

period of heating. The strip was then removed and cooled in air. The cooling through the critical point Ar_3 took a radial direction from the central position to the outside, and columnar crystals resulted. The centre part is fine-grained, because the temperature had not reached the crystallising point. These results are apparently quite contrary to those obtained on heating practically pure iron produced by fusion methods.¹

¹ Since writing the above, a joint paper by one of the authors and Dr H. C. H. Carpenter on "The Crystallisation of Pure Iron" has been presented to the Iron and Steel Institute, Sept. 1913, to which the reader is referred.

APPENDIX II.

THE NOMENCLATURE OF THE MICROSCOPIC SUBSTANCES AND STRUCTURES OF STEEL AND CAST-IRON.

At the Sixth Congress of the International Testing Association, held during the first week of September 1912, the following report on the Nomenclature of the Microscopic Substances and Structures of Steel and Cast-iron was presented, and formally adopted by the Association. The committee originally appointed to deal with the subject was as follows:—

Professor H. M. Howe, New York, *Chairman*.

Professor Albert Sauveur, Boston, *Secretary*.

Members: F. Osmond, Paris; Dr H. C. H. Carpenter, Manchester; Professor W. Campbell, New York; Professor C. Benedicks, Stockholm; Professor F. Wüst, Aachen; Professor A. Stansfield, Montreal; Dr J. E. Stead, Middlesbrough; Professor L. Guillet, Paris; Professor E. Heyn, Berlin; and Dr W. Rosenhain, Teddington.

The complete text of the report, omitting the introduction, is given below:—

At the end of the several descriptions the reader is referred officially to the illustrations in Osmond and Stead's "Microscopic Analysis of Metals." The references were to the 1904 edition, but have here been

corrected to apply to the body of the present work itself.

List of Microscopic Substances.

The microscopic substances here described consist of—

1. *Metarals*, true phases, like the minerals of nature. These are either elements, definite chemical compounds, or solid solutions, and hence consisting of definite substances in varying proportions. These include austenite, ferrite, cementite, and graphite.

2. *Aggregates*, like the petrographic entities as distinguished from the true minerals. These mixtures may be in definite proportions, *i.e.* eutectic, or eutectoid mixtures (ledeburite, pearlite, steadite), or in indefinite proportions (troostite, sorbite). Those aggregates which are important for any reason are here described.

(Many true minerals, such as mica, felspar, and hornblende, are divisible into several different species, so that these true mineral names may be either generic or specific. These genera and species are definite chemical compounds, in which one element may replace another. Other minerals, such as obsidian, are solid solutions in varying proportions, and in these also one element may replace another. Metarals, like minerals, differ from aggregates in being severally chemically homogeneous.)

These two classes may be cross-classified into—

- (A) The iron-carbon series, which come into being in cooling and heating.
- (B) The important impurities, manganese sulphide, ferrous sulphide, slag, etc.
- (C) Other substances.

The most prominent members of the iron carbon series are—

I. Molten iron, metaral, molten solution, but hardly a microscopic constituent.

II. The components which form in its solidification—

- (a) Austenite, solid solution of carbon or iron carbide in iron, metaral;
- (b) Cementite, definite metaral, Fe_3C ;
- (c) Graphite, definite metaral, C.

III. The transition substances which form through the transformation of austenite during cooling—

- (d) Martensite, metaral of variable constitution; its nature is in dispute;
- (e) Troostite, indefinite aggregate, uncoagulated mixture;
- (f) Sorbite, indefinite aggregate, chiefly uncoagulated pearlite plus ferrite or cementite.

IV. Products¹ of the transformation of austenite—

- (g) Ferrite;
- (h) Pearlite.

This transformation may also yield cementite and graphite as end-products in addition to those under (b) and (c).

In addition to the above, the names of which are universally recognised and in general use, the following names have been used more or less:—

- (i) Ledeburite (Wüst), definite aggregate, the austenite-cementite eutectic;

¹ In hypo-eutectoid steels these habitually play the part of end-products, though, according to the belief of most, the true end of the transformation is not reached till the whole has changed into a conglomerate of ferrite plus graphite.

- (j) Ferronite (Benedicks), hypothetical definite metal, β iron containing about 0.27 per cent. of carbon;
- (k) Steadite (Sauveur), definite aggregate, the iron-phosphorus eutectic (rare).

And three transition stages in the transformation of austenite, viz. :—

- (l) Hardenite (Arnold), collective name for the austenite and martensite of eutectoid composition;
- (m) Osmondite (Heyn), boundary stage between troostite and sorbite;
- (n) Troosto-sorbite (Kourbatoff), indefinite aggregate, the troostite and the sorbite which lie near the boundary which separates these two aggregates (obsolescent).

Definitions and Descriptions:

Carbon-Iron Equilibrium Diagram (fig. 192).—Under the several substances about to be described, an indication will be given of the parts of the carbon-iron equilibrium diagram (fig. 192) to which they severally correspond.

Austenite, Osmond (Fr. Austénite; Ger. Austenit; called also mixed crystals and γ iron. Up to the year 1900 often called martensite, and wrongly sometimes still so called).—Metal of variable composition.

Definition.—The iron-carbon solid solution as it exists above the transformation range, or as preserved with but moderate transformation at lower temperatures, e.g. by rapid cooling, or by the presence of retarding elements (Mn, Ni, etc.), as in

12 per cent. manganese steel and 25 per cent. nickel steel.

Constitution and Composition.—A solid solution of carbon or iron carbide (probably Fe_3C) and γ iron, normally stable only above the line PSK of the

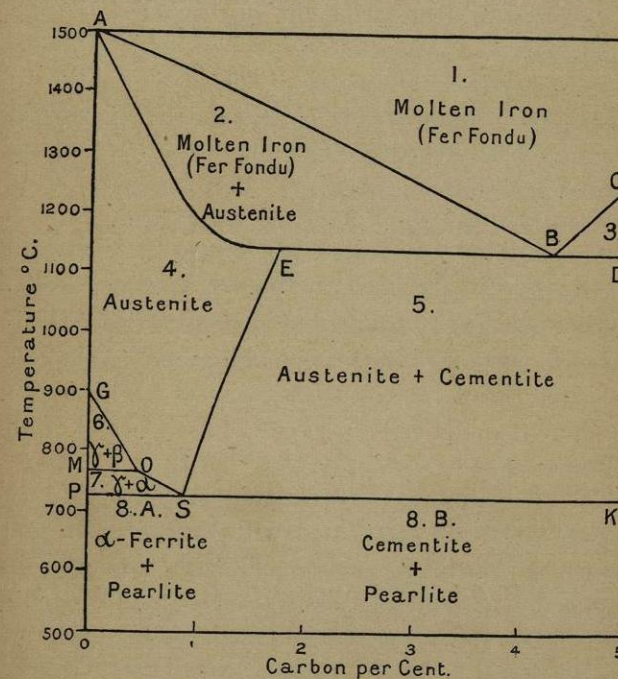


Fig. 192.¹—The line PSK is often called "A₁." The line GOS is often called "A₃," and this name is sometimes applied to the line SE.

carbon-iron diagram. It may have any carbon content up to saturation, as shown by the line SE, viz. :—about 0.90 per cent. at S (about 725° C.) to 1.7 per cent. at E (about 1130°). The theory that the iron

¹The diagram is based mainly on the work of Carpenter and Keeling. The new line AE is based on the work of Gutowsky, and has not yet been confirmed by other workers.—EDITOR.

and the carbide or carbon, instead of being dissolved in each other, are dissolved in a third substance, the solution of eutectic composition (Fe_{24}C , called hardenite), is not in accord with the generally accepted theory of the constitution of solutions, and is not entertained widely or by any member of this committee.

Crystallisation.—Isometric. The idiomorphic vug crystals are octahedra, much elongated by parallel growth. The etched sections show much twinning (Osmond and most authorities). Le Chatelier believes it to be rhombohedral. Cleavage octahedral.

Varieties and Genesis.—(1) Primary austenite formed in the solidification of carbon steel and hypoeutectic cast-iron; (2) eutectic austenite, interstratified with eutectic cementite, making up the eutectic formed at the end of the solidification of steel containing more than about 1.7 per cent. of carbon, and of all cast-iron.

Equilibrium.—It is normal and in equilibrium in Region 4, and also associated with β iron in Region 6, with a iron in Region 7, and with cementite in Region 5. It should normally transform into pearlite with either ferrite or cementite on cooling past A_1 into Region 8.

Transformation.—In cooling slowly through the transformation range, A_3 — A_1 , austenite shifts its carbon content spontaneously through generating proeutectoid ferrite or cementite, to the eutectoid ratio, about 0.90 per cent., and then transforms with increase of volume at A_1 into pearlite, *q.v.*, with which the ejected ferrite or cementite remains mixed. Rapid cooling and the presence of carbon, manganese, and nickel obstruct this transformation: (1) retarding

it; and (2) lowering the temperature at which it actually occurs; and, in addition (3), manganese and nickel lower the temperature at which in equilibrium it is due. Hence, by combining these four obstructing agents in proper proportions, the transformation may be arrested at any of the intermediate stages, martensite, troostite, or sorbite,¹ *q.v.*, and if arrested in an earlier stage, it can be brought to any later desired stage by a regulated reheating or “tempering.” For instance, though a very rapid cooling in the absence of the three obstructing elements checks the transformation but little and only temporarily, yet if aided by the presence of a little carbon, it arrests the transformation wholly in the martensite stage; and in the presence of about 1.50 per cent. of carbon such cooling retains about half the austenite, so little altered that it is “considerably” softer than the usually darker needles of the surrounding martensite, with which it contrasts sharply. Again, either (*a*) about 12 per cent. of manganese plus 1 per cent. of carbon, or (*b*) 25 per cent. of nickel, lower and obstruct the transformation to such a degree that austenite persists in the cold apparently unaltered, even through a slow cooling (Hadfield’s manganese steel and 25 per cent. nickel steel, manganiferous and niccoliferous austenite respectively).

Occurrence.—When alone (12 per cent. manganese and 25 per cent. nickel steel, and Maurer’s 2 per cent. carbon plus 2 per cent. manganese austenite) poly-

¹ Though the transformation can be arrested in such a way as to leave the whole of the steel in the condition of martensite, it is doubted by some whether it can be so arrested as to leave the whole of it in any of the other transition stages. Troostite and sorbite caused by such arrest are habitually mixed, troostite with martensite or sorbite or both, and sorbite with pearlite or troostite or both.

hedra, often coarse, much twinned, at least in the presence of martensite, and readily developing slip-bands. In hardened high carbon steel it forms a ground-mass pierced by zig-zag needles and lances of martensite.

Etching.—All the common reagents darken it much more than cementite, less than troostite or sorbite, and usually less, though sometimes more, than martensite, which is recognised by its zig-zag shape and needle structure. With ferrite and pearlite it is never associated.

Physical Properties.—Maurer's austenite of 2 per cent. manganese plus 2 per cent. carbon is but little harder than soft iron, and 25 per cent. nickel steel and Hadfield's manganese steel are but moderately hard. Yet, as usually preserved in hardened high carbon steel, the hardness of austenite does not fall very far short of that of the accompanying martensite, probably because partly transformed in cooling. (Osmond's words are that it is "considerably" softer than that of martensite.)

Specific Magnetism very slight, unless perhaps in intense fields. In Hadfield's manganese steel and 25 per cent. nickel steel, very ductile.

Illustrations.—"Microscopic Analysis of Metals," figs. 23, 133, and 134, pp. 37, 188, and 189.

Cementite (Sorby, "intensely hard compound"; Fr. Cémentite; Ger. Cementit; Arnold, crystallised normal carbide).—Definite metal.

Definition.—Tri-ferrous carbide, Fe_3C . The name is extended by some writers so as to include tri-carbides in which part of the iron is replaced by manganese, or other elements. Such carbides may be called "manganiferous cementite," etc.

Occurrence—(a) Pearlitic, as a component of pearlite, *q.v.*; (b) eutectic; (c) primary or pro-eutectic; (d) pro-eutectoid; (e) that liberated by the splitting up of the eutectic or of pearlite; and (f) uncoagulated in sorbite, troostite, and perhaps martensite; (c), (d), and (e) are grouped together as "free" or "massive."

Primary cementite is generated in cooling through Region 3; eutectic cementite on cooling past the line EBD; pro-eutectoid cementite in cooling through Region 5; pearlitic cementite on cooling past the line PSK, or A_1 . Though the several varieties of cementite are generally held to be all metastable, tending to break up into graphite plus either austenite above A_1 or ferrite below A_1 , yet they have a considerable and often great degree of persistence. The graphitising tendency is completely checked in the cold, but increases with the temperature and with the proportion of carbon and of silicon present, and is opposed by the presence of manganese.

Crystallisation.—Orthorhombic, in plates.

Structure.—(a) Pearlitic, in parallel unintersecting plates alternating with plates of ferrite; (b) eutectic, plates forming a network filled with a fine conglomerate of pearlite with or without pro-eutectoid cementite; (c) primary, in manganiferous white cast-iron, etc., in rhombohedral plates; (d) in hyper-eutectoid steel pro-eutectoid cementite forms primarily a network enclosing meshes of pearlite, through which cementite plates or spines sometimes shoot if the network is coarse; (e) cementite liberated from pearlite merges with any neighbouring cementite; (f) the structure of uncoagulated cementite cannot be made out. On long heating the pro-eutectoid and pearlitic cementite spheroidise slowly, and neighbouring par-

ticles merge; (g) in white irons rich in phosphorus in flat plates embedded in iron-carbon-phosphorus eutectic.

Etching, etc.—After polishing stands in relief. Brilliant white after etching with dilute hydrochloric or picric acid; darkened by boiling with solution of sodium picrate in excess of sodium hydrate.

Physical Properties.—Hardest component of steel. Hardness=6 of Mohs scale. Scratches glass and felspar, but not quartz; very brittle. Specific magnetism about two-thirds that of pure iron.

Illustrations.—“Microscopic Analysis of Metals,” figs. 125, 126, pp. 173 and 174.

Martensite (Fr. Martensite; Ger. Martensit).—Metaral. Its nature is in dispute.

Definition.—The early stage in the transformation of austenite characterised by needle structure and great hardness, as in hardened high carbon steel.

Constitution.—I. (Osmond and others) a solid solution like austenite, *q.v.*, except that the iron is partly beta, whence its hardness, and partly alpha, whence its magnetism in mild fields. II. (Le Chatelier) the same, except that its iron is essentially alpha, and the hardness due to the state of solid solution. III. (Arnold) a special structural condition of his “hardeningite” (austenite); not widely held. IV. A solid solution in γ iron. V. (Benedicks) the same as I., except that the iron is wholly beta, and that β iron consists of α iron containing a definite quantity of γ iron in solution.

Equilibrium.—It is not in equilibrium in any part of the diagram, but represents a metastable condition in which the metal is caught during rapid cooling, in transit between the austenite condition stable above

the line A_1 and the condition of ferrite plus cementite into which the steel habitually passes on cooling slowly past the line A_1 .

Occurrence.—The chief constituent of hardened carbon tool steels, and of medium nickel and manganese steels. In still less fully transformed steels (1.50 per cent. carbon steel rapidly quenched etc.) it is associated with austenite; in more fully transformed ones (lower carbon steels hardened, high carbon steels oil hardened, or water hardened and slightly tempered, or hardened thick pieces even of high carbon steel), it is associated with troostite, and with some pro-eutectoid ferrite or cementite, *q.v.*, in hypo- and hyper-eutectoid steels respectively. In tempering it first changes into troostite; at 350°–400° it passes through the stage of osmondite; at higher temperatures it changes into sorbite; and at 700° into granular pearlite. On heating into the transformation range this changes into austenite, which, on cooling, again yields lamellar pearlite.

Characteristic specimens are had by quenching bars 1 cm. square of eutectoid steel, *i.e.* steel containing about 0.9 per cent. of carbon in cold water from 800° C. (1472° F.).

Structure.—When alone, habitually in flat plates made up of intersecting needles parallel to the sides of a triangle. When mixed with austenite, zig-zag needles, lances, and shafts.

If produced by quenching after heating to 735° C., it consists of minute crystallites resembling the globulites of Vogelsang, which are rarely arranged in triangular order. At times so fine as to suggest being amorphous.

Etching.—With picric acid, iodine, or very dilute

nitric acid etches usually darker than austenite, but sometimes lighter, always darker than ferrite and cementite, but always lighter than troostite.

Illustrations.—"Microscopic Analysis of Metals," figs. 22, 135, pp. 36 and 190.

Ferrite (Fr. Ferrite; Ger. Ferrit).—Definite metal.

Definition.—Free α iron.

Composition.—Nearly pure iron. It may contain a little phosphorus and silicon, but its carbon content, if any, is always small, at the most not more than 0.05 per cent., and perhaps never as much as 0.02 per cent.

Occurrence.—(a) Pearlitic as a component of pearlite, *q.v.*; (b) pro-eutectoid ferrite generated in slow cooling through the transformation range; (c) that segregated from pearlite, *i.e.* set free by the splitting up of pearlite, especially in low carbon steel; (d) *uncoagulated* as in sorbite, and probably troostite. (b) and (c) are classed together as free or massive.

Thus ferrite is normal and stable in Regions 7 and 8.

Crystallisation.—Isometric, in cubes or octahedra.

Structure.—(a) Pearlitic ferrite, unintersecting parallel plates alternating with plates of cementite; (b) pro-eutectoid ferrite in low carbon steel forms irregular polygons, each with uniform internal orientation. In higher carbon steel, after moderately slow cooling, especially in the presence of manganese, it forms a network enclosing meshes of pearlite. In slower cooling this network is replaced by irregular grains separated by pearlite; (c) the ferrite set free by the splitting up of pearlite merges with the pro-eutectoid ferrite if any; (d) the structure of the ferrite in sorbite, etc., cannot be made out.

Etching.—Dilute alcoholic nitric or picric acid on

light etching leaves the ferrite grains white with junctions which look dark. Deeper etching, by Heyn's reagent, or its equivalent, reveals the different orientation of the crystals or grains, (a) as square figures parallel to the direction of the etched surface; (b) as plates which dip at varying angles and become dark or bright when the specimen is rotated under oblique illumination. Still deeper etching reveals the component cubes (etching figures, *Ätzfiguren*), at least if the surface is nearly parallel to the cube faces.

Physical Properties.—Soft; relatively weak (tenacity about 40,000 lbs. per sq. in.); very ductile; strongly ferro-magnetic; coercitive force very small.

Grain Size.—For important purposes (1) etch deeply enough, *e.g.* with copper-ammonium chloride, to reveal clearly the junctions of the grains; (2) count on a photograph of small magnification the number of grains in a measured field so drawn as to exclude fragments of grains; after (3) determining the true grain boundaries by examination under high powers (Heyn's method). Deep nitric acid etching is inaccurate, because an apparent grain boundary may contain several grains.

Illustrations.—"Microscopic Analysis of Metals," figs. 124, 139, pp. 169 and 206.

Osmondite (Fr. Osmondite; Ger. Osmondit).

Definition.—That stage in the transformation of austenite at which the solubility in dilute sulphuric acid reaches its maximum rapidity. Arbitrarily taken as the boundary between troostite and sorbite.

Earlier Definition.—Defined by the Fifth Congress as having the "maximum solubility in acids and by a maximum coloration under the action of acid metallo-

graphic reagents." The present definition is confined to maximum rapidity of dissolving, because we do not yet know that this in all cases coexists with the maximum depth of coloration, and, in any case, in which these two should not coexist, the old definition does not decide which is true osmondite.

Constitution.—The following hypotheses have been suggested, none of which has firm experimental foundation:—(1) A solid solution of carbon or an iron carbide in α iron. (2) The colloidal system of Benedicks in its purity, troostite being this system while forming at the expense of martensite, and sorbite, being this system coagulating and passing into pearlite. (3) The stage of maximum purity of amorphous α iron on the way to crystallising into ferrite.

Occurrence.—Hardened carbon steel of about 1 per cent. of carbon when reheated (tempered) to 350°–400° C. passes through the stage of troostite to that of osmondite, and on higher heating to that of sorbite. What variation if any from this temperature is needed to bring hardened steel of other carbon content to the osmondite stage is not known. In that it represents a true boundary state between troostite and sorbite it differs in meaning from troosto-sorbite, which embraces both the troostite and the sorbite which lie near this boundary. Indeed, osmondite has sometimes been used in this looser sense. Writers are cautioned that, however useful these terms may prove for making these nice discriminations, they are not likely to be familiar to general readers.

Etching.—According to Heyn it differs from troostite and sorbite in being that stage in tempering which colours darkest on etching with alcoholic hydrochloric acid.

The present definition and description of osmondite should displace previous ones, because they have the express approval of Professor Heyn, the proposer of the name, and M. Osmond himself.

Ferronite (Fr. Ferronite; Ger. Ferronit)(Benedicks).—Hypothetical definite metal.

Definition.—Solid solution of about 0.27 per cent. of carbon in β iron.

Occurrence (hypothetical).—In slowly cooled steels and cast-iron containing 0.50 per cent. of combined carbon or more, that which is generally believed to be ferrite, whether pearlitic or free, is supposed by Benedicks to be ferronite.

Hardenite (Fr. Hardenite; Ger. Hardenit).

Definition.—Collective name for austenite and martensite of eutectoid composition. It includes such steel (1) when above the transformation range, and (2) when hardened by rapid cooling.

Observations.—On the generally accepted theory that austenite is a solid solution of carbon or an iron carbide in iron, hardenite is the solution of the lowest transformation temperature, *i.e.* the eutectoid. The theory that instead it is a definite chemical compound, $Fe_{24}C$, is considered under Austenite. Its proposer includes under hardenite both eutectoid (0.90 per cent. carbon) austenite when above the transformation range, and the martensite into which that austenite shifts in rapid cooling (hardening).

Other Meanings.—Originally (Howe, 1888) collective name for austenite and martensite of any composition in carbon steel. Osmond (1897), austenite saturated with carbon. Both these meanings are withdrawn by their proposers.

Pearlite (Sorby's "pearly constituent"; at first

written "pearlyte"; Fr. Perlite; Ger. Perlit). — Aggregate.

Definition.—The iron carbon eutectoid, consisting of alternate masses of ferrite and cementite.

Constitution and Composition.—A conglomerate of about 6 parts of ferrite to 1 of cementite. When pure, contains about 0.90 per cent. of carbon, 99.10 per cent. of iron.

Occurrence.—Results from the completion of the transformation of austenite brought spontaneously to the eutectoid carbon content, and hence occurs in all carbon steels and cast-iron containing combined carbon and cooled slowly through the transformation range, or held at temperatures in or but slightly below that range, long enough to enable the ferrite and cementite to coagulate into a mass microscopically resolvable. Hence it is the normal constituent in Region 8. Its ferrite is stable, but its cementite is metastable and tends to transform into ferrite and graphite.

Varieties and Structure.—Because pearlite is formed by the coagulation of the ferrite and cementite initially formed as the irresolvable emulsion, sorbite (Arnold's sorbitic pearlite), there are the indefinitely bounded stages of *sorbitic pearlite* (Arnold's normal pearlite), *i.e.* barely resolvable pearlite, in the border-land between sorbite and laminated pearlite; *granular pearlite*, in which the cementite forms fine globules in a matrix of ferrite; and *laminated* or *lamellar pearlite*, consisting of fine, clearly defined, non-intersecting, parallel lamellæ alternately of ferrite and cementite. The name *granular pearlite* was first used by Sauveur to represent what is now called sorbite. This meaning has been withdrawn.

An objection to Arnold's name "normal pearlite" is

that it is likely to mislead. "Normal" here apparently refers to arising under normal conditions of cooling, but (1) it rather suggests structure normal for pearlite, which surely is the lamination characteristic of eutectics in general, and (2) the general reader has no clue as to what conditions of cooling are here called normal. Many readers are not manufacturers, and even in manufacture itself air cooling is normal for one branch and extremely slow furnace cooling for another. Arnold calls troostite "troostitic pearlite," and sorbite "sorbitic pearlitic." This is contrary to general usage, which restricts pearlite to microscopically resolvable masses.

Etching.—After etching with dilute alcoholic nitric or picric acid it is darker than ferrite or cementite, but lighter than sorbite and troostite. A magnification of at least 250 diams. is usually needed for resolving it into its lamellæ, though the pearlite of blister steel can often be resolved with a magnification of 25 diams. The more rapidly pearlite is formed, the higher the magnification needed for resolving it.

Illustrations, lamellar pearlite.—Osmond and Stead, "Microscopic Analysis of Metals," fig. 11, p. 18, granular pearlite, *ibid.*, fig. 21, p. 34; Heyn and Bauer, *Stahl und Eisen*, 1906, fig. 14, opposite p. 785.

Graphite (Fr. Graphite; Ger. Graphit).—Definite metal.

Definition.—The free elemental carbon which occurs in iron and steel.

Composition.—Probably pure carbon, identical with native graphite.

Genesis.—Derived in large part, and according to Goerens wholly, from the decomposition of solid cementite. Others hold that its formation as kish

may be from solution in the molten metal, and that part of the formation of temper graphite may be from elemental carbon dissolved in austenite. It is the stable form of carbon in all parts of the diagram.

Occurrence.—(1) As kish, flakes which rise to the surface of molten cast-iron and usually escape thence.

(2) As thin plates, usually curved, *e.g.* in grey cast-iron, representing carbon which has separated during great mobility, *i.e.* near the melting range.

(3) As temper graphite (Ger. Temperkohle, Ledebur), pulverulent carbon which separates from cementite and austenite, especially in the annealing process for making malleablised castings.

Graphite and ferrite are sometimes associated in a way which suggests strongly that they represent a graphite-austenite eutectic. But the existence of such a true eutectic is doubted by most writers.

Properties.—Hexagonal. H. 1-2; Gr. 2-255. Streak black and shining, lustre metallic; macroscopic colour, iron black to dark steel grey, but always black when seen in polished sections of iron or steel under the microscope; opaque; sectile; soils paper; flexible; feel, greasy.

Troostite (Fr. Troostite; Ger. Troostit).—Probably aggregate (Arnold, troostitic pearlite).

Definition.—In the transformation of austenite, the stage following martensite and preceding sorbite (and osmondite if this stage is recognised).

Constitution and Composition.—An uncoagulated conglomerate of the transition stages. The degree of completeness of the transformation represented by it is not definitely known and probably varies widely. Osmond and most others believe that the transformation, while generally far advanced, yet falls materi-

ally short of completion; but Benedicks and Arnold believe that it is complete. The former belief that it is a definite phase, *e.g.* a solid solution of carbon or an iron carbide in either β or γ iron, is abandoned. Its carbon content, like that of austenite and martensite, varies widely.

Occurrence.—It arises either on reheating hardened (*e.g.* martensite) steel to slightly below 400°, or on cooling through the transformation range at an intermediate rate, *e.g.* in small pieces of steel when quenched in oil, or quenched in water from the middle of the transformation range, or in the middle of larger pieces quenched in water from above the transformation range. With slightly further reheating it changes into sorbite; with higher heating into sorbitic pearlite, then slowly into granular pearlite, and probably indirectly into lamellar pearlite. It occurs in irregular, fine granular or almost amorphous areas, coloured darker by the common etching reagents than the martensite or sorbite accompanying it. A further common means of distinguishing it from sorbite is that it is habitually associated with martensite, whereas sorbite is habitually associated with pearlite.

Areas near the boundary between troostite and sorbite are sometimes called troosto-sorbite.

Properties.—Hardness, intermediate between that of the martensitic and the pearlitic state corresponding to the carbon content of the specimen. In general the hardness increases, the elastic limit rises, and the ductility decreases, as the carbon content increases. Its ductility is increased rapidly, and its hardness and elastic limit lowered rapidly by further tempering, which affects it much more markedly than sorbite.

Sorbite (Fr. Sorbite; Ger. Sorbit).—Aggregate (Arnold, sorbitic pearlite).

Definition.—In the transformation of austenite, the stage following troostite and osmondite, if this stage is recognised, and preceding pearlite.

Constitution and Composition.—Most writers believe that it is essentially an uncoagulated conglomerate of irresoluble pearlite with ferrite in hypo- and cementite in hyper-eutectoid steels respectively, but that it often contains some incompletely transformed matter.

Occurrence.—The transformation can be brought to the sorbitic stage (1) by reheating hardened steel to a little above 400°, but not to 700°, at which temperature it coagulates into granular pearlite; (2) by quenching small pieces of steel in oil or molten lead or even by air-cooling them; (3) by quenching in water from just above the bottom of the transformation range, Ar₁. Sorbite is ill-defined, almost amorphous, and is coloured lighter than troostite but darker than pearlite by the usual etching reagents. It differs further from troostite in being softer for given carbon content, and usually in being associated with pearlite instead of martensite, and from pearlite in being irresoluble into separate particles of ferrite and cementite.

As sorbite is essentially a mode of aggregation it cannot properly be represented on the equilibrium diagram. Its components at all times tend to coagulate into pearlite, yet remains in its uncoagulated state at all temperatures below 400°.

Properties.—Though slightly less ductile than pearlite steel for given carbon content, its tenacity and elastic limit are so high that a higher combina-

tion of these three properties can be had in sorbitic than in pearlitic steels by selecting a carbon content slightly lower than would be used for a pearlitic steel. Hence the use of sorbitic steels, *e.g.* first hardened and then annealed cautiously, for structural purposes needing the best quality.

Manganese Sulphide (Fr. Sulphure de Manganese; Ger. Schwefelmangan), MnS (Arnold and Waterhouse).—Metaral.

Occurrence, etc.—Sulphur combines with the manganese present in preference to the iron, forming pale dove or slate grey masses, rounded in castings, elongated in forgings.

Ferrous Sulphide (Fr. Sulphure de Fer; Ger. Schwefeleisen), FeS.—Metaral.

Occurrence.—The sulphur not taken up by the manganese forms ferrous sulphide, FeS, which probably associated in part with iron as an Fe-FeS eutectic, forms by preference more or less continuous membranes surrounding the grains of pearlite. Colour, yellow, or pale brown.

Sulphur Prints.—When silk impregnated with mercuric chloride and hydrochloric acid (Heyn's and Bauer's method), or bromide paper moistened with sulphuric acid (Baumann's method), is pressed on polished steel, the position of the sulphur-bearing areas, whether of FeS or MnS, records itself by the local blackening which the evolved H₂S causes. Phosphorus-bearing areas also slightly stain bromide paper.

Miscellaneous.

Eutectoid, Saturated, etc.—The iron carbon eutectoid is pearlite. Steel with more carbon than pearlite is

called hyper-eutectoid; that with less is called hypo-eutectoid. Arnold's names "saturated," "unsaturated," and "supersaturated," for eutectoid, hypo-eutectoid, and hyper-eutectoid steel respectively, have considerable industrial use in English-speaking countries, but are avoided by most scientific writers on the ground that they are misleading, because, *e.g.* there is only one specific temperature, A_1 , at which eutectoid steel is actually saturated, and, if any other temperature is in mind, that steel is not saturated. Above A_1 it is clearly under saturated.

The objection to the names sorbite, troostite, martensite, and austenite, that each of them covers steel of a wide range of carbon content, is to be dismissed because a like objection applies with equal force to every generic name in existence.

The theoretical matter in the report is, it is explained, given solely for exposition, and the committee disclaims the intent to impose any theory. The report was offered for adoption subject to this disclaimer, on the ground that the adoption of theories was beyond the powers of a Congress.



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