may not be able to remain in solution when the molten mass solidifies. If they do remain in solution, then a solid solution results; but if not, a heterogeneous mass is obtained.

Mixed crystals are also examples of solid solutions. Such crystals are best studied with salts crystallized from aqueous solution, and the alums furnish good illustrations. It is quite easy to form mixtures of common alum and chrome alum in any proportions.

Now these solid solutions which partake of the nature of mixed crystals are of considerable importance from a metallurgical point of view. All metals are of crystalline nature, and many of their crystalline forms belong to the cubic system—that is, they are isomorphous, and, all other conditions being favorable, should form mixed crystals. Thus it may be stated generally that, in the case of pure alloys of metals, the solid solutions take the form of mixed crystals. Gold and silver alloys give the simplest cases of solid solution of metals of uniform concentration. This is brought out by the freezing curve, which for a series of gold-silver alloys falls uniformly from the freezing point of gold to that of silver.

It has been stated that solid solutions in the case of metals are heterogeneous, on account of the slow diffusion which takes place in the molten metals as compared with the solutions of solids in liquids. But it would appear that this is only a matter of time, for if the alloy is kept molten sufficiently long, uniform concentration may be attained, and then the slow motions of the components in the solution would favor the retention of uniform concentration in the alloy on freezing. But another aspect of the question arises when chemical compounds are formed between two metals, or a metal and a non-metal. In this case any solution must be formed by the dissolution of the compound in excess of the main mass of the metal. A case in point is found in the alloys of copper and arsenic. Now there is not the slightest doubt but that arsenide of copper is formed and dissolved in the molten alloy. Micro-examination of copper-arsenic alloys shows that a separation takes place during the solidification. But it is probable that a certain percentage of arsenic in the arsenide forms a solid solution, which has a much less hurtful effect on the main mass of the metal than when a eutectic separates. This is a practical question of some importance to those who introduce small percentages of certain elements into copper to produce sound castings. For it is clear that the proportion of the added element should be about that required to form the solid solution; and this for arsenic in copper seems to be about 0.25 per cent of arsenic.

The relations of carbon to iron in alloys of these bodies have formed the subject of an enormous amount of work, and many investigators are still at work upon it. The only reference I wish to make to that work is in connection with the solid solutions of carbon in iron which exists in hardened steel, and which is known by the name of "hardenite," about which the last word has not been said. Now, Howe states that solid solutions are heterogeneous, and probably bases his opinion upon a micro-examination of hardened steel; but is it necessary to assume this heterogeneous character from an etched specimen? A solid solution should etch uni-

* Abstract of paper read before the Metallurgical Society at the Birmingham Municipal Technical School.

formly, and that is the only condition necessary; for if an etching liquid is used, it attacks the component of the solid solution for which it has the greatest affinity.

OLD INVENTIONS.

By F. M. FELDHAUS.

WE need not despise modern inventions in order to accord full recognition to those of the past. Centuries before the present age of invention able and ingenious mechanics, called, in Old German, *Antweremaister*,



FIG. 1.—MAGIC LANTERN INVENTED BY JOHANNES DE FONTANA ABOUT 1420.

and, in Latin, *encignerii*, were employed by princes to devise engines of war. Many of these men have left notes and sketches, among which may be found the germs of inventions which did not attain full development and practical application until after they had been laboriously re-invented, perhaps centuries later.

For example, the magic lantern, the progenitor of modern optical projection apparatus, was described and



FIG. 2.—LAMP WITH GLASS CHIMNEY, 1500.

illustrated by Johannes de Fontana in 1420 (Fig. 1). It was devised for military purposes, the idea being to project at night horrible pictures which would throw the enemy's outposts into panic. The drawing clearly shows the wax candle, the demon painted on the glass slide, and its colossal projection on the wall. This device, if it was ever put to practical use, must have been very effective in an age of superstition. The in-

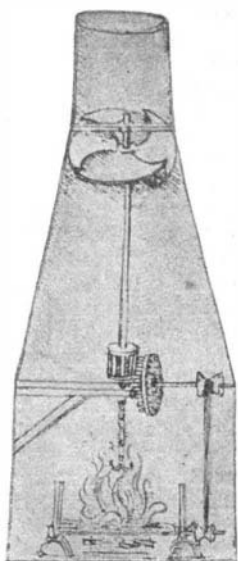


FIG. 3.—SPIT TURNED BY HOT AIR, 1500.

vention of the magic lantern is commonly attributed to the Jesuit monk Kircher, of Fulda, and the date ascribed to the invention is 1671, two hundred and fifty years after this drawing was made.

Fontana's lantern, furthermore, has a glass cylinder, identical in principle with the modern glass lamp chimney, which is generally supposed to have been in-

vented by Quinquet in 1756. Leonardo da Vinci, the eminent artist and scientist, was evidently familiar with the glass chimney, for it appears in a design for a lamp drawn by him in 1500 (Fig. 2). This design also includes a hollow lens, filled with water, to increase the intensity of the light in one direction.

Leonardo da Vinci, who suggested the mechanical

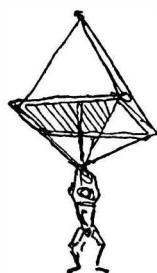


FIG. 4.—LEONARDO DA VINCI'S PARACHUTE, 1514.

application of the elastic force of steam, also invented a spit turned by a screw propeller driven by the upward current of hot air caused by the fire (Fig. 3). Among the mechanical engineers of the end of the medieval period, Leonardo stands pre-eminent. No other has left us so many suggestions, written or drawn, as he. Yet, though his fame as an artist is universal, his scientific and technical work is little known, with the exception, perhaps, of his work in

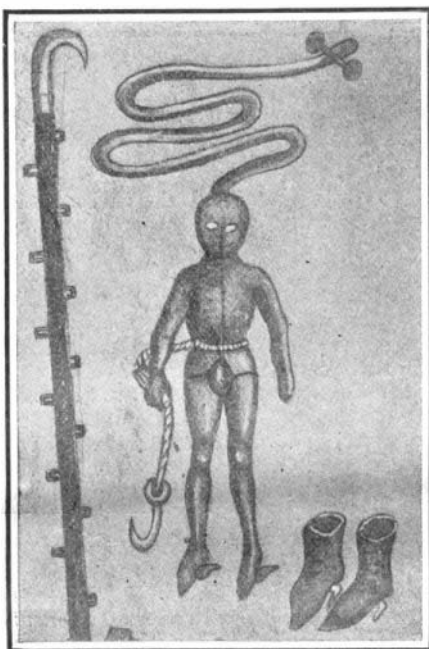


FIG. 5.—DIVING DRESS, 1500.

aeronautics. Fig. 4 shows the parachute which Leonardo invented in 1514 and which was destined to be brought forward as a new invention by Le Normand in 1783. In connection with this drawing Leonardo writes, "Any person who possesses a stiff canvas tent of twelve ells height and breadth may let himself fall from any height, no matter how great, without fear of injury."

The old engineers also sought to enter the realm of fishes. Diving and swimming apparatus occupy much



FIG. 6.—THE DIVING BARREL OF ALEXANDER THE GREAT. FROM A MINIATURE MADE ABOUT 1320.

space in many of their illustrated manuscripts. Fig. 5 is taken from a comparatively modern work of this character, written by the knight Ludwig von Eybe zum Hartenstein at the beginning of the sixteenth century. The picture shows a leather diving dress with goggles

and air tube, weighted shoes and a pole ladder, by which the descent and ascent were made. Many sunken objects may have been recovered, and many a good ship scuttled so secretly that the tale has not come down to us; for the old masters jealously guarded their knowledge and their art. Fame, social station and wealth depended on their ability to do things that no one else could do. To these inventors the problem of sustaining life under water must have appeared very alluring. The idea of the diving bell finds expression at a very early date. One of the oldest pictures of the diving bell occurs in a manuscript of the "Romance of Alexander," in the royal cabinet of engravings in Berlin. This picture, a painting in miniature, is very curious. Alexander the Great, wearing a crown, sits in a glass barrel ("tonnel de verre") which has been lowered into the sea by ropes, from a ship. The king has two lamps, presumably in order to study the denizens of the deep, one of which, many times larger than the ship or the barrel, is shown between them.

In a manuscript of the German poem "Salman and Morolf," written in 1190, and preserved in the royal library in Stuttgart, there was once a picture of a submarine boat, but the picture and some others have been cut out and stolen. The poem tells how Morolf built a small boat of leather which could not be injured by storms. Finding himself surrounded by twenty-four of the enemy's galleys he caused his boat to sink to the bottom of the sea where he remained fourteen days, breathing through an air tube. Though the idea common to the diving bell and the submarine boat is thus, as we see, seven hundred years old, the diving bell was first used in practice in 1538, when two Greeks exhibited it at the court of Charles V. of Spain and Austria. The first submarine or submergible boat was shown by Drebbel in London in 1624.

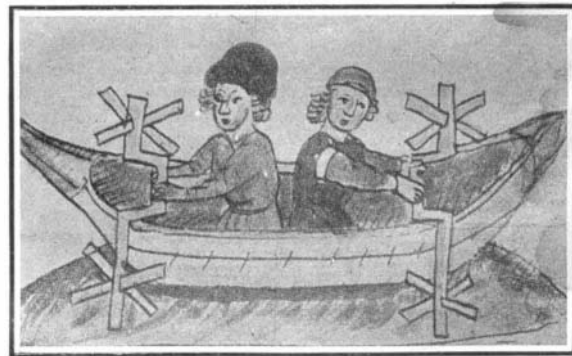


FIG. 7.—PADDLE-WHEEL BOAT, 1430.

The application of the paddle wheel to boats is another very old invention. The drawing of a paddle-wheel boat, shown in Fig. 7, dates from 1430. The accompanying text describes the boat as a war vessel employed by the Catalonians and carrying twenty-four men, though only two men are shown in the picture. In a sea fight such a vessel would appear to be more manageable than a galley with its many long oars.

The turbine or screw propeller was also invented long ago, not as a means of propulsion for boats, but as an improvement on the unwieldy mill wheel of the ordinary type. Its invention dates from the beginning of the 15th century and is ascribed, very strangely, to "a pope of Rome." The name of this wearer of the tiara is not definitely known. Fig. 8, a reproduction of a drawing made about 1575, shows, in the lower left-

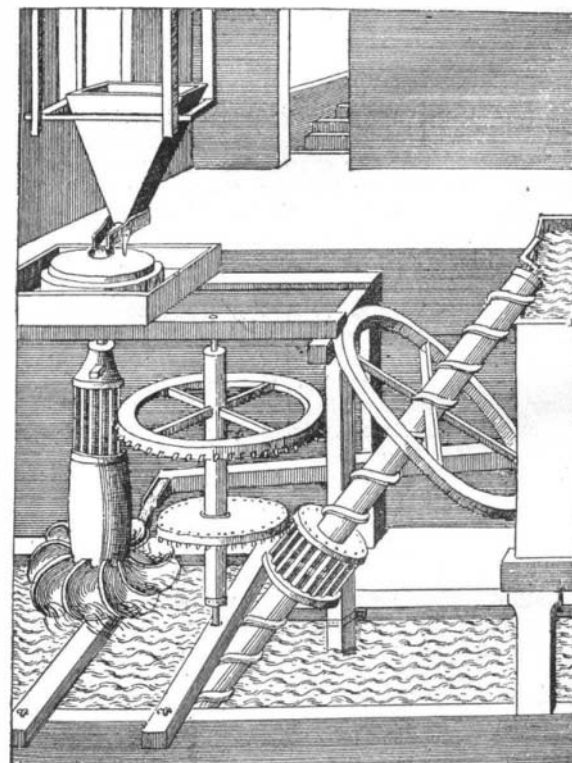


FIG. 8.—TURBINE, 1575.

hand corner, the peculiar form of turbine which Poncelet re-invented in 1826.

These old mechanics devote a very large amount of space to pictures of cannon. In one of the oldest illustrated manuscripts on the art of war of which we have any knowledge, written about 1380, we find a revolving cannon, an invention which is usually supposed