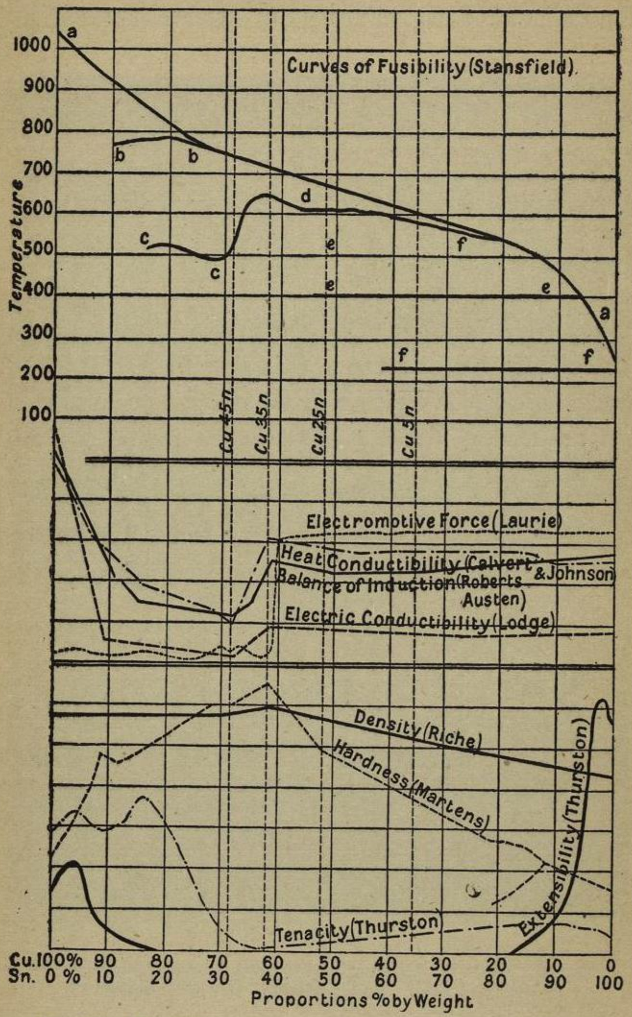

Fig. 26.—Equilibrium Curves and Physical Properties of the Alloys of Copper and Tin.

ruptions. Behrens,[1] by the study of the microstructure, has arrived at the idea of definite compounds still more numerous; and H. Le Chatelier[2] thinks he has isolated $SnCu_3$ by proximate chemical analysis. However, the alloy of this composition shows two liberations of heat. In fact, there is not, perhaps, a single one of the conclusions drawn from a series of experiments which is not contradicted or at least challenged by the conclusions drawn from another series. The aspect of the curve of fusibility alone shows the complexity of the question: certain alloys have three, and as many as four, points of transformation or of solidification, the position and sometimes the existence of which may be connected with the rapidity of cooling. Fortunately the problem is now solvable, thanks above all to micrographic analysis, which alone furnishes as many equations as unknowns, and has already given, through Guillemin, Behrens, and Charpy, very interesting results. The solution is now only a question of time, patience, and method.

Whilst awaiting it, there will be seen with interest several photomicrographs of bronzes obtained from beautiful preparations by Guillemin. The structure has been revealed in every case by heating so as to obtain colours; the dark parts of the photographs are those which are the first to take the oxidation tints.

A first series comprises bronzes cast in ingot moulds in the form of small bars, with a square section 15 by 15 mm., in which the percentage of tin varies from 9 to 33 per cent. All the photographs are enlarged 100

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[1] *Proc. Inst. Mech. Eng.*, pp. 70–91.

[2] *Bull. Soc. d'Encouragement*, 4e série, t. x. p. 388 (1895).

diameters, and would not show further details with even higher enlargements.

The bronze with 9 per cent. of tin (fig. 27) appears homogeneous; at least, the process of investigation shows it as such. There is probably only one point of fusion, for it is just at this percentage that the line BB of the second point of solidification on the curve of Dr Stansfield stops.

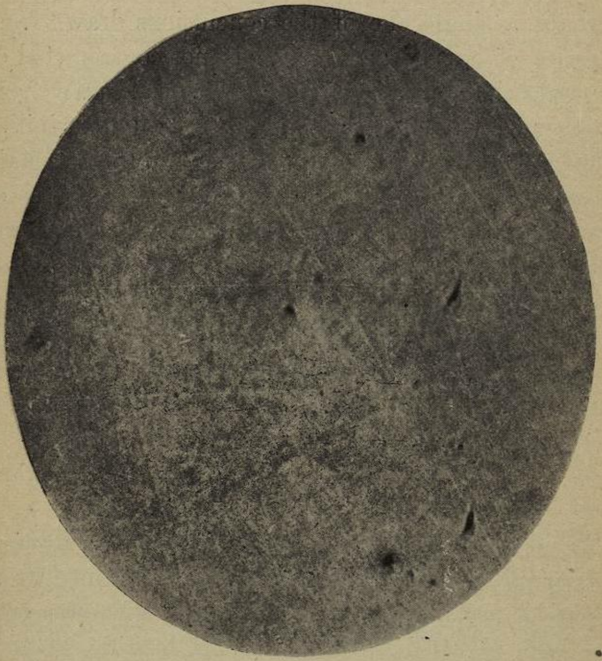

Fig. 27.—Bronze, containing 9 per cent. Tin, cast in an ingot mould. Heat, oxidation tinted. V × 100 diameters.

The bronzes with 11, 16, and 19 per cent. of tin (figs. 28, 29, and 30) show increasing proportions of a second constituent around the crystallites of the first.

Its point of solidification is probably indicated by the line *bb* of the diagram.

With 33 per cent. of tin the alloy again becomes homogeneous (fig. 31), and subdivides into jointed polyhedrons, although the composition does not correspond to a definite composition, and is comprised of $SnCu_3$ and $SnCu_4$.

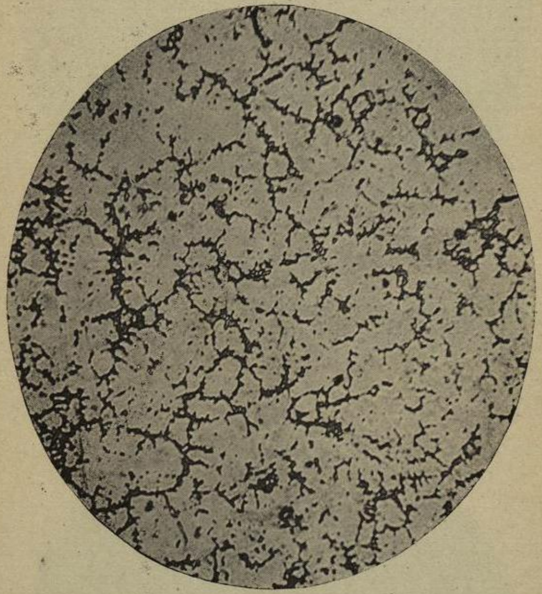

Fig. 28.—Bronze, with 11 per cent. Tin, cast in an ingot mould. Heat, oxidation tinted. V × 100 diameters.

Another series of photographs shows the influence of the rapidity of cooling on a bronze with 19 per cent. of tin.

A sample has been cast in sand and cooled slowly (fig. 32, 100 diameters). The crystallites first solidifying have acquired better defined forms than in the similar

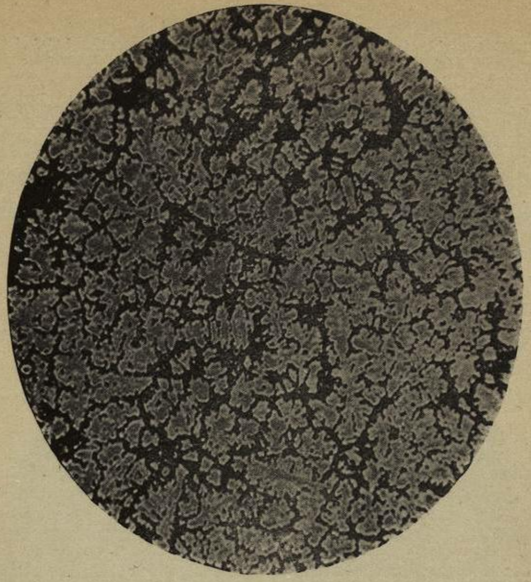

Fig. 29.—Bronze, with 16 per cent. Tin, cast in an ingot mould. Heat, oxidation tinted. V × 100 diameters.

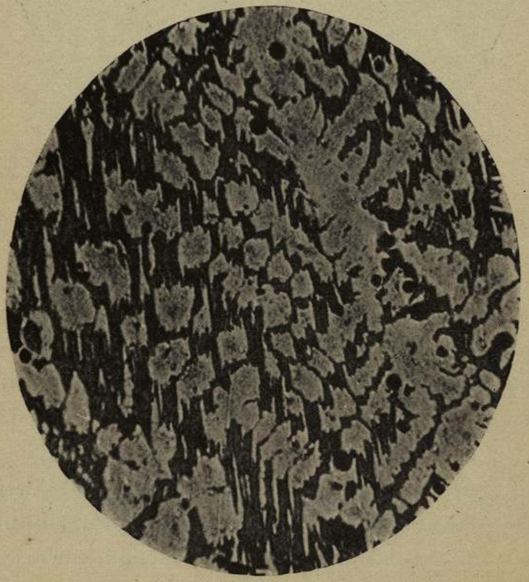

Fig. 30.—Bronze, with 19 per cent. Tin, cast in an ingot mould. Heat, oxidation tinted. V × 100 diameters.

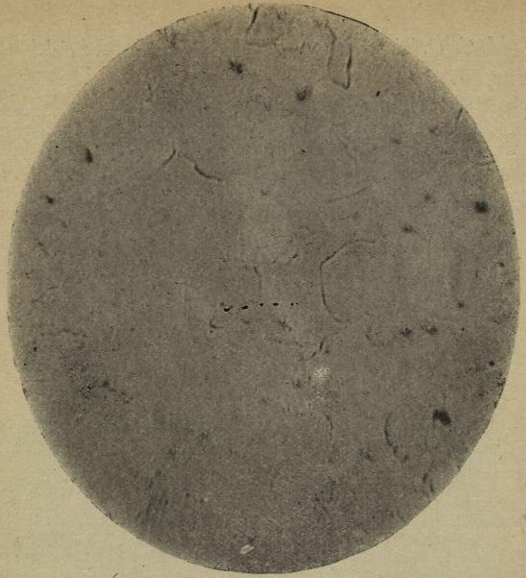

Fig. 31.—Bronze, containing 33 per cent. Tin, cast in an ingot mould. Heat, oxidation tinted. V × 100 diameters.

Fig. 32.—Bronze, with 19 per cent. Tin, cast in sand. Heat, oxidation tinted. V × 100 diameters.

sample cast in an ingot mould (fig. 30). Again, the matrix of the second solidification is no longer homogeneous; it is divided into two elements of which only one is coloured by oxidation, as is seen on a more enlarged photograph (fig. 33, 500 diameters).

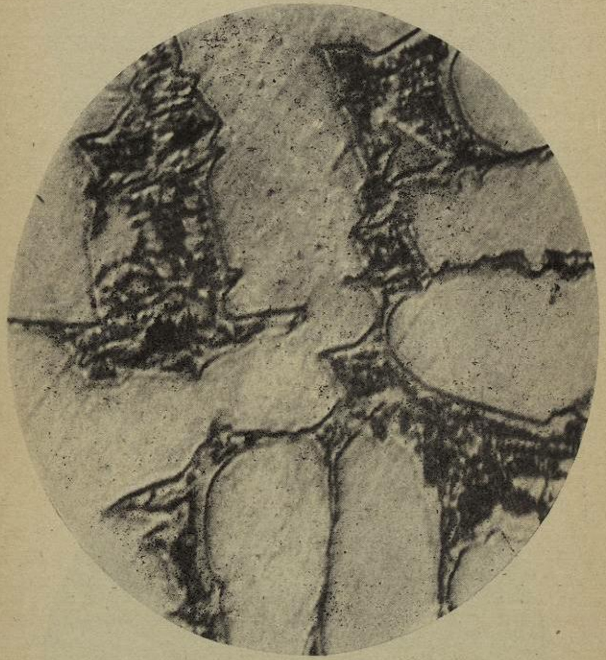

Fig. 33.—BRONZE, with 19 per cent. Tin, cast in sand. Heat, oxidation tinted. V × 500 diameters.

A second sample of the same composition has been quenched at a dull red heat in water at 50°; the general structure appears to have remained nearly the same if we look at the enlargement of 100 diameters (fig. 34). Under an enlargement of 500 diameters (fig. 35), it is seen that the matrix of second solidification cannot be resolved into two parts. The

transformation prevented by quenching is probably that which the line CC of the diagram indicates. This line CC appears then to correspond, not to the solidification of a liquid properly so-called, but rather to the resolution of a solid solution.

Influence of Pressure.—Hitherto we have not introduced the element of pressure; it must, however, have influence during the operations of forging, or simply during cooling, on account of the contraction of the exterior layers which are the first to cool. One of the effects of pressure is to displace the points of transformation, raising them or lowering them according to the sign of concomitant change of volume. This effect is not very marked on the points

Fig. 34.—BRONZE, with 19 per cent. Tin, quenched from dark red in water at 50°. Heat, oxidation tinted. V × 100 diameters.

of fusion; it appears to be much more so on the points of molecular transformation. Mallard and Le Chatelier thus lowered by more than 100° the isomeric modification of the iodide of silver.[1] Sir W. Roberts-Austen[2] lowered, by the same means, the recalescence; and it is probable that the pressure determined at first by the contraction, and then by the change of state and of volume of the iron, plays, as Professor Åkerman thinks, a great part in quenching.

Fig. 35.—BRONZE, with 19 per cent. Tin, quenched from dark red in water at 50°. Heat, oxidation tinted. V × 500 diameters.

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[1] *Comptes rendus*, t. xcix. p. 157 (1884).

[2] *Proc. Inst. Mech. Eng.*, p. 124 (1893).

PATHOLOGICAL METALLOGRAPHY.

This branch of Metallography is occupied, as its name indicates, with what might be called the diseases of metals.

Fig. 36 represents a network of fissures in steel quenched at too high a temperature. Professor Wedding[1] has wisely directed his studies towards faults of this kind.

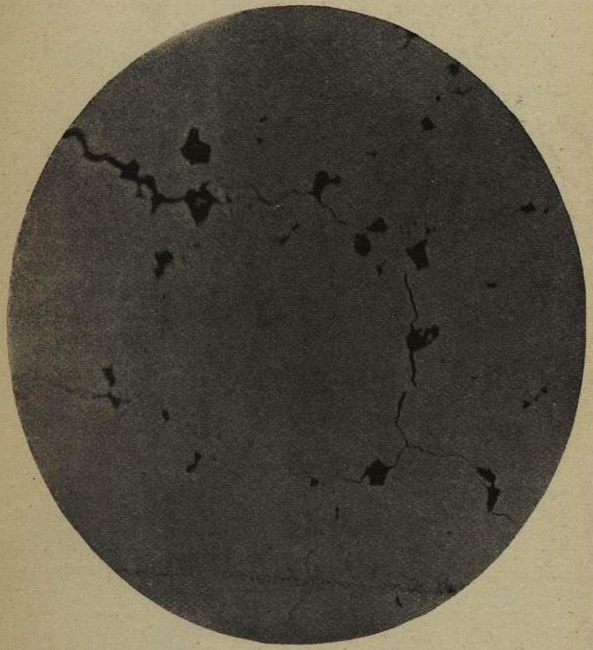

Fig. 36.—FORGED STEEL (1·24 per cent. carbon). Quenched from white heat. Polished. V × 20 diameters.

In fig. 37 we see how simple polishing reveals the inclusion of slag in steel. These inclusions are, in

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[1] *Stahl und Eisen*, t. xi. p. 879 (1891).

fact, very frequent: they are not very troublesome when the grains of slag are little and scattered; they

Fig. 37.—Cinder in a Steel. Polished. V × 1000 diameters.

may, however, become very dangerous if the slag forms extensive layers cropping out on the exterior surfaces, for they then constitute flaws likely to lead to fracture, which will gradually spread from place

to place. According to Professor Arnold, sulphur in the state of sulphide of iron causes analogous inclusions.

Dr Stead[1] has recently shown, by an ingenious process, the influence of these fragile filaments in a malleable body. A plate, having been previously polished and suitably attacked in order to show the structure, is then bent until the commencement of rupture is produced. It is immediately seen that the lines of rupture follow the slag in puddled iron, the cementite in cement steel, and the phosphide of tin in tin which contains phosphorus.

Fig. 38.—Gold, containing 0·2 per cent. Bismuth, cast in an ingot mould. Etched by nitro-hydrochloric acid. V × 17 diameters.

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[1] *Jour. of I. and S. Inst.*, 1897, part 1.

Foreign bodies and their chemical compounds do not always form these independent networks, which are sometimes useful, sometimes obnoxious, but the influence of which on the mechanical properties may be so great. They may also remain invisible and dissolve, modifying, although so attenuated, the state and the qualities of the metallic mass.

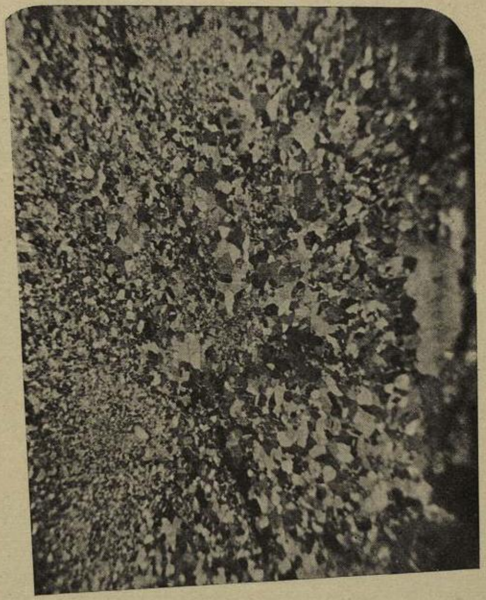

Fig. 39.—GOLD, containing 0·2 per cent. Bismuth, reheated to nearly 250°. Etched by nitro-hydrochloric acid. V × 17 diameters.

In every case the structure acquired from a cooling of fixed rapidity may be altered by an elevation of temperature, which redissolves the separated compound or causes the dissolved bodies to move.

For example, fig. 38 shows the structure of a little bar of gold alloyed with 0·2 per cent. bismuth and cast in an ingot mould; it is composed of elements largely prismatic, normal to the surfaces of cooling. After annealing for some minutes at about 250°, the prisms become subdivided into a large number of little polyhedrons, distinguished by the variations in their brightness according to the incidence of the light with respect to the crystalline grouping (fig. 39).

Fig. 40.—GOLD, containing 0·2 per cent. Antimony, cast in an ingot mould. Etched by nitro-hydrochloric acid. V × 17 diameters.

The fusion of the eutectic alloy of gold and bismuth might have been reached, and it is easily conceived that the recrystallisation of the mass has taken place, by a series of solutions and precipitations in succession, but the existence of a liquid is not necessary. An alloy of gold with 0·2 per cent. antimony, cast in an ingot mould like the former (arising from the researches of Sir W. Roberts-Austen[1]), is represented by figs. 40, 41, before and after annealing at 250°.

Fig. 41.—GOLD, containing 0·2 per cent. Antimony, reheated to nearly 250°. Etched by nitro-hydrochloric acid. V × 17 diameters.

Annealing has rendered the structure almost amorphous, although the more fusible of the alloys of gold and antimony do not melt below 440°.

We do not know *a priori* if such changes would be good or bad in a particular case, but we have learned that the structure and, accordingly, the properties of the refractory metal may be largely transformed by

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[1] *Trans. Roy. Soc.*, clxxix. p. 339 (1888), and clxxxvii. p. 417 (1896).

reheating at a relatively low temperature in the presence of a small proportion of certain impurities. This is a fact which commands serious attention.

The distinction between morbid accidents and physiological phenomena is not always so obvious as in the preceding examples. It may result from a convention founded on experience. If a certain

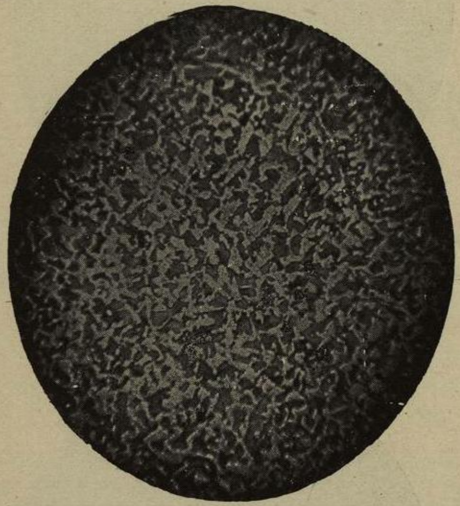

Fig. 42.—FORGED STEEL (0·45 per cent. carbon). Reheated to 750°. Polish-attack. V × 100 diameters.

mechanical and heat treatment gives to a certain metal the best possible qualities, the metal thus prepared will be regarded as healthy. And, conversely, the metal prepared by different processes might be regarded as diseased.

Here are some samples of steel, containing 0·45 per cent. of carbon, which have been, after forging, annealed respectively at the temperatures of 750°, 1015°, and 1390°. The three samples are mixtures

Fig. 43.—**Forged Steel** (0·45 per cent. carbon). Reheated to 1105°. Polish-attack. V × 100 diameters.

Fig. 44.—**Forged Steel** (0·45 per cent. carbon). Reheated to 1390°. Polish-attack. V × 100 diameters.

of ferrite and pearlite, but how different! In the first (fig. 42) the two constituents are in masses of small size irregularly mixed; in the second (fig. 43) the pearlite tends to form nuclei, which the ferrite surrounds with a continuous and ramified network; in the third (fig. 44) this structure is more accentuated, and the grains of pearlite have become so large that the photograph, at an enlargement of 100 diameters, does not show the whole of one of them. The aspect of the structure and the absolute dimensions of the grains are, as Professor Sauveur[1] has notably shown, characteristic of the heat treatment of steel, and, accordingly, of the correlative mechanical properties. Microscopic study allows us to recognise, after the event, the heat treatment which has been adopted, and to correct it if necessary.

Having thus dealt with the constitution and diseases of metals, it remains for us to perfect our means of safeguarding the former and of curing the latter, in order to secure, as far as possible, permanent strength for our structures. Towards the attainment of this end metallography offers a new means of diagnosis. The methods of manipulation improve daily, and the utility of the art appears more and more evident as its technique progresses.

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[1] *Trans. Amer. Inst. Min. Eng.*, t. xxii. p. 546 (1893).