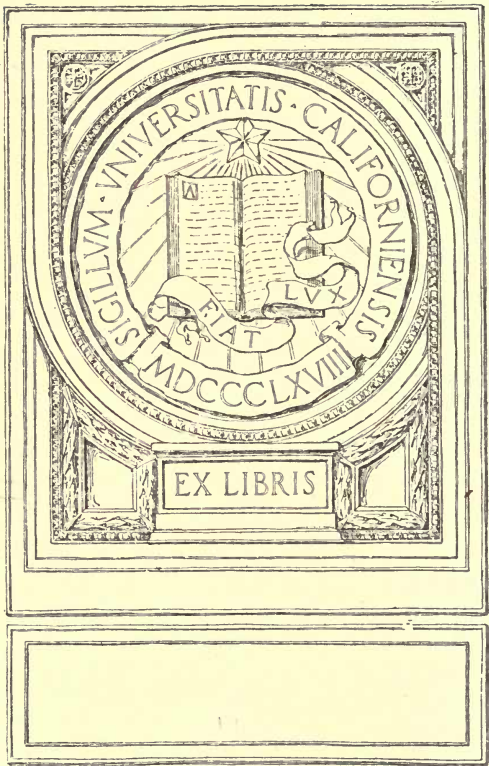


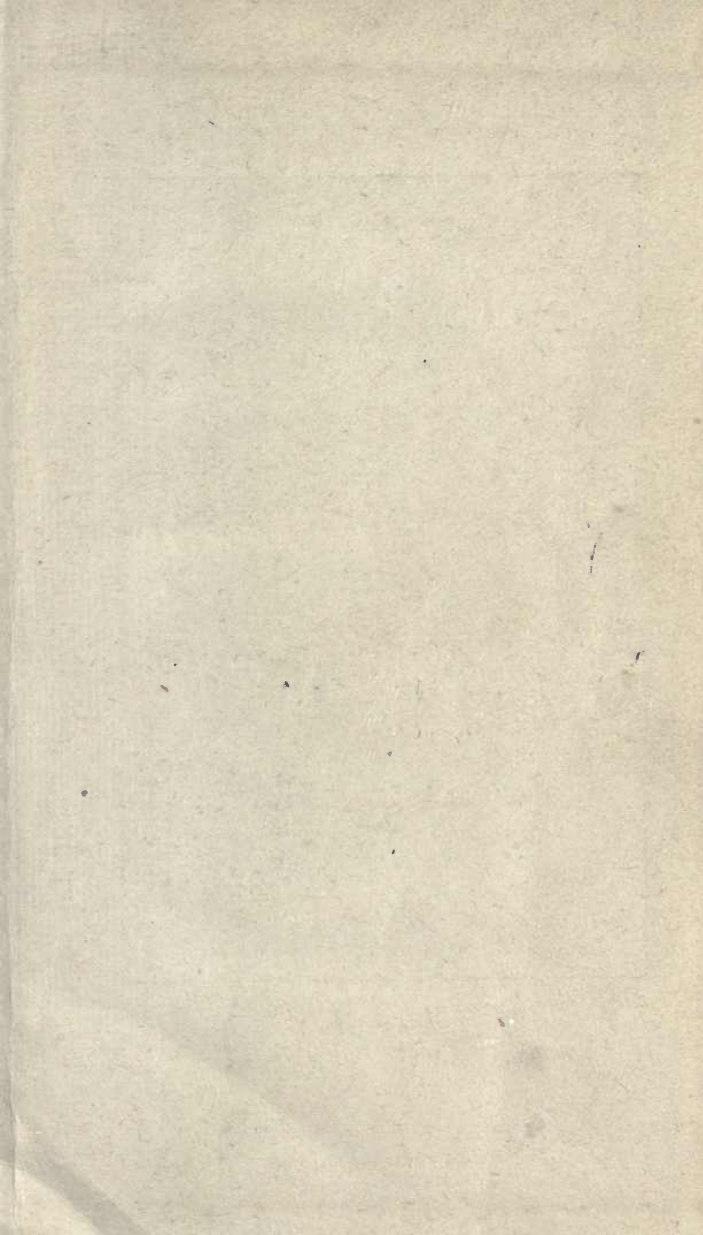
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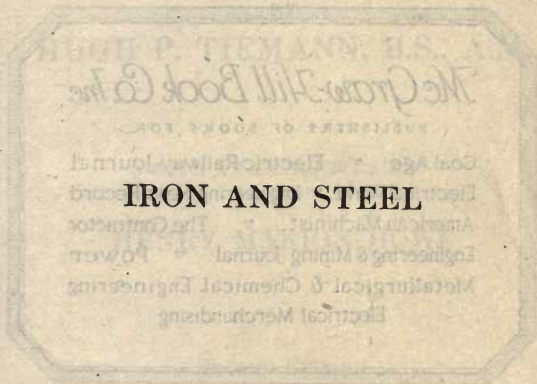
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IRON AND STEEL

A POCKET ENCYCLOPEDIA

INCLUDING ALLIED INDUSTRIES
AND SCIENCES



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IRON AND STEEL

(A POCKET ENCYCLOPEDIA)

INCLUDING ALLIED INDUSTRIES
AND SCIENCES

BY

HUGH P. TIEMANN, B.S., A.M.

WITH AN INTRODUCTION

BY

HENRY MARION HOWE

SECOND EDITION

REVISED, ENLARGED AND ENTIRELY RESET

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IRON AND STEEL

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ENGINEERING

THEIR PRACTICE

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INTRODUCTION

It is with gratitude as a reader, pride as a teacher, and pleasure as a friend that I write a word of introduction to this admirable work of my former pupil and long-time friend, the Author.

The jargon of the millman, like that of the philosopher, is a deplorable necessity. It is a collection of invaluable special tools for special men doing special work. When the dentist and the obstetrician regard the unfathomable mysteries of each other's "kits," each has the consolation that he need not attempt the fathoming. But alas, you and I cannot thus escape each other's jargon, for the metallographist must needs learn from the millman and the millman from the metallographist, and each has become the slave of his own tools, his own jargon. He talks and perhaps thinks in terms of it, if indeed we think in any language, which I doubt. At least, if he thinks in any language it is in his jargon. Life is too short, patience too flimsy, to permit our forcing our thoughts into others' minds by means of any tools other than our own jargon. The Author gives me an admirable case in point.

Foreman: "How does this steel work?"

Heater: "If you don't wash it, it won't clean."

This is "short hand" for: "The iron oxide or 'scale' which forms on the surface of this steel adheres so firmly that, unless it is heated so highly that it melts, some of it will cleave to the metal during the operation of rolling, and hence will deface the finished plates into which the steel is to be rolled." The heater's words are not English; they are jargon, and it is proper that they should be. If he persisted in translating them into English as I have done, and in talking English in general, he would simply justify the dismissal which would surely come. The guild has evolved its jargon for its own use. To replace it with the King's English would be about as unwise as to replace it with French or modern Greek, or to replace "short hand" with "long hand" in the reporting of debate.

When the metallographist and millman meet, it is as the meeting of French and Greek. The millman scolds the metallographist, yes, and I have had to endure with my scanty patience many such scoldings for deliberately inventing jargon, useful for the metallographic guild, but a stumbling block to the millman. Of course it is not I but the nature of things that ought to be scolded; but then it is pleasanter and less transparently foolish to scold me, especially if I have previously earned your gratitude by disentangling some of your fallacies and sophisms.

Now here comes the gallant Author to the aid of fumbling metallographist and irritated millman. With infinite pains, ingenuity, and skill he blesses both where they had banned each other, and enables the brothers to dwell together in harmony, unfolding to each the jargon of the other by means of a tri-lingual dictionary, translating the jargons of both into the common language, English.

Nor are they alone his debtors. Having long lived a metallographist and a teacher among the millmen, he discloses clearly, tersely, and graphically the manners and customs of the millmen, to wit the how and the why of their actual practice, as only a resident can know it. In short, he describes the actual metallurgical operations and apparatus in a way which seems to me most admirable.

I commend the book without reserve to the whole family of steel metallurgists, be they millmen, metallographists, teachers, or students.

HENRY M. HOWE.

PREFACE TO SECOND EDITION

THE present revision is the result, not only of certain omissions and shortcomings in the first edition, but also of the friendly reception and the helpful criticism accorded it.

The vast amount of time consumed—in no way evident from the result—in consulting references and authorities, collecting data, and condensing and practically rewriting the whole of the text, all of which had to be done without interference with regular business, prevented the completion of the task at an earlier date. It is hoped that an improvement will be found both in regard to the additional information and the method of treatment. The number of terms, and the text also, has been increased about fifty per cent.

The general processes of manufacture have undergone but little change, the principal development being in the greatly increased use of the electric furnace. The chief increase in the text is due to more extended discussions of subjects, such as heat treatment, physical properties, and testing, and to the numerous investigations of the more theoretical aspects of the subject, particularly those included under metallography.

For the benefit of those little versed in the metallurgy of iron and steel, and who may desire a guide to a more sequential—and hence logical—study than is afforded by the alphabetical arrangement of the text (which still seems best for ready reference) a brief outline of the metallurgy of iron and steel has been prepared which will be found immediately preceding the text.

Among a number of kind friends whose assistance is deeply appreciated, the author desires to express his thanks especially to D. M. Buck (Corrosion and Protection), L. J. Gray (Gages), E. S. Humphreys (Sheets and Tin Plate), E. A. Kebler (Pig Iron), and J. O. Leech (Specifications); the opportunity cannot be allowed to pass of calling attention to the cordial cooperation of the publishers, whose assistance in practical suggestions and care in the make-up of the book have contributed in no small degree to whatever success it has achieved.

H. P. T.

PITTSBURGH, PA.,
December, 1918.

PREFACE TO FIRST EDITION

OWING to the close relationship with other industries, such as coal, coke, etc., and from the fact that certain branches of science are involved in metallurgy, terms applying to these have been included in this book, in so far as they are commonly met with in the literature of iron and steel. In general, subjects of a mechanical or of an engineering nature have not been considered, as they are dealt with in the handbooks devoted especially to them. It may be found, however, that in some cases subjects have been incorporated which seem superfluous in a work of this character.

It has been the endeavor to make the book as compact as possible, at the same time giving sufficiently full explanations for ordinary purposes so that to the metallurgist who wishes to refresh his mind on some term rarely used, and to the person only slightly familiar with the ground, it may prove equally useful.

The general treatment, then, is a combination of a dictionary, a cyclopedia, and a handbook, possessing as well as omitting some of the features of all. The definitions or descriptions of isolated terms or processes are found under the respective headings, while those employed in connection with some special subject or process are found under the latter, reference being made, as a rule, by page numbers instead of by titles. In this way, the reader who desires enlightenment upon a single point, as well as he who is unfamiliar with the subject as a whole or who wishes to learn the terms used in a certain process, may do so as readily and as simply as possible.

Among the many authorities consulted, the most important is unquestionably the *Journal of the Iron and Steel Institute*, which is a veritable mine of information. The writer whose books have been drawn upon most largely is Prof. Henry M. Howe, who possesses in the highest degree the unusual and happy faculty of expressing what he has to say both clearly and concisely.

The Author's thanks are due to many good friends for the timely criticism and advice which they were ever ready to give. Among those to whom he is especially indebted are the following: J. W. Benner, W. A. Bostwick, Prof. William Campbell, Prof. Henry M. Howe, E. T. Ickes, Eliot A. Kebler, C. F. W. Rys, and Bradley Stoughton.

In conclusion, the Author will be most grateful to any one calling his attention to errors of omission as well as of commission.

H. P. T.

PITTSBURGH, PA.,
November, 1910.

OUTLINE OF

THE METALLURGY OF IRON AND STEEL

The term *iron* has such a variety of applications that, if used by itself, the exact meaning cannot be determined. In its chemical sense it refers to the element (see Chemistry), either isolated or combined with other elements; e.g., the percentage of the element present in metallic substances, iron ores, etc. In its metallic condition the carbon content (either expressed or implied) is the determining factor. In this case "iron" may refer to (a) the nearly pure substance (see Electrolytic Iron); (b) the product nearly free from carbon, more specifically known as *wrought (malleable) iron* or *puddled iron*; or (c) where the carbon content is high, termed *cast iron* or *pig iron*. *Steel* is the present name for iron produced by any process, in a fluid condition thereby permitting nearly complete elimination of slag, and containing any amount of carbon up to a content where it can no longer be usefully worked. Before the appearance of the Bessemer process, the classification provided for (a) *iron*, low in carbon, which was malleable and could not be usefully hardened, produced by a direct process or by puddling; (b) *steel* (higher in carbon) which was also malleable but could be usefully hardened, produced in the same way as iron and called *wrought steel*; by the conversion (*carburization*) of wrought iron into steel by *cementation (q.v.)*, the product being denominated *blister bars* or *cement bars* and used as such (*blister steel*) or remelted in the crucible process for *crucible steel* or *cast steel*; (c) *cast iron* as described above, so named because it could not be worked but could be given the desired form only by *casting* when molten into molds.

Metallic iron or steel is not found naturally in that condition. An apparent exception is the case of certain meteorites (*q.v.*). As it exists in chemical combination with other elements, principally as an oxide, and mechanically mixed with a certain amount of earthy matter (chiefly sand or clay), occurring in deposits known as *ore* (see Iron Ore), it becomes necessary to reduce it to the metallic state by an operation known as *smelting*. This is accomplished practically exclusively by carbon occurring in some form of solid *fuel*, such as coke, coal, or charcoal, which serves not only as the medium of reduction, but also for producing by combustion the heat (temperature) required to carry on this reaction. The heat for this and other processes is occasionally supplied by some other agency such as electricity (see Electric Processes).

The quality of an ore can in various cases be materially improved by *roasting* to burn away impurities, or by *washing* away a considerable portion of the earthy matter or *gangue* (see Ore). It may also be desirable to *agglomerate* fine ore or similar material into hard tenacious pieces or lumps (see Briquette).

In the production of metallic iron two conditions are necessary:

1. Reduction of the iron oxide, *i.e.*, elimination of the oxygen with which it is chemically combined; effected by part of the carbon of the fuel.

2. Separation and removal of the gangue with which it is mechanically mixed; usually by the addition of a substance or *flux* with which it unites to form a more fusible compound or *slag*.

Iron can be partially reduced at relatively low temperatures, *e.g.*, by carbon monoxide gas, and completely reduced at somewhat higher temperatures but still considerably below its melting point, by contact with hot carbonaceous matter. It is the latter method which was originally employed because the necessary temperature was readily secured by simple equipment such as a hole dug in a hillside where the prevailing winds supplied the air for combustion through suitable apertures in the roof. Soon, however, advances were made by developing a fireplace or *hearth* where charcoal could be burned intermixed with rich ore. Part of the ore was reduced and part was lost in slagging off the gangue. The reduced pasty iron collected at the bottom together with molten slag or portions of the original charge; additional fuel and ore could be thrown in through an opening in the front. However, as the size of the equipment was increased it was found advantageous to do the charging through a hole in the top or *stack*.

When natural draft failed to supply air at the necessary rate and pressure, bellows were substituted, and these, in turn, were replaced by some form of blowing engine (see Direct Processes). Greater height of stack, better insulation against loss of heat, and more rapid combustion all led to increased temperature (see Heat), and also more and more carbon was absorbed by the metal. Finally the condition was reached where the melting point of the iron was lowered sufficiently by the increased absorption of carbon to be below the temperature of reduction, and the product was then obtained in a liquid (molten) state. It was accordingly run or poured (*cast*) into suitable molds and hence was termed *cast iron*.

While at first, due to variations in temperature, the iron from the same furnace was sometimes pasty and sometimes molten, it was quickly realized that the greatest output and ease of handling resulted from the latter condition, hence the necessary steps were taken to make this condition permanent and resulted in the development of the present *blast furnace* (*q.v.*).

At the high temperature of the blast furnace nearly all the iron, manganese, and phosphorus are reduced and also certain proportions of silicon, sulphur, and other elements present. The high contents of elements other than iron prevent cast iron from being usefully malleable at any temperature, so that it must be given the desired form by pouring when molten into molds. If a malleable product

is desired the excess of these constituents (which therefore become in this sense impurities) must be removed by some *refining process* (see Purification).

The production of steel in two stages, *i.e.*, first as cast iron and second by subsequent refinement into steel, is termed an *indirect process* or method in contradistinction to the *direct process* in which, as described, the operation is arrested before the iron has absorbed any considerable quantity of carbon and consequently is still malleable.

Purification usually consists in oxidation carried to the point where the impurities or excess constituents are nearly all removed, or to the extent desired. As explained in Chemistry, it consists in causing these ingredients to combine with oxygen in which condition they pass into the slag if solid (or molten), or escape into the air if gaseous.

The terms *acid* and *basic*, whether applied to steel or a process, refer to the nature of the slag and the corresponding refining action which is occasioned. Since the effect of a given kind of slag should be confined to the charge, the lining of the containing vessel or furnace should be of the same nature, to remain nearly unaffected, thus giving rise to *acid* (lined) or *basic* (lined) vessels or furnaces.

Under oxidizing conditions the metalloids such as phosphorus and silicon can be eliminated by causing their oxides which are acid, to combine with, and be retained by, a base such as lime if this is present in sufficient excess. Sulphur presents certain difficulties to removal under oxidizing conditions, and the extent of its removal is usually erratic. In the elimination of impurities (basic process), at a relatively low temperature phosphorus and silicon are acted upon and eliminated in preference to the carbon, but if the temperature is high the carbon is immediately affected, which may result in less perfect elimination of the first named.

Under strongly reducing conditions, such as can be secured in the blast furnace or the electric furnace, the removal of the sulphur is under fairly constant control; also at very high temperatures it is claimed that phosphorus previously brought into the slag by oxidizing conditions can, by powerful reduction, as in the electric furnace, be converted into an even more stable phosphide.

There are two principal sources of oxygen (*a*) iron oxide, and (*b*) air, which are used either separately or in combination.

In *puddling* (*q.v.*) pig iron is melted on the hearth of a reverberatory furnace (see Furnace), in contact with iron oxide and exposed to the flame; in the *charcoal hearth processes* (*q.v.*) the pig iron is exposed in a hearth to the action of a blast in conjunction with the gas resulting when the fuel consisting of charcoal is burned to yield the necessary temperature. In both cases the product becomes pasty in its later stages and contains an admixture of slag most of which is expelled by subsequent hammering or rolling. The *open hearth process* (*q.v.*) is similar to puddling but, owing to the method of heating, the temperature is at all stages maintained above the melting point of the metal, and hence the product is fluid which permits of a nearly complete separation from the slag. The *Bes-*

semper process (q.v.) employs air alone which is blown through the molten metal.

The oldest method for producing steel in the fluid condition is the *crucible process* (q.v.) which consists principally in the remelting of suitable materials, with little if any purification aside from the elimination of oxides.

The final adjustment of the composition is described in connection with the various steel making processes, and consists essentially in adding the necessary ingredients for this purpose and also for that of deoxidation (see also Recarburization).

The properties of iron are chiefly affected by the carbon content, and most of the iron or steel of commerce contains this element as its principal constituent, together with varying amounts of manganese, phosphorus, sulphur, and silicon, together with certain other special elements, usually in traces, depending upon the nature or the source of the ore. *Special steels* (q.v.) contain one or more special elements, such as nickel, chromium, tungsten, etc., deliberately added (or present) in amounts sufficient to affect appreciably the physical properties. These serve both to intensify the effect of carbon, as well as to modify the general or specific properties, but without carbon their value would be greatly diminished.

It is possible under the proper conditions to add carbon to (*carburize*) the steel at temperatures considerably below its melting point, by heating in intimate contact with carbonaceous matter, and with exclusion of air or other oxidizing media. The process is relatively slow in comparison with treatment in the molten state, the time being roughly inversely as the temperature. A piece carburized only to a slight depth, to produce better wearing properties, is said to be *case hardened*. The process may be carried further so that all or nearly all the section is affected. This subject is discussed under Cementation and Cementation Process.

While cast iron as such is not usefully malleable, and is more brittle the greater the proportion of carbon in the combined state, it is possible to restore this property to a considerable degree. This is accomplished by heating white iron (see Pig Iron) castings in contact with iron oxide, at a temperature below their melting point, by which means the carbon is oxidized or converted into inert graphite. These are termed *malleable castings* (q.v.).

In the case of liquid steel, after the composition has been adjusted in the furnace or the ladle into which it is tapped, it is poured into molds (see Casting and Molding) producing castings which, if to be worked, are known as *ingots*. These are then forged or rolled to shape as described under Forging, Pressing, and Rolling.

The chemical composition is determined by analytical methods (see Chemistry) and the *physical properties* (q.v.) are checked by some method of *testing* (q.v.).

The investigation of the nature of the physical constitution and

conditions which are responsible for the physical properties shown, is dealt with under Metallography.

The structure may be advantageously or injuriously affected by purely thermal treatment (see Heat Treatment) or by the mechanical working to which it has been subjected (see Heat Treatment and Cold Working).

The joining together of two pieces, either in a pasty condition or by actual fusion commonly known as *welding*, is discussed under that heading.

The causes for the deterioration or rusting of iron products, whereby the metal tends to return to its original oxidized state, and the conditions or methods which retard or overcome this tendency are dealt with under Corrosion and Protection.

The manufacture of general products, such as plates, shapes and bars, is considered under Rolling, while special products, such as sheets and tin plate, tubes, and wire, are dealt with more fully under their respective headings.

conditions which are responsible for the appearance of defects shown
 a defect with under Metallurgy.
 The structure may be advantageously or injuriously affected by
 such thermal treatment as heat treatment or by the methods
 employed in which it has been subjected to heat treatment
 (see Section 10).
 The general behavior of the metal either in a cast condition or
 in a wrought condition is known as behavior, is discussed under
 cast behavior.
 The causes for the deterioration or rusting of iron products,
 especially the cast forms, is a subject of considerable interest,
 and the conditions of rusting are given in a separate section of
 the book under the name Corrosion and Protection.
 The manufacture of wrought products, such as plates, sheets and
 bars, is considered under Rolling, while special products, such as
 castings and the plate, tube, and wire are dealt with more fully
 under their respective headings.

IRON AND STEEL DEFINITIONS

A

- A.—(1) Chemical symbol for argon: see page 84; (2) critical point of Tschernoff: see page 265; (3) for coating: see page 433.
- A₁, A₂, A₃.—Critical points: see page 264.
- Ac₁, etc.—Critical points: see page 264.
- Ac_{cm}.—Critical point: see page 264.
- A_{cm}.—Critical point: see page 264.
- Ae, Ae₁, etc.—Critical points: see page 264.
- Ag.—Chemical symbol for silver (from the Latin *argentum*): see page 84.
- Al.—Chemical symbol for aluminum (*q.v.*).
- Ar_o.—Critical point: see page 264.
- Ar₁, etc.—Critical points: see page 264.
- Ar_{cm}.—Critical point: see page 264.
- Ar_{mc}.—Critical point: see page 264.
- As.—Chemical symbol for arsenic: see page 84.
- Au.—Chemical symbol for gold (from the Latin *aurum*): see page 84.
- A. A. S. M.—Association of American Steel Manufacturers.
- A. B. M. A.—American Boiler Makers' Association.
- A. E. R. A.—American Electric Railway Association, formerly the American Street & Interurban Electric Railway Association.
- A. E. R. E. A.—American Electric Railway Engineering Association, one of the subsidiary associations of the A. E. R. A.
- A. E. R. M. A.—American Electric Railway Manufacturers' Association, one of the subsidiary associations of the A. E. R. A., composed of manufacturers of electric railway supplies.
- A. F. A.—American Foundrymen's Association.
- A. I. M. E.—American Institute of Mining Engineers.
- A. O. H.—Acid open hearth: see page 309.
- A. R. A.—American Railway Association.
- A. R. E. & M. W. A.—American Railway Engineering & Maintenance of Way Association; name changed (1911) to American Railway Engineering Association.
- A. R. E. A.—American Railway Engineering Association; formerly the American Railway Engineering & Maintenance of Way Association; one of the subsidiaries of the A. R. A.
- A. R. M. M. A.—American Railway Master Mechanics' Association; one of the subsidiaries of the A. R. A.
- A. S. C. E.—American Society of Civil Engineers.
- A. S. & I. E. R. A.—American Street & Interurban Electric Railway Association; name changed (1910) to A. E. R. A.
- A. S. M. E.—American Society of Mechanical Engineers.
- A. S. T. M.—American Society for Testing Materials.
- A. S. & W. Gage.—American Steel & Wire Co.'s Gage; see page 188.

- Abel's Carbide of Iron.—Cementite: see page 272.
- Abrasion.—See pages 106 and 331.
- Abrasive Hardness.—See pages 331 and 478.
- Abscissa.—See Curve.
- Absolute Scale.—Of temperature: see page 205.
- Absolute Strength.—See page 468.
- Absolute Temperature.—See page 205.
- Absolute Zero.—See page 205.
- Absolutely Black Body.—See page 207.
- Absorbed Energy.—See page 481.
- Absorbens.—See page 120.
- Absorption.—See pages 199, 212 and 328.
- Absorption Point.—See page 265.
- Absorption Pyrometer, Féry.—See page 207.
- Absorption Temperature.—See page 265.
- Absorption Zone.—See page 292.
- Accelerated Corrosion Test.—See page 107.
- Accelerated Stress.—See page 333.
- Achondrite.—See page 292.
- Acicular Crystal.—See page 126.
- Acicular Martensite.—See page 275.
- Acid.—See page 88.
- Acid Bessemer Ore.—See page 243.
- Acid Bessemer Pig.—See page 343.
- Acid Bessemer Process.—See page 15.
- Acid Bessemer Steel.—Steel made by the acid Bessemer process.
- Acid Bottom.—See Lining.
- Acid Brittleness.—See page 507.
- Acid Clay.—See page 396.
- Acid Converter.—See page 16.
- Acid Flux.—See Flux.
- Acid Lining.—See Lining.
- Acid Open Hearth Process.—See pages 309 and 314.
- Acid Open Hearth Steel.—Steel made by the acid open hearth process.
- Acid Refractories.—See page 395.
- Acid Slag.—See Slag.
- Acid Theory of Corrosion.—See page 107.
- Acierage.—The electro-deposition of a thin layer of iron on engraved copper plates to make them more resistant to the wearing action of inking and printing.
- Acoustic Signals.—See page 210.
- Actinometer, Violle's.—See page 207.
- Active Combustion.—See page 202.
- Adamantine Silicon.—See Silicon.
- Adams Process.—See page 137.
- Addie Process.—For the recovery of tar and ammonia from the gas of a blast furnace using raw coal.
- Additions.—For recarburizing: see page 393.
- Additional Strains; Stresses.—See page 332.
- Additive Property.—See page 337.
- Adjustable Tuyere.—See page 182.

- Adjusting Process (Howe).**—One in which the composition is determined and arranged.
- Adsorption.**—See page 328.
- Adsorption Theory.**—Of passivity: see page 364.
- Advance Alloy.**—For thermo-couples: see page 209.
- Aeolic.**—See page 270.
- Aeolic Steel.**—See page 273.
- Aeolochronous.**—Or **Aeoliotachic**; suggested by Howe to express the fact that cooling and contraction, even if equal in amount, occur at different rates in different portions of a piece.
- Aeoliotachic.**—See Aeolochronous.
- Aeolotropic.**—See page 330.
- Aërolite.**—See page 290.
- Aërolitics.**—See page 291.
- Aërosiderite.**—See page 291.
- Aërosiderolite.**—See page 291.
- Affinity.**—See page 84.
- After Blow.**—See page 21.
- After Glow (rare).**—Recalescence: see page 265.
- Aggregate.**—See page 264.
- Aging.**—See page 333.
- Agglomeration.**—See page 81.
- Aggregation, State of.**—See page 81.
- Agitator, Allen's.**—See page 62.
- Agraphitic Carbon.**—See pages 50 and 278.
- Air Belt.**—See page 182.
- Air Box.**—See page 17.
- Air Casing.**—A casing enclosing air to prevent or reduce loss of heat by radiation.
- Air Chamber.**—See page 182.
- Air Channels.**—Flues under the hearth and the fire-bridge of a reverberatory furnace to keep them cool.
- Air Cooling.**—See pages 227 and 232.
- Air-dilution Pyrometer.**—See page 210.
- Air Dry.**—Dried by simple exposure to the air, without the application of heat.
- Air Furnace.**—See page 182.
- Air Gas.**—See Oil Gas.
- Air Hardening.**—See page 227.
- Air-hardening Steel.**—See page 445.
- Air Heating.**—Heating in air.
- Air Pits (Ewing and Rosenhain).**—An epithet applied to microscopic air bubbles, which have taken a geometrical form, found on the surface of certain metals cast on glass.
- Air Pyrometer.**—See page 205.
- Air-quenched Steel.**—See page 445.
- Air Quenching.**—See page 227.
- Air Refining Process.**—Bessemer Process, *q.v.*
- Air Thermometer.**—See page 205.
- Air Tinting.**—See page 288.
- Air Toughening.**—See page 232.
- Aired Bars.**—See page 71.

- Åkerman's Theory.**—Of hardening: see page 280.
- Alexander and M'Cosh Process.**—For the recovery of tar and ammonia from the gas of a blast furnace using raw coal.
- All-mine Pig.**—See page 350.
- Allen's Agitator.**—See page 62.
- Alleward Process.**—See page 154.
- Alligator Cracks.**—See page 112.
- Alligator Scale.**—A heavy, very infusible scale formed during the reheating of chrome steel.
- Alligator Shears.**—See Shears.
- Alligator Squeezer.**—See page 377.
- Alling's Test.**—See page 216.
- Allis-Andrew Process.**—See page 416.
- Allomorph.**—See page 122.
- Allotrimorphic Crystal.**—See page 122.
- Allotropic Modifications.**—Of iron: see page 264.
- Allotropic Theory.**—Of hardening: see page 279.
- Allotropic Transformation.**—See page 327.
- Allotropy.**—A change in the properties of an element without change of state. It is habitually accompanied by a change of internal energy. It is due in some, and perhaps in all, cases to a change in the number or in the arrangement of the atoms in the molecule (Howe). Allotropic varieties are sometimes termed *isomerides*.
- Alloy.**—A union, possessing metallic properties, of two or more metallic elements, or of metallic elements and metalloids, which are miscible with each other, at least to a certain extent, when molten to form a homogeneous liquid, and do not separate into distinct layers when solid. Such combinations when cold may consist of mechanical mixtures, eutectics or eutectoids, solid solutions, or chemical compounds, one or more of which may exist at the same time. **Amalgamation** is the alloying of mercury with some other metal yielding (at least temporarily) a plastic or liquid mass; the term is sometimes used improperly, where mercury is absent, in the ordinary sense of alloying. When composed of two or more elements they are termed respectively **binary, ternary, quaternary alloys**, etc. An alloy, composed of metallic elements only, is sometimes referred to as a **metallic, intermetallic, or simple alloy**; where a definite chemical compound exists, it may be termed an **intermetallic compound** or **definite alloy**; a mixture of the two, a **metallo-metallic compound**; a **eutectomeric alloy** is one which, in one proportion of its constituents, forms a eutectic. The **dominant metal** or **element** is one which principally affects the properties. Alloys may be divided into **ferrous** and **non-ferrous** depending on whether or not iron is the dominant element. They may also be classified as **heavy**, where they contain principally metals such as iron, nickel, or copper with a specific gravity over about 7; and **light**, with metals with a specific gravity less than this. **Fusible alloys** are those which melt at a very low temperature, *e.g.*, Wood's fusible alloy which melts at 65° C. (149° F.); they usually consist of bismuth, lead and tin in various proportions, and iron only as an impurity. **Magnetic**

alloys (generally referred to as **Heussler's alloys**) do not contain iron but consist of metals which, separately, are non-magnetic or only slightly so; the composition may be taken as approximately copper 60, manganese 20, aluminum 14. Overbeck suggested the term **metamagnetic alloys** for those which are paramagnetic or diamagnetic, according to the strength of the magnetic field—the case of some alloys of copper and zinc. **Hannover's process** for making **metallic sponges** consists in heating a eutectic alloy to a temperature within its freezing range (see *Metallography*, page 267) and centrifuging it, whereby the molten portion is expelled. What is known as the **superposing method** of forming alloys consists in first melting the metal of highest specific gravity and then pouring on top of this, in a molten condition, the other and lighter metal. The two metals will alloy in such a way that a vertical cross section will show crystals of a pure metal at one end and crystals of the other metal at the other end, while between these the metals will be found alloyed in all possible proportions (*Metallographist*, 1902, 247). (For further details of the constitution and properties of alloys see the treatises on the subject by Howe, Sauveur, Desch, Heyn, Rosenhain, Guertler, etc., also *Metallography*).

Alloy Cast Iron.—See page 351.

Alloy Element.—See pages 351 and 443.

Alloy Steels.—See page 443.

Alloyed Carbon Iron.—See page 443.

Almond Furnace.—A remelting or refining furnace of the reverberatory type; name derived from *allemand* (German).

Alpha Cementite.—See page 273.

Alpha (α) Iron.—See pages 264 and 272.

Alpha Iron Theory; Alpha Theory.—Of hardening: see page 280.

Altar.—Of a furnace: see pages 183 and 375.

Altered Iron.—See page 364.

Alternate Stresses.—See page 333.

Alumaloyd.—See page 372.

Aluminium (Eng.).—See Aluminum.

Alumino-ferrite.—See page 272.

Alumino-thermic Process.—Carried out by means of the heat developed by the burning (oxidation) of metallic aluminum; see Goldschmidt process and Rossi process.

Aluminous Clay.—See page 396.

Aluminum.—Al; at. wt., 27; melt. pt., 625° C. (1157° F.); sp. gr., 2.58 (by hammering or rolling this may be raised to 2.68). A white metal, with high tensile strength, malleability, and conductivity. Its principal application in the manufacture of steel is as a deoxidizer, for which purpose it is usually added (up to about 3 or 4 oz. per ton) in the mold during pouring. It is used as the pure metal, or as an alloy with iron called ferro-aluminum (see page 351), and is rarely a constituent of steel (see page 453).

Aluminum Coating.—See page 372.

Aluminum Steels.—See page 453.

Alundum.—A trade name for an abrasive consisting of fused alumina, produced in the electric furnace.

- Amalgamation.**—See Alloy.
- American Bloomary Process.**—See page 137.
- American Charcoal Irons.**—See page 350.
- American Forge.**—See page 137.
- American Forge and Foundry Iron.**—Graded by analysis: see page 348; graded by fracture; see page 347.
- American Lancashire Process.**—See page 77.
- American Process.**—For malleable castings: see page 258.
- American Steel & Wire Co.'s Gage.**—See page 188.
- American Wire Gage.**—See page 188.
- Amet-Ensign Oil Gas Producer.**—See Oil Gas.
- Amianthus.**—See Salamander.
- Amorphizing.**—See page 282.
- Amorphous.**—See page 119.
- Amorphous Antimony.**—See Antimony.
- Amorphous Boron.**—See Boron.
- Amorphous Carbon.**—See Carbon.
- Amorphous Cement Theory.**—See page 281.
- Amorphous Fracture.**—See page 178.
- Amorphous Iron Theory.**—Of hardening: see page 281.
- Amorphous Phase.**—See page 281.
- Amorphous Silicon.**—See Silicon.
- Amorphous State.**—See page 281.
- Amorphous Sulphur.**—See Sulphur.
- Amorphous Theory.**—Of hardening: see page 281.
- Amorphous Tin.**—See Tin.
- Amount of Heat.**—See page 199.
- Amsler-Laffon Test.**—(1) Hardness test: see page 478; (2) vibratory test: see page 482.
- Analysis; analytic (al) Chemistry.**—See page 82.
- Analytical Reaction.**—See page 87.
- Anchor Bolt.**—In molding: see page 299.
- Ancony (obs.).**—See page 135.
- Anderson Furnace.**—See page 154.
- Angle of Contact.**—In rolling: see page 407.
- Angular Fracture.**—See page 179.
- Angular Method of Rolling.**—See page 420.
- Anhedron.**—See page 122.
- Anhydride.**—See page 88.
- Anion.**—See page 89.
- Anion Discharge Theory.**—Of passivity: see page 364.
- Anisometric System.**—Of crystallization: see page 120.
- Anisotropic; Anisotropy.**—See page 330.
- Ankerite.**—A crystallized variety of dolomite containing a large proportion of iron.
- Ankony (obs.).**—Double gross ton of 2464 pounds.
- Annealing.**—(1) Of crucibles: see page 112; (2) of steel or iron: see page 231; (3) of malleable castings: see page 258; (4) of sheets: see page 431; (5) of tubes: see page 492.
- Annealing Box.**—See page 431.
- Annealing Carbon.**—See pages 257 and 278.
- Annealing Charge.**—See page 233.

Annealing Furnace.—A type of furnace used for annealing, *i.e.*, heating to a low temperature: see Furnace.

Annealing Oven.—For crucibles: see page 112.

Annealing Pit.—A pit, generally lined with brick, in which castings, particularly cast-iron car wheels, are allowed to cool slowly.

Annealing Pot.—See pages 258 and 431.

Annealing Temperature.—The temperature to which material is heated for annealing.

Annealing Twin.—See page 125.

Anode.—See page 89.

Anodic Passivity.—See page 364.

Anodic Polarization.—See page 364.

Anorthic System.—Of crystallization: see page 120.

Ansaldo Process.—See page 60.

Anthracite; anthracite coal.—See Coal.

Anthracite Coal Apples.—See Coal.

Anthracite Furnace.—Kind of blast furnace: see page 39.

Anthracite Pig.—See page 343.

Anthracitic Coal.—See Coal.

Anti-cement.—In cementation: see page 70.

Anti-fatigue Steel.—See page 452.

Anti-friction Metal.—A bearing metal, such as babbitt, used to reduce the friction of bearings. It usually consists of various proportions of lead, tin, zinc, and antimony.

Antimony.—Sb; at. wt., 120; melt. pt., 630° C. (1166° F.); sp. gr., crystalline, 6.7 to 6.8, amorphous, 5.78. It is found in the free state, but its most important occurrence is in combination with other elements. When pure it is a white brittle metal. It is not of value as a constituent of steel, as it is generally considered that even very small percentages render it both hot and cold short. Metallic antimony as found on the market is sometimes known as French metal.

Anti-piping Thermit.—See page 61.

Anvil; Anvil Block.—See Hammer.

Anvil Effect.—The effect on rails due to pounding of flat wheels and lack of counterbalance of driving wheels. Especially pronounced when the track is frozen. The road bed is considered as forming the anvil, on which the rails receive the hammer-like blows of the wheels.

Aphanitic Fracture.—See page 178.

Apparent Elastic Limit.—See page 470.

Apparent Stress.—See page 332.

Apple, Coal.—See Coal.

Applied Chemistry.—See page 81.

Aproning.—In puddling: see page 377.

Aqua Regia.—See page 84.

Aqueo-igneous Fusion; Aqueous Fusion.—See page 201.

Arbitration Bar.—See page 484.

Arborescent Crystal.—See pages 55.

Arc Furnace; Heating.—See page 153.

Arc Radiation Furnace.—See page 153.

Arc-resistance Furnace.—See page 153.

Arc Welding.—See page 503.

Argillaceous.—Containing or consisting of clay.

Argillaceous Iron Ore; Siderite.—See page 244.

Armco Iron.—The trade name for so-called “ingot iron,” extremely low in carbon and other elements, produced by a special open hearth process.

Armor Plate.—Special, usually heavy, iron plates, forming a protective sheathing for war vessels and also for certain types of land fortifications, designed to withstand the penetration of projectiles. Much lighter plates, sometimes less than one-quarter inch thick, have recently been developed for the protection of motor cars, railway trains, etc. At first it was made of cast iron, or of untreated wrought iron; later, of alternate layers of steel and wrought iron, cast or welded together (**compound armor plate**, or **steel-faced wrought-iron armor plate**), the steel to give hardness, and the wrought iron toughness. It is at present made exclusively of steel (usually special steel), one face of which is carburized (by heating in contact with carbonaceous matter at a high temperature) and hardened to a depth of about an inch, the carburizing effect decreasing with the depth below the surface, the rest of the plate being comparatively soft (low in carbon) and tough; this is called **face-hardened armor plate** or **cemented armor plate**.

The **De Marre formula** gives the striking velocity necessary to effect complete penetration of **homogeneous nickel steel** (not carburized on one face but of uniform composition and structure throughout); it is as follows:

$$V = (3.00945) \frac{0.75d \times 0.7e}{0.5p}$$

V = striking velocity in foot pounds;

d = caliber of gun in inches;

e = thickness of plate in inches;

p = weight of projectile in pounds.

A correction of the velocity thus calculated must be made, depending upon the size of gun and thickness or type of plate. The penetration of a given projectile, with corresponding resistance offered by the plate, based on this formula, is known as the **figure of merit**.

The **Beardmore process** consists in casting alternate layers of hard and soft steel. This material is then rolled or forged, hardened, etc.

Bessemer's process for armor plate consisted in piling alternately plates of cast (crucible) steel on plates of puddled or scrap iron which were first carefully cleaned, and then coated with a very fusible flux. The pile was then welded together, etc.

The **Corey re forging process** consisted in forging nearly to size, then carburizing and forging down to exact size, followed by hardening.

In the **Demenge process** for face hardening, one side of the mold is lined with carbonaceous material, to be later taken up by the steel, and the opposite side is formed as a chill, consisting of a mass of iron through which water may be circulated.

The **Ellis process** for making compound armor consisted in fastening a hard steel and a soft iron plate together by pouring molten steel between.

Gruson's chilled cast-iron armor was made by pouring cast iron in chill (iron) molds.

Thomas Hampton's process consisted in taking steel plates or slabs which were piled, reheated, and rolled or hammered together, then carburized on one face, and afterward rerolled, if desired, and hardened.

The **Harvey process** consists in impregnating one face of a soft steel plate, which has been rolled or forged down, with carbon by heating it for a number of days at a temperature sufficient to melt certain grades of cast iron (say, 1200°C. ; 2192°F.) in contact with carbonaceous material, after which the carburized face is hardened by spraying it with cold water. This method of heating is sometimes referred to as **decremental hardening**, since the carbon (and with it the hardness) decreases below the carburized surface.

The **Krupp process** is very similar to the Harvey, one patent specifying heating the plate with the surface to be carburized in contact with illuminating gas which deposits a layer of fine carbon which is readily taken up by the steel; another has to do with producing a fibrous structure by making the steel of special composition, and by heating it to a certain temperature. The product is sometimes called **Krupp cemented armor** (**K. C. armor**).

The **St. Chamond armor plate** consists of steel containing nickel and chromium in addition to carbon.

The **Tressider process** for hardening armor plate consists in subjecting one or both faces to a spray of cold liquid supplied under considerable pressure by a great number of small jets.

Whitworth armor plate was made of fluid compressed steel built up in hexagonal sections, each of which was composed of concentric rings around a central circular disk, the object being to eliminate the liability of cracking, or to restrict its area.

The **Wilson process** for making compound armor plate consisted in pouring molten steel on a soft iron plate, in the ratio of one-third steel to two-thirds iron. The resulting ingot was then heated, rolled, and machined. This is an improvement of **Camel's method**.

See also Casting for certain other methods similar to those described above.

Armored.—A term sometimes used for case-hardened: see page 67.

Armored Glass.—See Wire Glass.

Armorized.—A term sometimes used for case-hardened: see page 67.

Arnold's Subcarbide Theory.—Of hardening: see page 280.

Arnold Test.—See page 482.

Arnoldite: Arnoldite Steels.—See page 277.

Arrestation Point.—See page 264.

Arrested Purification.—Not carried to its greatest possible extent, as in pig washing.

Arrhenius' Theory.—See page 89.

Arris.—The rough edge resulting from the cold shearing of plates, etc.

Arsenide Ore.—See page 244.

Arsenopyrite.—See page 245.

Artificial Steel.—See page 71.

Ascensional Casting.—See page 57.

Ash; Ashes.—In its chemical sense ash is the incombustible residue of a substance; **ashes**, and sometimes **ash**, is used for that portion of a fuel which has not burned, but which may contain a small proportion of combustible matter.

Asiderite.—See page 291.

Assaying.—See page 82.

Association.—See page 84.

Assorting Room.—See page 433.

Astrolithology.—See page 291.

Asymmetric System.—Of crystallization: see page 120.

Ataxite.—See page 292.

-ate.—Chemical suffix: see page 88.

Atmosphere.—(1) The gaseous envelope surrounding the earth; (2) the pressure of the air at the surface of the earth, generally considered as 14.7 pounds to the square inch, with the barometer at 30" (760 millimeters): commonly used as a unit for expressing gas pressures.

Atom.—See page 81.

Atom, per cent.—See page 83.

Atomic Aggregate.—See page 81.

Atomic Heat.—See page 85.

Atomic Theory.—See page 81.

Atomic Volume.—See page 87.

Atomic Weight.—See page 83.

Atomicity.—See page 86.

Attack.—Form of testing: see page 482.

Attack-polishing.—See page 288.

Atrition.—See page 331.

Atwood Process.—See page 117.

Aubertin and Boblique Process.—See page 384.

Auchy's Chemical Theory.—Of iron-carbon steels: see page 278.

Austenite.—See page 274.

Austenite-pearlite Inversion.—See page 275.

Austenite Range.—See page 275.

Austenite Steels.—See page 276.

Austenitic Manganese Steel.—See page 451.

Austenitic Steels.—See page 445.

Austenoid.—See page 275.

Austenite-martensitic Steel.—See page 276.

Autoclave.—See Slag Cement.

Autoelectrolysis.—See page 108.

Autogenous Electrolysis.—See page 108.

Autogenous Soldering, Welding.—See page 505.

Autographic Recorder.—In testing: see page 471.

Automorphic Crystal.—See page 122.

Autoreduction.—Of certain compounds which can be reduced to the metallic condition by the simple application of heat.

Avogadro's Law.—See page 85.

Axe Temper.—See Temper.

Axial Forces; Load.—See page 332.

Axial Segregate.—See page 56.

Axial Stresses.—See page 332.

Axis.—See Curve.

Axis of Principal Stress.—See page 332.

B

- B.**—(1) Chemical symbol for boron, *q. v.*; (2) grade of wrought iron, also of wire: see page 509.
- Ba.**—Chemical symbol for barium: see page 84.
- Be.**—Chemical symbol for beryllium (now called glucinium): see page 84.
- Bi.**—Chemical symbol for bismuth; see page 84.
- Br.**—Chemical symbol for bromine: see page 84.
- B. G.** (Eng.).—Sheet and hoop iron standard gage.
- B. H.**; **B. B. H.**—Best hammered; best best hammered; trade designations for qualities of hammered wrought iron.
- B. O. H.**—Basic open hearth: see page 309.
- B. O. V.**—Brown oil of vitriol: sp. gr., 1.6 to 1.74.
- B. & S. Gage.**—Brown & Sharpe gage: see page 188.
- B. T. U.**—British thermal unit: see page 199.
- B. W. G.**—Birmingham wire gage: see page 188.
- Baby Bessemer Converter.**—See page 23.
- Bacillar Structure.**—See page 125.
- Back.**—Of a converter: see page 18.
- Bacon and Thomas Process.**—See page 384.
- Bailey Resistance Furnace.**—See page 154.
- Bajault and Roche Process.**—See page 113.
- Baked.**—(1) Of steel: see page 226; (2) of wire: see page 507.
- Baker.**—For wire: see page 507.
- Baker Process.**—See page 384.
- Balanced Roll.**—See page 406.
- Ball.**—(1) In puddling: see page 376; (2) in making welded tubes: see page 490.
- Ball Mill.**—A mill for grinding materials into a very fine powder, consisting of a revolving cylinder in which are heavy stone or iron balls.
- Ball Stuff.**—See pages 17 and 396.
- Ball Test.**—For hardness: see page 477.
- Bail and Wingham Process.**—See page 384.
- Ballantine Method.**—For determining hardness: see page 478.
- Baller.**—See page 21.
- Balling Furnace.**—See page 377.
- Balling-heat Processes.**—See page 134.
- Ballistic Test.**—See page 482.
- Balthasar Mill.**—See page 417.
- Banal Deformation.**—See page 126.
- Banded Structure.**—See page 127.
- Bank.**—(1) A row of soaking pits having the same set of regenerators; (2) to shut down a blast furnace temporarily by cutting off the blast: see page 37; (3) a rack or place where rolled material is piled to cool (Eng.).
- Bank Oven.**—See page 95.
- Bar.**—See page 468.

- Bar Iron.**—Wrought iron in the form of bars.
- Bar Mill.**—See pages 413.
- Bar Steel.**—See page 71.
- Barba's Law.**—See page 473.
- Barff Process; Barffed.**—See page 367.
- Bark.**—Of steel: see page 226.
- Bark Mill.**—A mill for crushing the graphite used in the manufacture of graphite crucibles.
- Barked Fracture.**—See page 178.
- Barnett Process.**—See page 379.
- Barrel.**—Of a roll: see page 403.
- Barrow Charging.**—See page 33.
- Barus Gas Pyrometer.**—See page 207.
- Barus Thermolectric Pyrometer.**—See page 208.
- Basal Cleavage.**—See page 124.
- Base.**—(1) In chemistry: see page 88; (2) ground mass: see page 125; (3) of a paint: see page 305.
- Base Box.**—Of tin plate: see page 433.
- Base Material.**—Of enamels: see page 370.
- Base Metal.**—See page 84.
- Base-metal Couples.**—See page 209.
- Basic Bessemer Ore.**—See page 243.
- Basic Bessemer Pig.**—See page 343.
- Basic Bessemer Process.**—See page 15.
- Basic Bessemer Steel.**—Steel made by the basic Bessemer process.
- Basic Bottom.**—See Lining.
- Basic Clay.**—See page 396.
- Basic Converter.**—See page 17.
- Basic Crucible Process.**—See page 113.
- Basic Flux.**—See Flux.
- Basic Iron.**—See page 343.
- Basic Lining.**—See Lining.
- Basic Material.**—See page 17.
- Basic Open Hearth Process.**—See pages 309 and 315.
- Basic Open Hearth Steel.**—Steel made by the basic open hearth process.
- Basic Pig Iron.**—See pages 343 and 346.
- Basic Purifying Processes.**—See page 382.
- Basic Refractories.**—See page 396.
- Basic Slag.**—See Slag.
- Basicity.**—See page 87.
- Basin.**—In puddling: see page 374.
- Bastard Slag.**—See Slag.
- Bat-Stick.**—A stick—usually a sledge handle—used by a hammerman for the purpose of revolving the axle or forging on which he may be working. Usually the forging is hanging in a sling, supported by a chain pulley. The hammerman slips his bat-stick between the reins of the tongs next the jaws and uses it as a lever to turn the forging after each blow of the hammer (G. Aertsen).
- Batch.**—In making crucibles: see page 112.
- Bates Process.**—See page 68.
- Batho Furnace.**—See page 312.

- Batted.**—Of wire: see page 508.
- Battery.**—See Hammer.
- Battetura (Eng.).**—Hammer scale.
- Bauernofen.**—See page 147.
- Baumann's Method.**—For sulphur prints: see page 288.
- Baur Method.**—For determining hardness: see page 480.
- Bauschinger's Formula.**—For tensile strength: see page 337.
- Bauxite; Bauxite Brick.**—See page 398.
- Baykoff's Method.**—For hot etching: see page 287.
- Bead.**—Or blister: see page 71.
- Beaded Pearlite.**—See page 274.
- Beading.**—Of boiler tubes; rounding off the ends after expanding, or the ends so rounded off.
- Beam.**—Of a testing machine: see page 469.
- Bean Ore.**—See page 244.
- Bear.**—See Salamander.
- Beardmore and Cherrie Process.**—See page 60.
- Beardmore Process.**—See page 8.
- Bearing Compression.**—See page 336.
- Bearing Metal.**—Used for bearings: same as Anti-friction Metal.
- Beasley Process.**—See page 379.
- Beaumontague (Eng.).**—A compound used for filling up holes in castings, etc., for the purpose of concealment.
- Becquerel Effect.**—See page 209.
- Becquerel Gas Pyrometer.**—See page 207.
- Becquerel Optical Pyrometer.**—See page 207.
- Becquerel Thermoelectric Pyrometer.**—See page 208.
- Bed.**—(1) Layer, e.g., a bed of coal; (2) bottom of a furnace, etc.
- Bedson Continuous Galvanizing Process.**—See pages 370 and 509.
- Bedson Mill.**—See page 412.
- Beehive Coke; Oven.**—See page 95.
- Beetle.**—Or maul: a heavy wooden mallet.
- Behrens Scale.**—Of hardness: see page 480.
- Beilby's Amorphous Cement; Amorphous Phase:** see page 281.
- Beilby's Hard Iron.**—See page 281.
- Beilby's Theory.**—Of hardening: see page 281.
- Belford Process.**—See page 137.
- Belgian Mill.**—See page 416.
- Bell.**—(1) Of a blast furnace: see page 32; (2) in the manufacture of tubes: see page 489.
- Bell and Hopper.**—See page 32.
- Bell-Krupp Pig Washing Process.**—See page 383.
- Bell Process.**—(1) Of dephosphorizing or pig washing: See page 383; (2) for purification: see page 384.
- Bellied (Belly) Core.**—See page 299.
- Bellied (Belly) Bass.**—See page 405.
- Belly.**—Of a converter: see page 17.
- Belly Helve.**—See Hammer.
- Belly Walls.**—Of a blast furnace: see page 27.
- Belt Driven.**—See page 407.
- Bench Hardened Wire.**—See page 508.
- Bend (Bending) Test.**—See page 476.
- Bending Moment.**—See page 337.

- Bending Resilience.**—See page 331.
- Bending Rolls.**—Heavy rolls of cast iron or steel, set in strong housings, and used either for the straightening of crooked plates, or for bending them into arcs of circles or into complete cylinders.
- Bending Strength.**—See page 330.
- Benedicks' Colloid Hypothesis.**—Of osmondite: see page 277.
- Benedicks' Equilibrium Diagram.**—See page 271.
- Benedicks' Formula.**—For Brinell hardness number: see page 478.
- Benedicks' Reagent.**—See page 287.
- Benedicks' Theory.**—Of beta iron: see page 280.
- Benefaction; Beneficiation.**—See Ore.
- Benmutic.**—See page 270.
- Benmutic Steel.**—See page 273.
- Berard Process.**—See page 317.
- Bernardos Process.**—See page 503.
- Berner Process.**—See page 137.
- Berthelot Calorimeter.**—See page 201.
- Bertrand Process.**—See page 368.
- Bertrand-Thiel Process.**—See page 315.
- Bessemer Ferro-silicon.**—See page 354.
- Bessemer Iron; Metal; Pig.**—See page 343.
- Bessemer Ore.**—See page 243.
- Bessemer (Anthony) Process.**—Consisted in exposing molten pig iron to the action of air, steam, or even pure oxygen in a cylindrical, revolving reverberatory furnace.
- Bessemer (Henry) Process.**—(1) For armor plate: see page 8; (2) for fluid compression: see page 63; (3) for making continuous sheets: see page 65.
- Bessemer Process.**—For making steel, sometimes called **converting process** and, rarely, **air refining process** or **pneumatic process**: A process for the production of steel consisting in blowing air through molten pig iron contained in a suitable vessel, whereby the impurities are oxidized and removed, and the product is obtained in a fluid condition. Depending upon the nature of the lining of the vessel, there are two modifications: (a) **acid Bessemer process** (the original process, hence also called simply **Bessemer process**) by which nearly all the silicon, carbon, and manganese are eliminated; and (b) **basic Bessemer process** (due to Thomas, aided to some extent by Gilchrist, and sometimes called **Thomas-Gilchrist process** or, on the Continent, **Thomas process**) in which there is elimination of nearly all the silicon, carbon, and manganese, as in the acid process, and, in addition, most of the phosphorus and part of the sulphur.
- The vessel or converter is usually pear- or egg-shaped, the bottom (rarely one side) of which is perforated with a large number of holes through which a powerful blast of air enters and passes through the bath of metal, thereby oxidizing the impurities which go into the slag if solid, or out of the mouth of the converter if gaseous. After the oxidation of the impurities, the bath contains a certain amount of oxide and free oxygen which are removed by manganese in some form with or without extra carbon.

The equipment of a modern plant consists (in this country) essentially of usually two to four converters, provided with cranes and other appliances for pouring in the molten pig and handling the finished steel, etc.; cupolas for melting the pig (direct metal from the blast furnace, with the intervention of mixers, is now

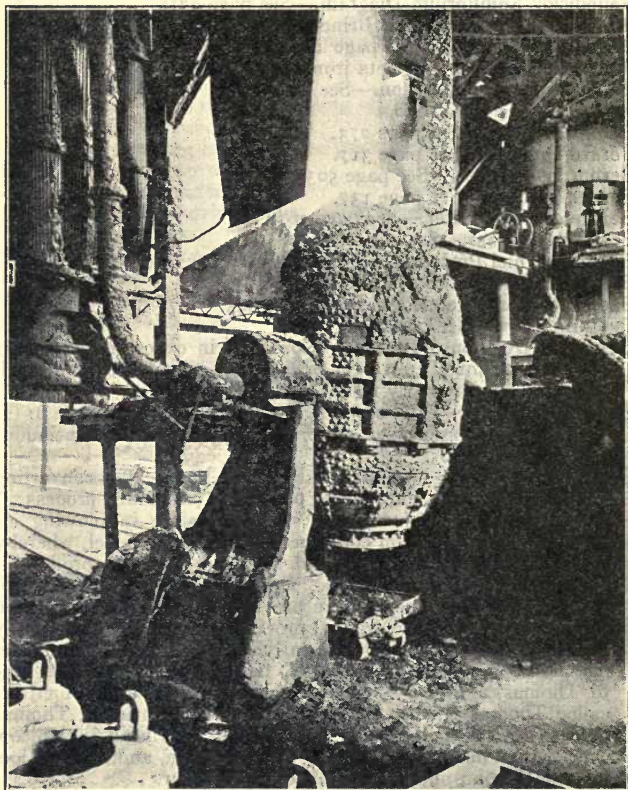


FIG. 1.—Converter in action.

generally used), and spiegel if rail steel is to be made; blowing engines (in a separate building) for supplying the blast. The operation of the vessels is controlled by a blower stationed on a platform (pulpit) situated at a little distance so he can see all that is going on. There are also pouring platforms, yards, etc.

The converter is lined with either acid or basic material (acid

converter, basic converter) depending upon the practice, and is mounted at about the middle on trunnions so it can be tilted to various angles (**tilting converter, tipping converter**). In the original form it was set on a permanent foundation and could not tip (**fixed converter, stationary converter**), this type being still employed in Sweden (Swedish fixed converter). The vessel consists of a steel shell suitably lined, and comprises three sections: the **bottom**, the middle part or **body (belly)**, and the upper part or **nose** which is open at the top or **mouth**. The blast, at a pressure of about 20 to 25 pounds to the square inch, is admitted at the bottom through tuyères or holes formed in bricks of a special design, called **tuyere bricks** (each of which contains a number of holes), around which is rammed refractory material (**bottom stuff**), the whole being held in a suitable casting. As the lining of the bottom wears away much more rapidly than that of the vessel proper, A. L. Holley designed one which could be readily detached and replaced by a fresh one (**Holley movable or removable bottom**). A modification of this, where the blast connections do not need to be broken, the bottom being simply slid out of a frame, is termed a **draw bottom**. The bottom is closed by an iron plate (**bottom plate**), between which and the bottom of the tuyeres is an open space (**wind box, blast box, air box, or tuyere box**) into which the blast is admitted. For basic practice the tuyere holes are usually formed by ramming lime around pins which are subsequently withdrawn, this forming what is called the **plug**; a bottom made in this way is sometimes termed a **pin bottom**. For acid vessels the body and nose sections are lined with blocks or pieces of ganister or firestone set in **ball stuff** (a mixture of ground ganister or quartz and sand with a little clay to make the mass plastic). For basic practice crushed burnt dolomite mixed with tar or pitch (**basic material**) is rammed in. The bottoms and basic lining must be dried very carefully before use. In acid practice the bottoms last about 23 to 25, occasionally up to 30, heats, and the vessel linings up to five or six thousand or more; in basic practice the bottoms last about 20 to 40, and the vessel linings 100 to 200 heats. While the vessel is in service it is patched between heats, and more thoroughly on Saturday nights, by throwing on the worn spots ball stuff or **vessel patching**, and at the same time any accretions (**kidneys**) are pried off. If one of the tuyeres burns through, the vessel may be turned down while the charge is still in it, and the defective tuyere either cut out and a fresh one put in its place, a **dummy tuyere** (without any holes in it) inserted, or else it may be **noodled**, *i. e.*, strips (**noodles or rat tails**) of ball stuff forced into the holes, and an iron plate clamped on over the bottom, and in this last case it is called a **blind tuyere**.

The vessel may have one of two forms, **eccentric** or **concentric**. In the former case one side of the nose is straight while the other is curved, thus bringing the center of the mouth to one side of the vertical axis; in the latter case the taper or curve of the nose is uniform all the way around, which brings the mouth directly in the center. When a vessel is tipped on its side (**turned down**) there

must be enough curve or belly to permit the iron to lie below the level of the tuyeres. In the eccentric converter, for given cubical contents, the belly is greater. With this type the converter is tilted to the same side to receive the molten pig and also to discharge the **blown metal** (pig iron purified by blowing air through it). The concentric converter is turned down on one side (**iron side**) to receive the pig, and on the other side (**steel side**) to discharge the blown metal. In the eccentric converter the side of greatest

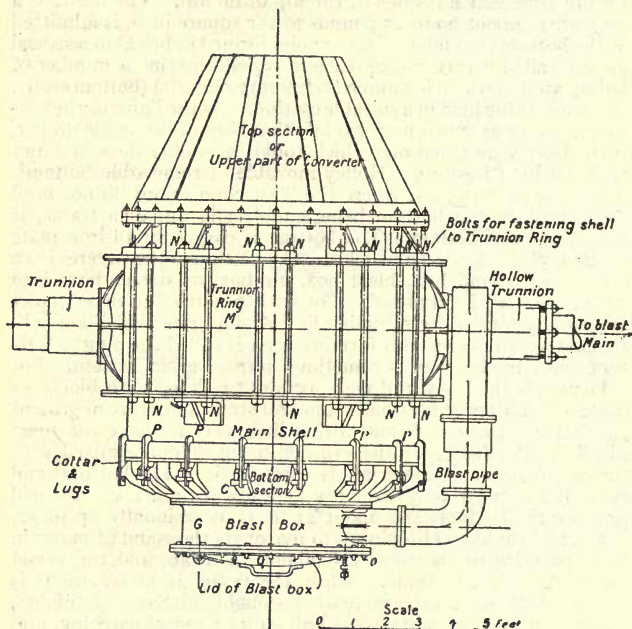


FIG. 2.—Elevation of converter.
(Harbord and Hall, "Metallurgy of Steel".)

curvature is called the **belly**; the part of this side next the bottom, the **shoulder**; the middle of the smaller side, the **back**; and the upper part of that side next the nose, the **breast**.

As already stated, in the ordinary type of converter, the air is introduced through the bottom, and this is termed a **bottom blown converter**. Practically only in the case of baby Bessemer converters, the air may be introduced through tuyeres or holes in the side for the purpose of reducing the necessary pressure of blast: this is known as a **side blown converter**. In some of the earlier types of converter attempts were made to introduce the blast through a pipe thrust down nearly to the bottom of the bath, and

this was called an internally blown converter. One form of tuyere for this purpose, termed a built up tuyere, consisted of an iron tube continued down and attached to the tuyere proper; it was

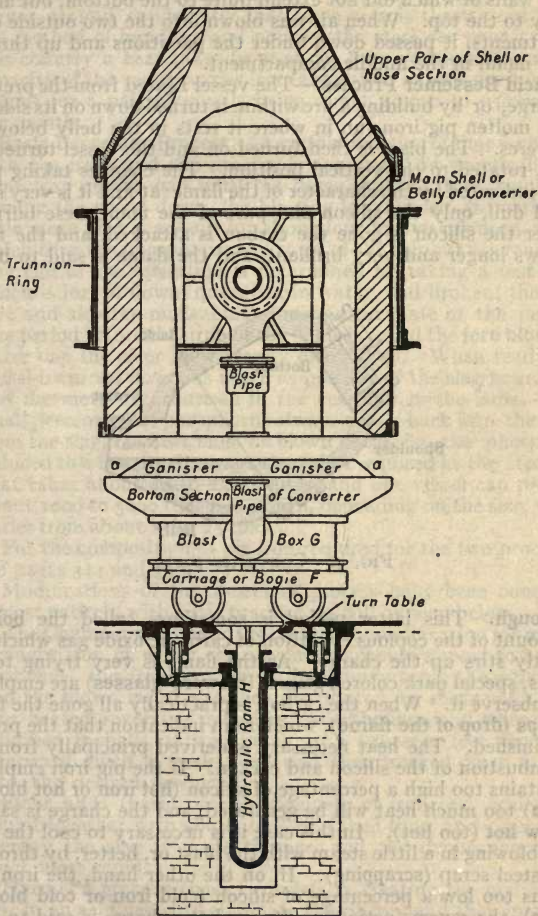


FIG. 3.—Section of concentric converter.
(Harbord and Hall, "Metallurgy of Steel".)

protected by hollow circular bricks similar to the sleeve bricks used for covering the stopper rod of a ladle. A process devised by Davy consisted in using an ordinary ladle covered with a lid

through which a tuyere passed nearly to the bottom of the ladle. One style of internally blown converter, called a **tank converter**, was a lined iron tank with usually three compartments, the dividing walls of which did not extend quite to the bottom, but all the way to the top. When air was blown into the two outside compartments, it passed down under the partitions and up through the metal in the middle compartment.

Acid Bessemer Process.—The vessel heated from the previous charge, or by building a fire within, is turned down on its side and the molten pig iron run in where it rests in the belly below the tuyeres. The blast is then turned on and the vessel **turned up**, *i.e.*, rotated to the vertical position. The changes taking place are indicated by the character of the flame: at first it is very short and dull, only the silicon and part of the manganese burning; after the silicon is gone the carbon is attacked, and the flame grows longer and very brilliant, and the flame is said to **break**

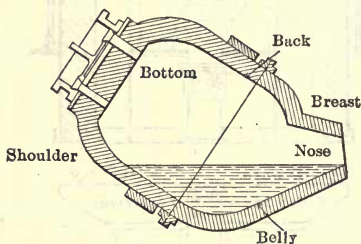


FIG. 4.—Converter parts.

through. This latter period is sometimes called the **boil** on account of the copious evolution of carbonic oxide gas which violently stirs up the charge. As the flame is very trying to the eyes, special dark colored glasses (**blowers' glasses**) are employed to observe it. When the carbon is practically all gone the flame **drops (drop of the flame)**, which is an indication that the process is finished. The heat necessary is derived principally from the combustion of the silicon and carbon. If the pig iron employed contains too high a percentage of silicon (**hot iron** or **hot blowing iron**) too much heat will be generated, and the charge is said to **blow hot** (too hot). In this case it is necessary to cool the bath by blowing in a little steam with the blast or, better, by throwing in steel scrap (**scrapping**). If, on the other hand, the iron contains too low a percentage of silicon (**cold iron** or **cold blowing iron**), the reverse action results, and the charge is said to **blow cold**. The necessary additions for deoxidizing the steel and giving it the right composition may be made in the vessel, or more usually in the ladle (see Recarburization). Metal which has been blown too long (**overblown**) is overoxidized, and hence inclined to be wild. The charge is said to have been **blown full** when prac-

tically all the carbon has been removed. If the blowing is stopped shortly before this point is reached, the metal is said to be **blown young** (rarely termed a **hard blow**). **Slopping** is where the metal surges around so violently that some of it is thrown out. For the method of handling and pouring the steel, see page 57. In this country a heat takes from about 8 to 15 minutes, and the capacity of the vessels varies from about 8 to 20 tons per heat, the output for a pair of vessels being about 40,000 to 65,000 tons per month.

Basic Bessemer Process.—A certain amount of lime is charged with the iron, and the process is conducted in practically the same way as the acid until the flame drops. Here, instead of turning the vessel down, the blowing is continued (sometimes a little more lime is added) for about four to five minutes, during which time the phosphorus and some of the sulphur are removed. The end of the operation is determined by taking a test ingot which is forged down, quenched in water, and broken; the fracture and also the malleability indicate the state of the process. The period before the drop of the flame is called the **fore blow**, the latter one the **after blow** (rarely **over blow**). When ready, the vessel is turned down, as much as possible of the slag poured off, and the metal recarburized in the vessel or in the ladle. As a small percentage of phosphorus always passes back into the metal from the slag, the heat must be **blown down**, *i.e.*, the phosphorus reduced to a lower percentage than that required in the steel. A heat takes about 20 to 25 minutes, and one vessel can produce about 1000 to 5000 tons per month, depending on the size, which varies from about 15 to 25 tons.

For the composition of pig iron required for the two processes, see pages 344 and 346.

Modifications of the Bessemer process have been concerned almost entirely with basic practice, as will be seen below.

The **Champin pneumatic process** was a modification for making wrought iron of which the advantages would appear to be very doubtful. Pig iron was blown in a converter in the usual way, and the blown metal was then distributed, by means of a ladle, into heated revolving cylinders, called **ballers**, and when it had solidified in balls, it was taken to a squeezer (see page 377), afterward given a wash heat, and then worked down as usual into the desired product.

Flohr adds (basic process) briquets of iron ore, scale, etc., bound together with about 10% of slaked lime, and claims that thereby the slag is made thinner, and the dephosphorization much more rapid.

Harmet's process (basic) consists in treating the molten pig, first in an acid vessel to eliminate the silicon, and then in a basic vessel to remove the phosphorus and the remaining impurities, care being taken that none of the silicious slag from the first vessel goes into the second; this is also termed **repouring process**, or **transfer process**.

The object of **George Lauder's Process** was to leave the desired amount of carbon in the bath at the end of the blow;

this was to be secured by first blowing and decarburizing only a portion of the charge, the remainder being added and blown only sufficiently to oxidize the silicon; the necessary amount of manganese was added as usual.

The **Massenez modification** of the basic process for treating high silicon metal consists in charging only part of the lime at the commencement of the process, and when the carbon flame appears (showing the silicon has been eliminated) as much as possible of the slag is poured off; the balance of the lime is then added, and the blowing completed.

In **Pettitt's process** (basic) iron oxide was used to effect the removal of the phosphorus, irrespective of the lining of the converter.

Rochussen and Daelen's process consisted in charging rich iron ore into the converter (acid) with the molten pig, and in lining the converter with it previous to the blow. The claim was made that the amount of blast required was largely diminished while the amount of steel was increased, but the excessive corrosion which must take place would more than offset any such advantages.

Schiebler's process (basic) consists in charging the metal and part of the lime in the vessel, and both the metal and slag are poured out when the first or phosphatic slag is formed. The treatment is completed in a reverberatory furnace having a basic or a neutral hearth, with the addition of the balance of lime or flux.

Stock Converter Process.—"This is a combination of an oil-melting furnace and small side-blown converter which has lately been erected at the Darlington Forge, and is said to be giving very good results. Materials are charged cold into the previously heated converter; oil fuel under a pressure of about 40 pounds to the square inch is supplied through flexible tubing to small tubes about $\frac{1}{2}$ of an inch in diameter, let into the main blast tuyeres, which are about 2 inches in diameter, and air for combustion, at a pressure of about $1\frac{1}{2}$ pounds, is admitted. When the charge is melted, which takes about $1\frac{1}{2}$ hours for a 3-ton charge, the converter is rotated to the blowing position, the oil shut off, and the bath of metal subjected to a blast of air on the surface for about 16 to 19 minutes, when the vessel is rotated into the teeming position and finishing metal added in the usual way. The waste gases pass through an economizer which, when the converter is in the blowing position, is opposite the mouth of the converter, and this economizer contains the blast pipes through which the blast passes on its way to the converter, and in passing through which, it is heated up to a temperature of about 800° F. Owing to the intense heat developed during melting and blowing with heated blast, the converter has to be lined with magnesite bricks, but low phosphoric iron is used and no attempt is made to dephosphorize. The advantages of this converter are that no impurities are taken up by the pig iron during melting, as in case of coke melting in cupolas, and owing to the hot blast being used a very high temperature is obtained, insuring a very fluid metal, which makes the

process particularly applicable for manufacture of steel castings. The vessel is mounted so that it can be rotated into the different positions for charging, blowing, and teeming" (F. W. Harbord in Harbord & Hall's "The Metallurgy of Steel," Vol. I, p. 78).

In the **Swedish process** the practice consists in taking the metal direct from the blast furnace without any intermediate mixer, and stopping blowing when the carbon has been reduced to the desired percentage, which is determined by the appearance of the sparks and the flame, and also by taking tests; a fixed converter is used (**Swedish fixed converter**).

Walrand's method for reducing the length of the after blow in the basic process was to add fluorspar with the lime to make the slag fusible early in the process. Although the time for the after blow was reduced, it was found that skulls were more likely to be formed.

In **Walrand and Delattre's modification** of the basic process, the metal, after being partially blown in an acid vessel, was run into a ladle intended to retain the silicious slag, and was then poured into a basic vessel where the blowing was completed.

Walrand and Legenisel's process, designed for use in baby Bessemer converters, consisted in the addition of ferro-silicon to the charge after a preliminary blow, to have the steel hot enough for making small and intricate castings.

In **Warner's process** (basic) iron ore, containing too much phosphorus for the acid, and too little for the basic process, is smelted with the addition of basic slag or phosphoric material to yield basic Bessemer pig. This is first desiliconized in one converter with soda ash and limestone, and then taken to a second, and finished as usual.

Ordinary converters vary from about 5 to 25 tons capacity per heat; for making castings, smaller sizes are generally employed, up to about 5 tons, and are called **baby Bessemer converters**; only in contradistinction to these, the ordinary sized ones are termed **large or big Bessemer converters**. Various modifications of converters, as mentioned below, have been made from time to time, but principally of a mechanical nature. Sir Henry Bessemer covered the ground so completely that a radical departure seems impossible.

In the **Cambier converter**, which is of small size, the blast enters at the side, not through tuyeres, but through holes in the lining which are inclined downward at a slight angle.

The **Clapp-Griffith converter** is essentially a small, high, side-blown, stationary vessel, with a spout or slag hole at such a level that the slag runs out of it during the boil. This feature appears to be the only real novelty.

The **Davy portable converter** was a small converter of the usual type, but was so constructed that, after the charge had been blown and made ready for casting, it could be carried to the molds and the metal poured directly into them without the intervention of a ladle.

Deighton's method of operating was to have at least two spare vessels, one of which would always be ready to replace a vessel

requiring relining, so the only lost time would be that necessary for changing.

In **Eldred's converter** the air pipe to the blowing engine is connected with an auxiliary furnace in such a way that either pure air or part air and part waste gases can be used for blowing the charge, the object being to control the temperature of the charge and prevent it from getting too hot.

The **Hatton converter** was claimed to be an improvement of the Clapp-Griffith, having a movable bottom, and regulating valves for the blast; it also lacked the slag spout or hole.

Laureau's converter was a small, tilting, side-blown converter, with the tuyeres placed high, and set in a separate ring which could be easily removed and replaced, as the lining in the neighborhood of the tuyeres is worn away most rapidly.

In the form devised by **T. Levaz**, the converter, which is of small size, and tilting, with side blast, has the upper part enlarged to form a pocket to receive the metal when the vessel is turned down. **Murdock's converter** has essentially the same feature.

The **Paxson-Deemer converter** is a small, tilting, side-blowing vessel, the tuyeres being placed at the level of the metal so the blast strikes it partly above and partly below the surface.

Raapke's converter is of small size and of the fixed type, with tuyeres on one side and tapping hole on the other. Oxygen is added to the blast, and means are employed for utilizing the heat evolved for heating the blast and for preparing the oxygen.

The **Robert converter** has a D-shaped cross-section with horizontal tuyeres, slightly inclined to the radial, on the flat side only, giving the bath a whirling motion; it is of small size and is tipping. The original form was circular, and was called the **Walrand converter**, later modified, the **Walrand-Delattre**, this being further modified by Robert to the form described.

In **Sherk and Rutter's converter**, which is tilting, there are a number of tuyeres so placed that only a small portion of the blast enters below the surface of the metal, and by tilting the converter the proportion may be modified.

In the **Stoughton or long tuyere type**, which is a side-blown converter of small size, the tuyeres are on one side, discharging the blast immediately at the surface of the metal. The lining on the tuyere side is thicker than elsewhere, which serves to increase the time the vessel can remain in service without relining, and also insures better direction of the blast.

Thomas' converter was similar to a stationary converter in form, but was mounted on rockers so it could be inclined with less costly mechanism than that required by the regular tilting type.

The **Tropenas process** employs a small, tilting, side-blown converter with two rows of tuyeres on one side. The lower set directs the blast on the surface of the metal, and the upper set (called **tuyeres of combustion**) supply air for burning the carbon monoxide to carbon dioxide, thereby getting a greater heat efficiency.

The **Wills converter** is a small side-blown vessel consisting of two sections, a ladle section and a dome section; the tuyeres are arranged to give the metal a rotary motion. The metal may be tapped (*a*) out of a hole at the bottom of the ladle section, (*b*) through the nose by turning the converter down, or (*c*) the ladle section can be removed, and the metal poured directly from this into the molds.

The **Witherow converter** is very similar to Hatton's, but claimed to be simpler as regards the controlling mechanism for the blast.

Witnufft's converter was an early type of fixed converter with tuyeres on each side inclined downward.

The **Zenzen converter** is a small, tilting, side-blown converter varying only in slight details from others of this type.

Bessemer Steel.—Steel made by the Bessemer process.

Besson.—"Iron of Bessemer:" name suggested for iron or low-carbon steel produced by the Bessemer (pneumatic) process.

Best or B.—A brand of wrought iron plate or bar equivalent to No. 3 quality, or that grade which is just superior to the commonest. It is obtained by piling, reheating, and rerolling either No. 1 and No. 2 iron, or all No. 3 brands. The best plates of the first-class houses are, however, equal to the best, best best, and treble best of other firms (Horner).

Best Best or B. B.—A brand of wrought iron plate or bar indicating a superior quality obtained by piling, reheating, and rerolling best or No. 3 bars (Horner).

Best Best Best or B. B. B., or Treble Best.—A brand of wrought iron plate or bar indicating the best quality of iron made. It is obtained by repiling, reheating, and rerolling the best best quality (Horner).

Best Bar.—See page 378.

Best Charcoal Iron.—Wrought iron made by some charcoal-hearth process.

Best Tap (Eng.).—See page 376.

Beta I; Beta II.—See page 280.

Beta (β) Iron.—See pages 264 and 272.

Beta Iron Theory; Beta Theory.—Of hardening: see page 279.

Béton (French).—Concrete béton armé, reinforced concrete.

Betty (Eng.).—A crowbar.

Bibasic.—See page 87.

Bickley Mill.—See page 417.

Biedermann and Harvey Process.—See page 317.

Big Bessemer Converter.—See page 23.

Billet.—See page 411.

Billet Chute.—A chute or inclined bin for loading billets on cars, and generally operated in connection with a billet conveyor.

Billet Conveyor.—A device for handling billets, usually consisting of an endless chain of small rollers passing around and driven by drums.

Billet Mill.—See page 411.

Billet Test.—See page 483.

- Billeting Rolls.**—See page 411.
- Billing Process.**—(1) Of casting: see page 60; (2) for fluid compression: see page 63.
- Bimetallic Thermometer.**—See page 205.
- Bimetallic Wire.**—See page 509.
- Binary Alloy.**—See Alloy.
- Binary Compound.**—See page 88.
- Binary Theory.**—See page 89.
- Binding Coal.**—See Coal.
- Binding Material.**—A material used to bind (usually) refractory substances together; (1) by combining with them, as a small percentage of lime in silica bricks, (2) by being more fusible, as clay in sand, and (3) carbonaceous compounds which lose their volatile matter on heating, such as sugar, flour, oil, etc.
- Bink Process.**—See page 71.
- Binocular Microscope.**—See page 285.
- Bird's Mouth Weld.**—See page 502.
- Birmingham Wire Gage.**—See page 188.
- Bismuth.**—Bi; at. wt., 208.5; melt. pt., 268.3° C. (515° F.) sp. gr., 9.75. A white metal with a faint reddish tinge. Usually occurs in the uncombined condition. It is not of importance in the manufacture of steel, and appears to act much like antimony.
- Bite.**—Of rolls: see page 407.
- Bituminous Coal; Shale.**—See Coal.
- Black Annealing.**—See page 431.
- Black Band.**—A kind of iron ore: see page 244.
- Black Body; Black Body Temperature.**—See page 207.
- Black Center.**—See page 178.
- Black Clay.**—See page 302.
- Black Edged Plate.**—See page 432.
- Black Fracture.**—See page 178.
- Black-heart Castings; Malleable.**—See page 258.
- Black Heat; Hot.**—Color temperature: see page 210.
- Black Iron Objects.**—See page 364.
- Black Iron Sand.**—See page 244.
- Black Japan.**—See page 365.
- Black Loam.**—See page 301.
- Black Oxide (rare).**—Oxide (of iron).
- Black Patch.**—See page 432.
- Black Pickling.**—See page 431.
- Black Plate.**—See page 431.
- Black-red Heat.**—Color temperature: see page 210.
- Black Sand.**—In a foundry, old sand.
- Black Temperature.**—See page 207.
- Black Wash Coating.**—See page 298.
- Blacking; Blacking Bag.**—See page 298.
- Blacklead Blacking.**—See page 298.
- Blacklead Crucible.**—See page 111.
- Blair; Blair-Adams Process.**—See page 137.
- Blank.**—A piece of metal prepared especially to be manufactured into some particular object.

Blanket.—In connection with a flame, to reduce the proportion of air to make it as reducing as possible.

Blaseofen.—See page 147.

Blast.—The name given to air under pressure used for purposes of combustion, etc., as in the blast furnace or the Bessemer converter; in some cases for cooling purposes, as in the case of tools. If preheated, it is termed **hot blast** or **warm blast**; if not preheated, **cold blast**. A blast under considerable pressure is sometimes referred to as a **cutting blast**; if weak, a **soft blast**.

Blast Box.—See page 17.

Blast Furnace.—A shaft furnace (see page 181), in its early days called a **high furnace**, supplied with blast for producing pig iron by smelting iron ores. It is continuous in operation, the solid raw materials being charged at the top, and the molten pig iron and slag collected at the bottom and tapped out at intervals. Large furnaces are about 80 to 100 feet high; have an output up to 600 or 700 (commonly 300 to 500) tons per day, and employ blast at a pressure of 5 to 25 (usually 10 to 15) pounds per square inch, and at a temperature of about 900° to 1400° F. (485° to 760° C.). The modern equipment consists essentially of the furnace proper or **stack**; powerful blowing engines for compressing the air for the **blast**; **stoves** for preheating the blast; appliances for charging the raw materials; a **cast house** for disposing of the molten iron; and a power station.

Stack.—There are three well defined divisions, usually circular—practically now never oval or square—in section. At the bottom—is the **hearth** (well, laboratory, or **crucible**) of cylindrical shape; above this the walls diverge, forming an inverted truncated cone, called the **bosh** (also the name for the greatest diameter of the furnace), above which the walls converge to the **top** (**throat** or **mouth**), forming another truncated cone set upright. In a furnace with **saucer bosh** or **belly walls**, the walls above the bosh, instead of being straight, are slightly convex. The design (**lines**) of a furnace depend both upon the nature of the ore and the kind of product desired. For the fine, soft Mesaba ores it is usual to sharpen the angle of the bosh, decrease the height of the bosh, and increase the diameter of the hearth; for example, where high silicon is desired in the pig, the diameter of the hearth is decreased. The furnace is built of fire-brick (cold-blast furnaces are also built of stone), usually but not always incased in a steel jacket extending part or all the way up. The fire-brick portion is referred to as the **lining**. The section above the bosh is supported on a **mantle** (**mantel**) **ring** (**lintel plate**) and columns. Up to a certain distance from the bottom of the furnace the walls are protected from corrosion by **cooling plates** of bronze or other metal through which water circulates; sometimes water is caused to flow down the outside. Within the past few years **thin-lined furnaces** have been constructed where the thickness of the lining has been greatly reduced; the lining is entirely cased in steel plates and the cooling plates are continued practically up to the top; the object is the better maintenance of the lines, and incidentally to save on the cost of construction.

Blast.—Formerly the blast was always used cold (**cold blast**) but this practice is now restricted to a few small furnaces as a rule employing charcoal for fuel. **Hot blast** was introduced by Neilson about 1828 and effected a great economy in fuel. The blast temperature varies from about 900° to 1200° F. (480° to

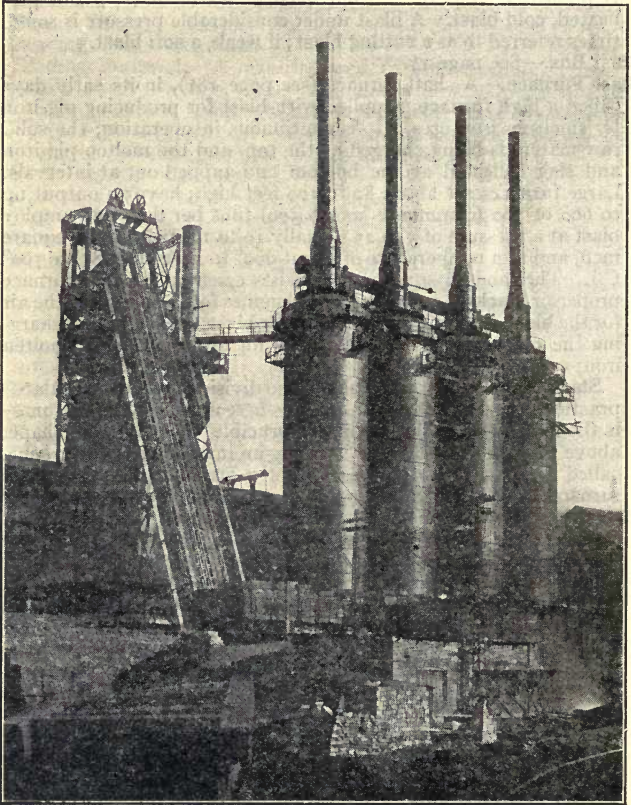


FIG. 5.—Blast furnace and hot blast stoves.

650° C.) in this country, and up to about 1600° or even 1800° F. (870°; 980° C.) in some European practice. The average temperature carried on furnaces burdened with Mesaba ore seldom exceeds 1100° F. (595° C.), ranging far lower than that commonly applied in European practice and lower also than on most of our

eastern furnaces using magnetic ores, due to the Mesaba ores being more easily reducible (Brassert).

Dry Blast.—The practical application of this to blast furnace work is comparatively recent and is due primarily to the Gayley process which will be described later, after considering the general conditions involved.

The blast does not consist solely of oxygen and nitrogen, but contains, in addition to these elements, varying amounts of moisture (among other substances) depending upon the temperature and the degree of humidity of the air. The amount of moisture per cubic foot of air (at atmospheric pressure) will vary from less than 1 grain in winter to over 8 grains in summer, and while even this latter amount might, at first glance, seem inconsiderable, a brief consideration of the volume of air passing through a modern furnace will show that this is far from being the case. "With air containing 1 grain of water per cubic foot, there is passed into the furnace, for each 1000 cubic feet used per minute, practically 1 gallon of water per hour. A furnace of average size in the Pittsburgh district consumes about 40,000 cubic feet of air per minute, which would pass into the furnace 40 gallons of water per hour for each grain of moisture contained in a cubic foot of air" (Gayley).

The amount of moisture varies not only from day to day but from hour to hour, and numerous investigations have shown that

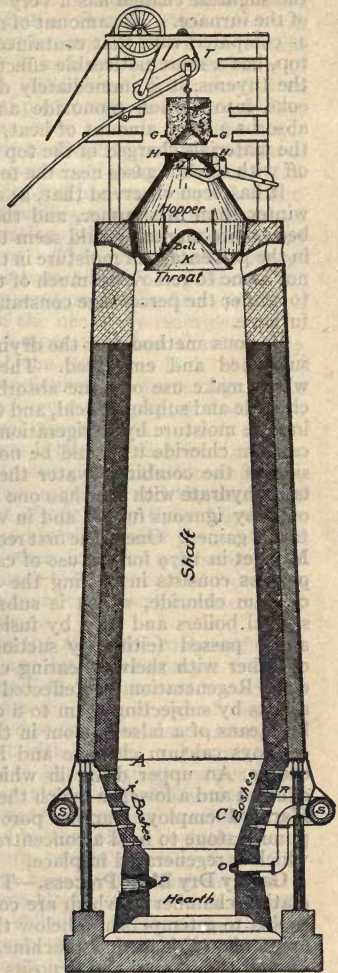


FIG. 6.—Section of one of the Duquesne blast furnaces.

the slightest change has a very marked effect upon the working of the furnace. The amount of moisture from the air, while small as compared with that contained in the materials charged in the top, has a more noticeable effect for the reason that, entering at the tuyeres, it is immediately decomposed by the incandescent coke into carbon monoxide and hydrogen, a reaction which absorbs a large amount of heat, while the moisture contained in the materials charged in the top is simply evaporated and driven off with the hot gases near the top of the furnace.

It has been observed that, as a rule, furnaces worked better in winter than in summer, and the reason this difference has not been more marked would seem to be on account of the variation in the percentage of moisture in the air. The aim of the process is not alone to remove as much of the moisture as possible, but also to render the percentage constant, and with it the working of the furnace.

Various methods for the drying (**desiccation**) of air have been suggested and employed. These may be divided into those which make use of some absorbent substance, such as calcium chloride and sulphuric acid, and those which are based on extracting the moisture by refrigeration. In connection with the use of calcium chloride it should be noted that before complete expulsion of the combined water there exists what is known as the **tardy hydrate** with less than one molecule of H_2O ; this is removed only by igneous fusion, and in view of the added cost no advantage is gained. One of the first records is that of a patent granted to **Mushet** in 1879 for the use of calcium chloride, etc. The **Fryer process** consists in passing the air over broken pieces of fused calcium chloride, which is subsequently regenerated partly in special boilers and then by fusion. In the **Cremer process** the air is passed (either by suction or under pressure) through a chamber with shelves bearing calcium chloride, sulphuric acid, etc. Regeneration was effected without removal of the drying agents by subjecting them to a current of hot air or waste gases by means of a false bottom in the shelves. The **Elsner process** employs calcium chloride and is carried out by means of two drums: An upper drum in which the desiccation of the air is effected and a lower in which the calcium chloride is regenerated. **Harbord** employs various porous substances such as peat or pumice stone to hold a concentrated solution of calcium chloride which is regenerated in place.

Gayley Dry Blast Process.—The apparatus consists of a refrigerating chamber in which are coils of pipe through which brine, cooled to a temperature below the freezing point of water by an ammonia refrigerating machine, is passed. The air circulates around these pipes and deposits on them its moisture as snow or ice. When the deposit becomes too thick (about every three days) it is melted off by passing heated brine through the pipes. The desiccated (cooled) air is then introduced into the blowing engines and goes thence, in the usual manner, through the stoves and into the furnace.

Dry blast was first tried with Isabella Furnace No. 1 of the

Carnegie Steel Company, on August 11, 1904. The dry blast was not introduced all at once, but at first only one-third was used. At the same time the burden was gradually increased until, at the end of two weeks, it had reached an increase of 20%. It was found that the saving in coke amounted to about 400 pounds per gross ton of pig iron produced on a former consumption of a little less than 2200 pounds. As the water extracted from the blast amounted to about 69 pounds per ton of iron, corresponding to about 80 pounds of coke, this would not account for all the saving. This subject has occasioned considerable discussion by practical blast furnacemen and scientists, and many and various are the explanations which have been offered to account for the results obtained. That now generally recognized as the correct solution was advanced by J. E. Johnson, Jr., and is based upon a critical temperature in the furnace which must be surpassed to accomplish the necessary reactions. The difference between this critical temperature and that actually attained marks the efficiency of the furnace. It is therefore obvious that a slight increase when figured as a percentage of the temperature above the critical is very much greater than when figured as a percentage of the actual temperature.

Among the attendant advantages is the fact that, owing to the greater density of the air as introduced into the blowing tubs, fewer revolutions of the engines are required, and the decreased cost from this nearly offsets that of operating the refrigerating plant. Another advantage is found in the smaller percentage of flue dust produced, particularly when fine ores are being used. In the case of the Isabella Furnace this was reduced from 5 to 1%. The process is in use at a number of blast furnace plants both in the United States and abroad.

In the Miles dry blast process the air, after compression, is desiccated by cooling in two steps by water sprays: first by ordinary river water, and second, by refrigerated water. It depends on the fact that, to secure the same degree of desiccation, the cooling need not be carried so far after compression as if uncompressed. It is claimed that with blast at 10 pounds pressure the moisture can be reduced to about 1.38 grains per cubic foot of air when refrigerated water is used; and still further when brine (which can be cooled to a lower temperature) is substituted.

The blast is introduced near the bottom of the bosh through a number of pipes or tuyeres (twyers, tweers), usually 8 to 16 in number, which are protected from burning by being encased in water-cooled metal castings, tuyere blocks (tuyere arch cooler). The opening in the furnace wall is called the tuyere arch, and the space between this and the block, the breast (water breast). Depending upon the point at which the cooling water is introduced, the tuyere is said to be side-fed or bottom-fed. The overhang of a tuyere is the amount it projects into the furnace beyond the inner wall. The Scotch tuyere is of cast iron, with a wrought-iron coil of pipe, for the cooling water, cast in the walls. The Lancashire tuyere is a hollow truncated cone with double walls, the cooling water flowing between them. An open spray

tuyere is somewhat similar to the above, but the rear end is open (**open tuyere**), and the walls are kept cool by jets of water from perforated pipes inside. In the **spreader tuyere**, which is of a somewhat similar type, the water is distributed over a sheet to cool the upper part of the shell, a jet of water cooling the nose, and the water running back over the bottom to the outlet. A **vacuum** or **exhaust tuyere** is one from which the water is sucked out, instead of being forced through, to lessen the leakage in the furnace if the tuyere breaks. The blast from the stoves is led into a large pipe (**bustle pipe**) surrounding the furnace and above the tuyeres with which it is connected.

At a point near the top of the hearth is a hole for tapping the slag (**slag notch, cinder notch, flushing hole, monkey**), and lower down and to one side is the **iron notch, metal notch** or **tapping hole** for tapping out the molten iron. In one type of furnace there was a plate (**guard plate**) over the cinder hole with the tapping hole in it. In modern furnaces the hearth is entirely within the furnace, and is called a **closed hearth**, the contents being tapped through a hole in the wall. This arrangement was first introduced by Lürmann, and was called a **closed front (Lürmann front)**. "It was formerly the custom to have an **open fore part (open front)**. In front of the furnace there was an arched-over opening extending from the furnace bottom to a little above the level of the tuyeres; the sides and roof of this opening formed a cavity known as the **fore hearth**. A wall of fire-brick called the **dam**, was carried to the tuyere level; it formed the back of the fore hearth, and was supported by a stone (**dam stone**) or cast-iron **dam plate**; in the dam plate was a vertical slit, which was stopped with loam, and which allowed of a tapping hole being made at any convenient level, while the excess of cinder ran off through a semicircular cinder notch. The arch above the dam was called the **tymp (timp)**; it was kept in position by a **tymp plate (tymp stone)** of cast iron, and generally cooled by running water" (Turner). In **Lürmann's closed front arrangement** the slag was tapped through a water-cooled tuyere (**scoria block**) situated in a water-cooled cast-iron plate (**scoria plate**).

At the top of the furnace is the charging arrangement consisting usually of two **bells**, a large one below, and a smaller one above, each fitting in a **hopper (bell and hopper, cup and cone)**, and so arranged that only one is lowered at a time, thus preventing the escape of gas. Various forms of **ore-distributing devices (distributors)** have been designed to secure an even distribution of the charge within the furnace; for example there may be an apron either fixed (**Killeen distributor**) or movable (**McDonald distributor**) between the large bell and the **inwall** (interior wall) to deflect the descending charge. A **revolving top** is where the chute or bell is revolved a certain amount for each addition; the older form is accordingly distinguished as a **stationary top**.

Charging.—The ore is kept in huge piles (**stock pile**) in a yard, and is handled by large traveling cranes (**ore bridge, gantry crane**). It is loaded into bins from which it is run into small hopper-bottom cars (**larry, lorry**) equipped with scales for

weighing it, and from these is dumped into the buckets or boxes (**skips**) which are hoisted to the top of the furnace up an inclined bridge (**skip bridge**), and dumped automatically on the upper bell. Depending upon whether there is a single or a double track (in the latter case one skip ascending while the other is descending) it is **single** or **double-skip charging**. The limestone is similarly handled; the coke is measured by volume (occasionally weighed), the contents of the skip representing a definite weight. This method is known as skip charging. The older method, now seldom employed for new furnaces, is to weigh the materials in wheel-barrows which are raised to the top of the furnace by an elevator (**hoist, lift**), and dumped around the bell by hand (**barrow charging**). One complete unit or charge of ore, coke, and limestone is called a **round**.

Blast Furnace Gas.—The gas is taken off at the top of the furnace through one or more openings connecting with a large pipe (**downcomer**) which leads to a large chamber (**dust catcher, dust chamber**) on the ground, where, the direction of the gas being changed, most of the dust (**flue dust**), consisting of a mixture of fine ore and coke together with a little lime, carried over mechanically, is deposited. As a rule no water is employed (**dry dust catcher**), but the gas, if to be used for gas engines, is later purified by being led through a chamber (**scrubber**) where it is sprayed with water and passed over moistened bricks. In such case the gas from the dust catcher is known as **raw** or **dirty gas**; after a preliminary treatment, as **primary gas**; and after final treatment, as **clean gas** or, in some cases, **secondary gas**. There are various systems; **dry cleaning** without water, and **wet cleaning** or **washing** with water sprays. In the latter process, at present more commonly used, the dust, collected in reservoirs as mud, is called **sludge** or **pond sludge**. **Compound gas** was a name suggested for blast furnace gas passed through a coke oven, whereby it was claimed a gas was produced containing less carbon dioxide and less nitrogen than when used separately. A marked increase in efficiency is shown when purified gas is used for heating the stoves. Part of the gas is used for heating the stoves, and part for burning under boilers or in gas engines. Owing to the high percentage of nitrogen the calorific power of the gas is low (85 to 100 B.T.U.). Its composition is approximately:

Carbon monoxide,	24 %	by volume,	24 %	by weight.
Carbon dioxide,	12 %	“ “	17 %	“ “
Nitrogen,	60 %	“ “	58 %	“ “
Hydrogen,	2 %	“ “	0.2 %	“ “
Hydrocarbons,	2 %	“ “	0.8 %	“ “

The top of the furnace may be provided with a number of counter-weighted doors (**explosion doors**) which open automatically to relieve any excessive pressure of gas within, or these may be omitted (**closed top**) and the top designed of sufficient strength to withstand this, thus preventing solid material from being blown out. A door or valve which can be opened from the ground

to relieve the pressure is called a **bleeder**. In early practice, when the gas was allowed to escape the furnace had an **open top**, the gas burning on coming in contact with the air. In this case a chimney (**tunnel head**) was provided to carry it away from the charging hole for the protection of the workmen.

Stoves for heating the Blast.—These are cylindrical in form, up to 100 feet high or a little over, and consist of a steel or iron shell lined with fire-bricks which form a number of flues or passages. Depending upon the number and the arrangement of the flues, they are known as **two-pass stoves**, **three-pass stoves**, etc. They are regenerative (see page 203) in principle, gas being introduced and burned at the bottom, the products of combustion going out at the top, and the blast being forced through in the opposite direction, the two operations not occurring at the same time. A large furnace generally has four stoves, three of which are being heated (**on gas**) while the fourth is heating the blast (**on wind**). The earlier stoves had cast-iron pipes (**pipe stove**, **metal stove**, or **direct firing stove**) heated externally, and through which the blast passed continuously on the recuperative (see page 204) principle. The pipes sometimes had the shape of the curved butt of a pistol, and were then known as **pistol-pipe stoves**. In using preheated air (**hot blast**), the temperature is sometimes regulated by **leveling**, *i.e.*, admitting a certain proportion of cold air to the blast when a fresh stove is put on, and then gradually cutting it down to nothing by the time the stove is taken off. A device suggested, called an **equalizer**, resembles a fire-brick stove, except it is used continuously, the fire-brick on the inside serving to absorb heat from the blast if it is too hot, and give it up again if the blast is too cold, thus keeping the temperature nearly constant. To remove the moisture in the blast, and so get greater efficiency from the furnace, the blast, before going to the stoves, may be passed over pipes in which iced brine is circulated, and on which the moisture is deposited as ice: this constitutes the **Gayley dry blast process**.

Operation.—The charge, consisting of ore, coke, and limestone (coal or charcoal rarely replace the coke), is put in at the top of the furnace, at nearly regular intervals, the operation being continuous. The ratio which the ore bears to the total charge is known as the **burden (ore burden)**. If this ratio is too great or too small the furnace is said to be **overburdened** or **underburdened** respectively. With ordinary ore, containing about 50% of iron, the proportions of materials entering and leaving the furnace, based on one ton of pig iron produced, are approximately as follows, expressed in tons:

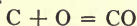
Materials entering the furnace	Materials leaving the furnace
Ore..... 2	Pig iron..... 1
Coke..... 1	Slag..... 1½
Limestone..... ½	Gases..... 6
Air..... 4	
Total..... 7½	Total..... 7½

It will be noted that the air constitutes over one-half of all the materials going into the furnace, while the escaping gases represent over three-quarters of the material leaving the furnace. This difference is due to the fact that the oxygen, carbon and certain other substances which enter the furnace as solids are converted into the gaseous state by chemical reactions which they undergo. The height of the materials in the furnace is maintained at a constant level called the **stock line**. This is determined either by thrusting a rod through a hole in the top by hand, or by an automatic device (**stock indicator**) consisting essentially of a rod connected to a wire which passes over a pulley and leads to a dial or other device on the ground. The blast entering the furnace near the bottom burns the fuel which supplies the heat as well as the carbon necessary for the reduction (deoxidation) and carburization of the ore, at the same time rendering it and the slag molten. If, owing to improper working, the materials become pasty (**gobbing up or engorgement**), they may then (a) stick to the sides forming a **ring**, (b) arch across producing a **scaffold or bridge**, or (c) form a large mass called a **skull**, thereby preventing the descent of the charge above, and the furnace is then said to be **hanging**. When this obstruction gives way, allowing the superincumbent mass to fall, it is called a **slip**. Attempts to break down (**blow down**) the scaffold may be made by alternately decreasing and increasing the pressure of the blast (**jumping**) or also by increasing the temperature (**coddling**). To bring down a scaffold and other obstructions, a **torpedo (blast furnace torpedo)**, containing an explosive, may be introduced through one of the tuyeres or through a hole cut in the wall of the furnace and discharged. Sometimes there seems to be too much lime on the furnace for the given condition, and still it is showing a **lean cinder** (slag low in lime); this is what is commonly termed **not working her lime**, and is caused by a high fusion zone accompanied by a cold bottom and high top heat (Imhoff). On the other hand a slip will often bring down too much limestone so that it will cause the slag to be infusible or pasty; this is known as a **lime set**. If the heat generated within the furnace is not sufficient, the furnace is **working cold**, and may result in scaffolds (**cold scaffold, cold hanging**), which may also be occasioned by the furnace **working hot** (too hot), called **hot scaffold or hot hanging**. When the charge is composed of materials of such a size and nature that the blast passes through them (they are said to **take the blast**) easily; the charge is **open**. On the other hand, when the blast does not ascend uniformly, the condition is called **blast wandering**. The action of the charge in opening up irregular openings for the blast is known as **channeling**, a term also sometimes applied to the abrasive action of the charge on the furnace walls giving rise to grooves or channels. If the penetration of the blast, in the region of the tuyeres, is insufficient, it is likely to cause **pillaring**, a condition where there is a pillar of cold stock extending up through the middle of the hearth and surrounded by an annular column of activity. When a portion of the wall of the furnace, above the water-cooled part, becomes unduly heated,

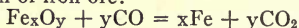
with the danger of burning through, the furnace has a **hot jacket** or **hot spot**. Depending upon the reactions taking place in different regions or **zones** of the furnace, they are called **zone of heat interception**, near the top; farther down, **zone of carbon deposition**; still lower, **zone of incipient fusion**; then **zone of slag formation**; and, at the tuyeres, **zone of complete fusion**.

In practice there are four important reactions which may be given as follows:

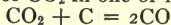
- (1) Oxidation of coke:



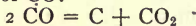
- (2) Reduction of iron ore:



- (3) Decomposition of CO_2 in one or more ways, *e.g.*:



- (4) Decomposition of CO :



(4) Can proceed only where the temperature lies between 400° and 600° C. (750° and 1110° F.); above 600° C. (1110° F.) it proceeds with great slowness (Mathesius). The **heat balance** of a blast furnace is an analysis and statement showing the amount and sources of heat entering the furnace either as sensible heat in the blast, etc., or what is generated within by the combustion of fuel; this must of course equal the amount of heat leaving the furnace in different forms (sensible or latent) in the gases, slag and iron, and by radiation through the furnace walls.

Casting.—The cinder is tapped out at more frequent intervals than the iron (it has been suggested to tap the iron out continuously by a syphon-like arrangement), those before the tapping of the iron being called **flushes**. The operation of tapping the iron is usually known as **casting**, and the yield of iron, the **cast**. If part of the iron does not come out readily, it is said to **lie back**. When the hearth is nearly empty, part of the blast escapes with a roaring sound, and the furnace **blows**. The iron is led through troughs or **runners** to the **pig beds** if it is to be sand cast (see page 342), or into ladles if the metal is to be used direct in the molten condition (**direct metal**), or is to be cast into pigs in a pig machine. The small amount of slag which comes out of the iron notch is separated from the iron by means of a depression in the main runner, near the furnace, called the **skimmer**, the iron here flowing under a clay-washed cast-iron plate or bridge set vertically, the slag which is much lighter being backed up and flowing off at one side. The iron from the main runner is prevented from entering the side runners, until desired, by **shutters**, which are implements of cast iron washed with clay, shaped like a spade with a rod cast in them for a handle, and which are thrust down into the junction of the two runners. (For the method of handling the iron and the slag, see Pig Machine and Slag Machine.) The **cinder notch** is opened up by a pointed bar, and closed by holding another bar, with an enlarged end, in the hole until the cinder chills against it. The **iron notch** is opened by drilling out

the clay with which it is closed, and finally driving in a pointed bar. It is closed by slackening the blast, and then packing in balls of clay, either by hand with bars, or by a machine called a **gun, notch gun, or blast furnace gun**. This machine consists of two cylinders tandem, each containing a piston on the same rod, the first being actuated by steam or compressed air, and the second serving to drive the balls of clay, which are thrown in at a hole in the top of the cylinder.

When a furnace is started up it is said to be **blown in**, and when it is taken out of commission it is **blown out**. Where the operation is stopped temporarily by **taking off** (stopping) the blast and closing up all the openings, it is **banked** (damped down);

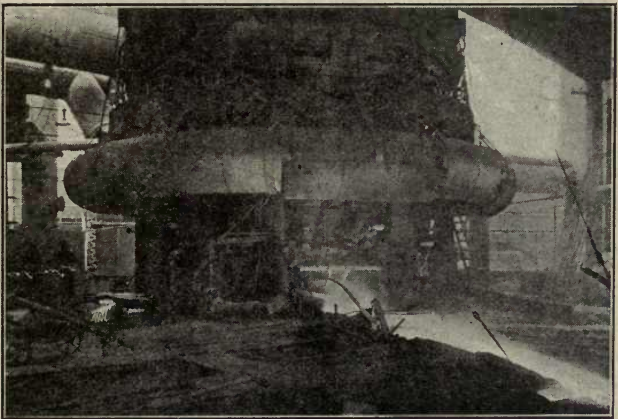


FIG. 7.—Blast furnace casting.

when operating, it is **in blast**. The methods employed for blowing in a furnace may differ in certain details, but the following description covers the general practice (sometimes referred to as **scaffolding down**). A wooden scaffold is erected inside the furnace at a height a little above the level of the tuyeres. On this is piled on end one or more tiers of cordwood. The hearth is then filled with coke up to about the bottom of the tuyeres, and the space between this and the scaffold is filled in with thoroughly dried kindling wood in order to ignite the mass from the outside through one of the tuyeres. A considerable amount of coke is dumped in at the top of the furnace, the last portion being mixed with some finely broken clay which, when melted, serves to warm up the tapping holes. Very little ore and flux are added for some time, the proportion being increased gradually until the full burden is reached after a day or two. After a furnace is blown

out, accretions (**scars**) may be found on the walls, consisting of partially fused matter and pieces of coke, limestone, etc. In the hearth, usually where the bottom has been worn away, may be found a metallic mass, called a **salamander** (*q.v.*) or **bear**, which consists of pig iron containing nitrocyanide of titanium, and usually also there is iron with less carbon and silicon than in the regular pig iron. Under the superintendent, the operations are conducted by a **blower** who has general charge of one or more furnaces, the **hot blastman** who has charge of the stoves, and the **keeper** who attends to tapping the furnace and getting the runners, molds, etc., in shape.

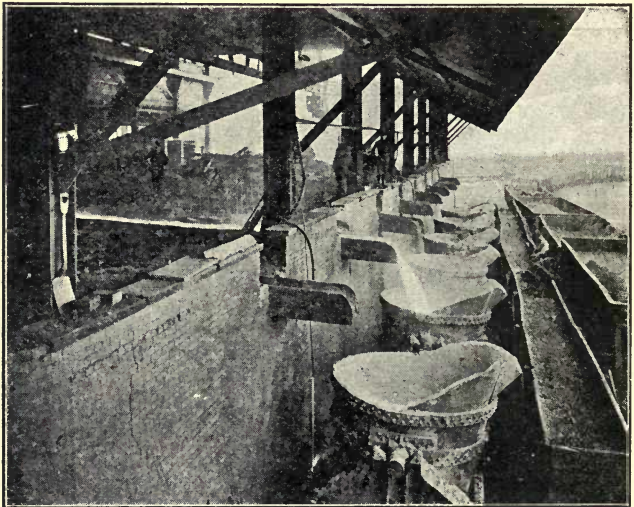


FIG. 8.—Blast furnace casting—Running the molten pig iron into ladles for use as direct metal.

J. E. Johnson's Process is a method of **spheroidizing graphite** in cast iron. This is effected "by bessemerizing the iron at a relatively low temperature, and thus removing its silicon with but little removal of carbon but with important absorption of oxygen. The graphite of the resultant produce assembles in large part in relatively harmless spheroids, instead of spreading out as usual into broad continuity destroying flakes. He then remelts his iron, adding enough silicon to bring about the degree of graphitization desired in the castings themselves. The spheroidizing tendency persists through this remelting, so that the graphite in the resulting castings also is in compact masses" (Howe).

Classification of Furnaces.—According to the methods of operating:

- I. Fuel used:
 - (a) **Coke furnace.**
 - (b) **Charcoal furnace.**
 - (c) **Anthracite furnace** (a certain proportion of the fuel is coke).
 - (d) **Coal furnace** (Scotland only).
- II. Blast:
 - (e) **Hot blast furnace.**
 - (f) **Cold blast furnace.**
- III. Charging:
 - (g) **Barrow charging** (hand).
 - (h) **Skip charging** (mechanically).

Merchant furnaces are those whose product is for sale.

- Blast Furnace Coke.**—See page 96.
- Blast Furnace Gas.**—See page 33.
- Blast Furnace Gun.**—See page 37.
- Blast Furnace Lining.**—See page 27.
- Blast Furnace Reactions.**—See page 36.
- Blast Furnace Slag Cement.**—See Slag Cement.
- Blast Furnace Torpedo.**—See page 35.
- Blast Temperature.**—See page 28.
- Blast Wandering.**—See page 35.
- Blau Furnace; Blauofen.**—See page 135.
- Blazed Pig.**—See page 343.
- Blazing off.**—See page 231.
- Bleckley Mill.**—See page 417.
- Bled Ingot.**—See page 58.
- Bleeder.**—See page 34.
- Bleeding.**—(1) Of ingots which have not entirely solidified, so that when they are rolled or forged, the solid skin is broken and the fluid portion forced out; (2) in a furnace lined with cinder, melting or fluxing out a part of the lining when it becomes too thick, by raising the temperature; (3) in puddling: see page 377; (4) red streaks of rust on boiler scale, indicating corrosion in the metal underneath.
- Blending.**—Mixing ores to get a suitable composition.
- Blind Pass.**—See page 405.
- Blind Tuyere.**—See page 17.
- Blister.**—(1) In cemented steel; see page 71; (2) suggested as a shorter term for blister bar or blister steel; (3) an excrescence on the surface of steel produced by a gas bubble present or found beneath the surface while the metal is hot and plastic; very fine blisters are called **pinhead** or **pepper blisters**.
- Blister Bar, Metal, Steel.**—See page 71.
- Block.**—(1) An ingot (rare); (2) the solid brick-work surrounding the port of a regenerative furnace; (3) a revolving drum, slightly tapered from bottom to top, for drawing wire through the die, and on which it is wound: see page 508.
- Block Furnace.**—See page 134.

- Block Movement.**—See page 281.
- Block Oven.**—See pages 95 and 134.
- Blomary** (obs.).—Bloomary: see page 134.
- Blood-red Heat.**—Temperature color: see page 210.
- Bloodstone.**—See page 243.
- Bloom.**—See pages 135 and 411.
- Bloom Steel** (Eng.).—Steel rolled into blooms.
- Bloomary; Bloomery; Bloomary Process.**—See page 134.
- Blooming Mill; Rolls.**—See page 411.
- Blow.**—(1) To force air into or through; (2) of a blast furnace: see page 36; (3) of castings: see page 55.
- Blow Cold.**—See page 20.
- Blow Down.**—(1) In Bessemer practice: see page 21; (2) in blast furnace practice: see page 35.
- Blow Full; Hot.**—See page 20.
- Blow In; Blow Out.**—Of a blast furnace: see page 37.
- Blow Young.**—See page 21.
- Blower.**—(1) In Bessemer practice: see page 16; (2) of a blast furnace: see page 38; (3) a defective tube: see page 492.
- Blowers' Glasses.**—See page 20.
- Blowhole.**—See page 55.
- Blowing Engines.**—Those for compressing the air for the blast used in blast furnaces, Bessemer converters, etc., are of two general types; (a) either steam or gas-driven reciprocating engines, or (b) turbine-driven rotary engines (**turbo-blowers**). The air is sucked into and compressed in cylinders (**blowing tubs**), and passes thence into the blast main.
- Blowing Tub.**—See Blowing Engine
- Blowing Up.**—See Water Gas.
- Blown.**—Of a casting: see page 55.
- Blown Metal.**—See page 18.
- Blowy.**—Of a casting: see page 55.
- Blue Annealing.**—See page 431.
- Blue Billy.**—See page 245.
- Blue Furnace; Oven.**—See page 135.
- Blue Iron Earth.**—See page 244.
- Blue Powder.**—See page 371.
- Blue Short; Shortness.**—See pages 46 and 198.
- Blue Stone.**—Commercial sulphate of copper.
- Blue Temper.**—See page 230.
- Blue Vitriol.**—Commercial sulphate of copper.
- Blue Working.**—See Hardness.
- Blueing.**—See page 367.
- Blume.**—See page 147.
- Bob.**—Tup or drop weight: see page 481.
- Bod.**—See page 182.
- Body.**—(1) Quality and uniformity to yield easy and proper working; (2) consistency or density, as in paints, etc.: see page 365; (3) of a converter: see page 17; (4) of a roll: see page 403.
- Body Core.**—See page 299.
- Body Force.**—See page 331.
- Body Iron** (Eng.).—Of wrought iron, especially Swedish, considered

of special suitability for manufacturing into crucible steel (Brearly).

Boecker Mill.—See page 417.

Bog Iron Ore; Bog Ore.—See page 244.

Bogey Casting.—See page 57.

Bogie; Bogey.—Same as Buggy; a flat car or wagon usually running on a narrow-gage track.

Bohemian Process.—See page 76.

Boil.—(1) In Bessemer practice: see page 20; (2) in open hearth practice: see page 314; (3) in puddling: see page 376.

Boiled Bar (obs.).—Common puddled bar.

Boiler Compound.—See page 366.

Boiling.—See page 202.

Boilings.—See pages 377 and 438.

Boiling Point.—See page 202.

Boiling Process (obs.).—Puddling Process (*q.v.*).

Bolometer.—See page 207.

Bolting.—See page 408.

Bolting-down Rolls (Eng.).—See page 414.

Bond.—See page 86.

Bone (Eng.).—A hard streak in a piece of steel which is being rolled or forged, produced by uneven heating.

Bone Ash; Dust.—See page 68.

Bone Phosphate of Iron.—A material sometimes added to a blast furnace charge when it is desired to increase the content of phosphorus in the pig, *e.g.*, for certain castings. It is usually considered that 2.18 parts are equivalent to 1 part of P_2O_5 .

Bonehill Process.—See page 380.

Bontempi Process.—See page 368.

Bookwalter Converter.—Another name for the Robert converter: see page 24.

Boot.—Of a bloomary: see page 135.

Borax.—See Flux.

Boreas Steel.—A trade name given to an early grade of self-hardening steel.

Borchers Furnace.—See page 154.

Bordered Boundary.—See page 128.

Boring Gases (Howe).—Those obtained on boring cold solidified metal under water.

Boron.—B; at wt., 11; sp. gr., amorphous, 2.45, crystalline, 2.53 to 2.68. Occurs combined, and is not of importance as a constituent of steel: see page 453.

Boron Steels.—See page 453.

Bosh.—See page 27.

Bot; Bott; Bot Stick; Botting Up.—See page 182.

Bottling.—See page 336.

Bottom.—Of a converter: see page 17.

Bottom-blown Converter.—See page 18.

Bottom Board.—In molding: see page 297.

Bottom Casting.—See page 57.

Bottom Cut; Discard.—See Discard.

Bottom-fed Tuyeres.—See page 31.

- Bottom Part.**—Of a mold: see page 297.
- Bottom Plate.**—Of a converter: see page 17; (2) of a bloomary: see page 135; (3) the plate on which an open-bottom mold stands, usually called stool.
- Bottom Pouring.**—See pages 57 and 299.
- Bottom Pouring Ladle.**—See Ladle.
- Bottom Stuff.**—See page 17.
- Boucher Process.**—See page 166.
- Bouiniard Process.**—See page 317.
- Boulet Process.**—See page 71.
- Boulton Process.**—See page 61.
- Boundary Edging.**—See page 128.
- Boundary Filling; Strength.**—See page 282.
- Bower Process.**—See page 367.
- Bower-Barff Process.**—See page 367.
- Bowke (Eng.).**—A South Staffordshire term meaning a small wooden box in which iron ore is hauled underground (Raymond).
- Box.**—(1) An iron receptacle for holding small material, and usually handled by a crane; (2) a charging box: see page 314; (3) the nut or hole with female thread in a housing, through which the screw turns.
- Box Annealing.**—See pages 232 and 431.
- Box Groove; Pass.**—See page 405.
- Box Piling.**—See page 378.
- Boydell Process.**—See page 73.
- Boyle's Law.**—See Gas.
- Boys Radiation Pyrometer.**—See page 207.
- Brake Burns.**—See Crack.
- Brake Test.**—See page 483.
- Branch Core.**—See page 299.
- Branding.**—See Marking.
- Branning Machine.**—See page 432.
- Brasque.**—To line with some inactive or harmless material, or one which will not interfere with a given operation, *e.g.*, to brasque a clay crucible with charcoal or lampblack.
- Brasses.**—(1) The boxes made of brass or bronze containing the babbitt or other bearing metal on which the necks or journals of a roll, etc., turn. **Bushing metal** is the name sometimes given to an alloy of copper and tin (bronze) used for this purpose; (2) pyrites in coal (Eng. and Welsh).
- Bray Continuous Sheet Mill.**—See page 433.
- Braze.**—See page 505.
- Break.**—See Curve.
- Break Down.**—(1) Of ingots, etc., to reduce the section by rolling or forging, more particularly, the preliminary operation; (2) of equipment which fails under load.
- Break Out; Through.**—(1) Of the flame in the Bessemer process, when the carbon begins to burn: see page 20; (2) of molten metal which forces its way through a furnace wall.
- Breaker.**—(1) A machine for breaking up the sow and pigs: see Pig Breaker; (2) in coal mining, the building and machinery where

the coal is crushed to obtain the desired size, and also where the slate is picked out.

Breaking.—See page 330.

Breaking-down Point.—See page 334.

Breaking-down Rolls.—See page 414.

Breaking-down Temperature.—For ordinary tool steel: see page 446.

Breaking Load.—See pages 336 and 471.

Breaking Spindle.—See page 407.

Breaking Stress.—See page 336.

Breaking-up Process.—See page 75.

Breast.—(1) Of a Bessemer converter: see page 18; (2) the front bank of an open hearth furnace; (3) that side of the hearth of a shaft furnace which contains the metal notch (Raymond).

Breast Hole; Plate.—See page 182.

Breccia; Breccia Structure.—See page 125.

Breeches Runner.—See page 57.

Breeze.—Coke breeze: see Coke.

Breeze Oven.—An oven in which breeze (fine coal or coke) is burned.

Breuil Test.—See page 482.

Brick Kiln; Oven.—See page 182.

Bridge.—(1) In a blast furnace: see page 35; (2) in a reverberatory furnace: see page 183.

Bridge Wall.—See pages 183 and 375.

Bright Annealed Wire.—See page 509.

Bright Blue Temper.—Oxide color: see page 230.

Bright Crystalline Fracture.—See page 178.

Bright Finished Wire.—See page 507.

Bright Fracture.—See page 178.

Brighten.—Of fuel in a blast furnace, etc., which is cool (not burning well), to increase the temperature, as by injecting oil.

Brilliant Fracture.—See page 178.

Brimstone Acid.—Made by dissolving in water the fumes from burning sulphur; sulphurous acid. It contains no arsenic.

Brinell's Formula.—For hardness number: see page 477.

Brinell Hardness; Hardness Number.—See page 477.

Brinell Meter.—See page 478.

Brinell's Notation.—For critical point: see page 265.

Brinell Refining Process.—See page 384.

Brinell Test.—For hardness: see page 477.

Brinell and Wahlberg Test.—See page 482.

Bring Down.—Of metal in a cupola, etc., to melt.

Bring to Nature.—See page 376.

Bring Up.—Or fetch up, to increase, *e.g.*, the percentage of carbon: see page 393.

Briquette; Briquetting (Briquet; Briquetting).—A block or brick (or the method of production) of a substance not of itself coherent enough, and to correct which some binding material is used. Fine substances such as coal, ore, etc., are cemented together by fusible (caking) coal, pitch, lime, etc. After mixing, the material is put in molds, usually under considerable pressure, and with

or without the application of heat. The briquettes are then taken out, and dried, etc., as necessary. Some of the various processes may be mentioned briefly as follows:

The **Schumacher process** "consists in mixing with flue dust a small amount of liquid containing some such material as magnesium or calcium chloride in solution, then thoroughly mixing the flue dust to produce as nearly a homogeneous mass as possible, and finally passing it through a briquetting press capable of producing high pressures up to about 6800 pounds per square inch" (Clark). The **Scoria process** "involves the use of granulated blast furnace slag and lime as a binder. Magnetically concentrated flue dust, thoroughly mixed with the binding agents, is pressed (at approximately 1500 pounds per square inch) into the form of rectangular bricks and then subjected to the action of live steam for several hours" (Clark). The **Gröndal process** "consists in forming briquettes of moistened flue dust (or fine ore) without any binder, piling these briquettes carefully on small platform cars and running the cars into heating ovens, where the briquettes are subjected to a high temperature over a considerable period of time. The carbon contained in the briquettes is burned out, causing a sintering action throughout the briquette, which causes the formation of a firm yet porous brick" (Clark). In the **tunnel kiln process**, as practised at one plant, flue dust is first magnetically concentrated and "the concentrate is then briquetted in a press exerting a pressure of about 7000 pounds per square inch, and the briquettes finally treated by passing them through long tunnel kilns in which they are subjected for about 5 hours to a temperature rising to about 2400° F. in the hottest zone" (Clark). The **Weiss process**, used for briquetting ore, flue dust, and also metallic borings is based on the use of lime as a binder in conjunction with the formation of the carbonate by the introduction of CO_2 . This gas, under pressure is caused to penetrate the bricks, cold at the beginning and warm at the end, in order to produce a firm bond of calcium carbonate. The **Ronay process** is also used for briquetting borings, these being subjected to heavy pressure, gradually applied, to squeeze out the contained air; no binder is employed.

Roasting, sintering or clinkering are resorted to for the purpose of obtaining a suitable product for use in the blast furnace, etc., by partially fusing the material and so obtaining it in coherent form. In the **Heberlein pot method**, or **Huntington-Heberlein pot process**, "flue dust is treated by first thoroughly mixing it into a mass as nearly homogeneous as may be, then charging the same into a large pot shaped somewhat like a Bessemer converter and holding several tons of material. The material is ignited from the bottom and a draft of air forced up through from the bottom. The air supports combustion of the carbon contained in the mass and the ignition gradually progresses upward. The result is to burn out the carbon and to sinter the contents of the pot into a solid, though porous mass. When the sintering action has progressed throughout the material, the pot is inverted and the mass which falls out of the pot is broken into pieces small

enough for use in the blast furnace" (Clark). The **Greenawalt process** "involves the same principle of roasting or sintering, but differently arranged apparatus is used. The principal difference is that the draft is down through the mass of material to be heated rather than up" (Clark). In the **Dwight and Lloyd process** the fundamental principle is the same as in other roasting processes. "The essential features of this method are comprised in the form of apparatus used. The draft to support combustion during the sintering process is downward, but instead of carrying on the action in large pots, it is carried on in a much larger number of smaller pans. These pans are joined end to end to form a continuous conveyor" (Clark). The **rotary kiln process** "which may be termed **sintering**, but which perhaps is more clearly expressed as **nodulizing** or **clinkering**, consists in treatment of flue dust (or ore) in a rotary kiln similar to that used in the cement industry for the burning of cement clinker. Flue dust without preliminary treatment is charged into the upper end of an inclined kiln in which a high temperature is maintained by the combustion of fuel at the lower end. This fuel is generally pulverized coal, blown in with an air blast. The material is conveyed through the kiln by the rotation thereof and is agitated thereby while subjected to the high temperature. The result is to sinter the flue dust and to cause the small sintered particles to agglomerate into nodules varying in size from an eighth of an inch to an inch and a half in diameter and roughly spherical in shape. These nodules are porous and of excellent quality, physically and otherwise, for use in a blast furnace" (Clark). The **West sintering process** consists of a furnace with a movable bottom on which a block of the material is built as fast as the continuous action of the heat will agglomerate or stick the particles together. The material can be delivered to the furnace in several ways: (1) Letting it fall from the roof and spreading it out mechanically to form a thin layer; (2) using a kind of injector operated by air, and moving it over the area; (3) using a type of continuous furnace with the bottom moving slowly along, the dust being charged in definite places. After the block is built up to the capacity of the furnace, it is withdrawn and the sinter removed by a crane, and then broken to size as desired. If the breaking is done while the mass is red hot there will be the minimum of effort and cost (West).

Briquetted Borings.—See Briquette.

Bristol Gas Pyrometer.—See page 207.

British Formula.—For quality: see page 340.

British Imperial Wire Gage.—See page 188.

British Thermal Unit.—See page 199.

British Yield Point.—See page 471.

Brittle; Brittleness.—See also page 331. The tendency to rupture under shock or stress, more particularly one which is suddenly applied, without any appreciable elongation or reduction of area. It is the opposite of toughness, but should not be confused with hardness, as the latter is not synonymous. **Mechanical brittleness** (Arnold) is where a piece of metal snaps off on any

attempt to bend it. **Potential or vibratory brittleness** (Arnold) is where metal gives excellent tensile tests, will bend double readily without fracture, but is nevertheless very liable to fracture suddenly under vibration or alternation of stress, at a stress below its elastic limit. **Intermittent brittleness** (Le Chatelier) is where either brittleness or toughness may be produced according to the previous treatment. **Stead's brittleness** is of rare occurrence, and is produced by heating very low carbon steel for a long time (days) to between 500° and 750° C. (930° and 1380° F.). The crystals become large, and the steel loses a large part of its strength and ductility. **Shortness** is used synonymously with brittleness: (a) **red shortness or hot shortness**, when hot; (b) **cold shortness**, when cold; (c) **blue shortness**, brittleness when cold, due to working at about a blue (temper color) heat, say 300° C. (570° F.). Material slightly red short is also called **tender or weak**. **Slag shortness** is brittleness due to slag inclusions.

Brittle Fracture.—See page 178.

Brittle Hardness.—See page 452.

Broad Twin.—See page 125.

Broken Hardening.—See page 228.

Broken Rails.—See Rail Failures.

Brooman Process.—See page 71.

Brown Coal.—See Coal.

Brown Hematite: Iron Ore.—See page 244.

Brown Mill.—See page 417.

Brown Ore.—See page 244.

Brown Process.—See page 385.

Brown (George) Process.—See page 114.

Brown (Henry) Process.—See page 71.

Brown Pyrometer.—See page 207.

Brown and Sharpe Gage.—See page 188.

Browne Process.—Pig iron is refined in any way, and alloys of iron rich in manganese or silicon are then added.

Brownhill and Smith Mill.—See page 417.

Browning; Browning Steel.—See page 368.

Bubble.—Blister: see page 71.

Bubbling Process (obs.).—(1) Bessemer process; (2) puddling process.

Bucher Process.—See page 373.

Buckle.—See page 58.

Buckled Plate.—(1) A defect: see page 175; (2) plates which are slightly dished to stiffen and strengthen them (Eng.).

Buckshot Cinder.—See Slag.

Buckwheat Coal.—See Coal.

Budd Process.—See page 385.

Buddle.—See Ore.

Buffing.—See page 285.

Buffington Process.—See page 368.

Bug.—See Ladle.

Buggy.—A flat car or wagon running on a narrow-gage track.

Buggy Casting.—See page 57.

Built-up Tuyere.—See page 19.

- Bulk Modulus.**—See page 335.
- Bull Dog.**—See page 376.
- Bull Head.**—See page 412.
- Bull Ladle.**—See Ladle.
- Bull Process.**—(1) Direct process: see page 138; (2) purification process: see page 385.
- Bundle.**—See pages 94 and 507.
- Bundle Iron (rare).**—Nail rods made by cutting up plates in a slitting machine, and put up in bundles.
- Bung.**—See page 114.
- Bunsen Mill.**—See page 417.
- Burden, Ore.**—Of a blast furnace: see page 34.
- Burden Squeezer.**—See page 377.
- Burgess Process.**—See page 166.
- Burke Furnace.**—See page 154.
- Burkheiser Process.**—See page 96.
- Burning.**—(1) Of crucibles: see 112; (2) combustion: see page 202; (3) of iron or steel: see page 226; (4) of molds: see page 298; (5) of bricks: see page 395.
- Burning in.**—(1) Casehardening: see page 67; (2) of enamels: see page 370.
- Burning off.**—In tempering: see page 231.
- Burning on; Together.**—Form of soldering: see page 65.
- Burning Zone.**—See page 226.
- Burnishing.**—See page 285.
- Burnt Lime.**—See pages 175 and 396.
- Burnt Mine (Eng.).**—Roasted iron ore.
- Burnt Ore.**—In malleablizing: see page 258.
- Bursting Theory.**—Of rupture: see page 179.
- Bushel (Busheling) Bar; Iron; Furnace; Scrap.**—See page 379.
- Bushing Metal.**—See Brasses.
- Bustle Pipe.**—See page 32.
- Bustling (obs.).**—See page 74.
- Butt.**—(1) The bottom end of an ingot, etc.; (2) the edge or vertical surface of a plate or a piece of skelp; a term used in the manufacture of welded pipe.
- Butt Ingot.**—A short ingot, the last one poured from a heat, for which there is not sufficient steel to fill the mold.
- Butt Weld.**—See page 502.
- Butt Welded Pipe; Butt Welding.**—See page 489.
- Buzzing (obs.).**—See page 74.
- By-product.**—Not the chief product; secondary.
- By-product Coke, Oven, Recovery.** See page 96.

C

- C.**—(1) Chemical symbol for carbon; (2) symbol for the unit of electric current, the ampere; (3) Centigrade scale: see page 204; (4) indicating a falling temperature: see page 205.
- Ca.**—Chemical symbol for calcium (lime), *q.v.*
- Cb.**—Chemical symbol for columbium: see page 84.
- Cd.**—Chemical symbol for cadmium: see page 84.
- Ce.**—Chemical symbol for cerium: see page 84.
- C_f.**—Nature of carbon: see page 278.
- Cl.**—Chemical symbol for chlorine: see page 84.
- Co.**—Chemical symbol for cobalt, *q.v.*
- Cr.**—Chemical symbol for chromium, *q.v.*
- Cs.**—Chemical symbol for cæsium: see page 84.
- Cu.**—Chemical symbol for copper (Latin, *cuprum*), *q.v.*
- C to C.**—Center to center, used as points of measurement in machinery, etc.
- C. D.**—Cold drawn.
- C. H. B.**—Charcoal hammered bloom.
- C. H. No. 1.**—Charcoal hammered No. 1.
- C. H. No. 1 F.**—Charcoal hammered No. 1 flange.
- C. H. No. 1 F. B.**—Charcoal hammered No. 1 fire box.
- C. H. No. 1 F. F. B.**—Charcoal hammered No. 1 flange fire box.
- C. H. No. 1 S.**—Charcoal hammered No. 1 shell.
- C. I.**—Calorific intensity: see page 203.
- C. J.**—Cold junction (of a couple): see page 209.
- C. No. 1.**—Charcoal No. 1.
- C. No. 1 R. H.**—Charcoal No. 1 reheated.
- C. P.**—(1) Chemically pure: see page 89; (2) calorific power: see page 203.
- C. R.**—Cold rolled.
- Cabbling.**—See page 377.
- Cadinho Furnace.**—See page 138.
- Cadmia.**—See Zinc.
- Caking Coal.**—See Coal.
- Calcar.**—See page 181.
- Calcareous.**—Limy.
- Calcareous Ore.**—See page 243.
- Calcination.**—Applying heat to a substance to drive off the volatile matter, usually without the access of air; **roasting** is the same operation with access of air, and usually at a higher temperature, but below the fusion point. Calcination is frequently used as the name for both. See also Ore.
- Calcining Kiln.**—A kiln for calcining or roasting ores, limestone, etc.; see page 181.
- Calcite.**—See Flux.
- Calcium.**—Ca; at. wt., 40; melt. pt., 760° C. (1400° F.); sp. gr., 1.85. A silvery white metal moderately soft and malleable. Is not found free in nature its principal occurrence being as the carbon-

ate, limestone. It alloys with silicon, and this material, termed silico-calcium, has been tried as a deoxidizer for steel. The element is sometimes referred to as **lime**, e.g., carbonate of lime, instead of carbonate of calcium.

Calcium.—Fluorspar: see Flux.

Calcium Chloride.—(1) As a flux: see page 176; (2) in hot etching: see page 287.

Calcium Fluoride.—See Flux.

Calebasse (French).—A crude form of furnace, used in place of a cupola, for melting pig iron for small foundries. It consists of an upper part (*la tour*) removable from a lower part (*le creuset*), blast being supplied by a single tuyere. There is no tap hole, the bottom part serving also as a ladle.

Calescence; Calescence Point.—See page 265.

Caliber; Calibre.—(1) The diameter, especially the inner diameter or bore; (2) also used as a measure of length, especially of a gun, in terms of the bore, thus an 8" gun 50 calibers long would have a length of 400" or 33' 4".

Calibration.—Of a testing machine: see page 469.

Calibre.—Same as caliber, *q.v.*

Californian Furnace.—See page 162.

Calipers.—See page 187.

Callendar Dish Radio-balance.—See page 207.

Callendar Gas Pyrometer.—See page 207.

Callendar & Griffiths Electrical Resistance Pyrometer.—See page 208.

Callendar Recording Pyrometer.—See page 210.

Caloric.—See page 199.

Calorie.—See page 199.

Calorific Agent.—See page 200.

Calorific Intensity.—See page 203.

Calorific Power.—See page 203.

Calorimeter.—See page 201.

Calorimetric Method.—Of determining critical points: see page 265.

Calorimetric Pyrometer.—See page 207.

Calorimetry.—See page 201.

Calorizing.—See page 372.

Calory (obs.).—Calorie: see page 199.

Cam Squeezer.—See page 377.

Camber.—(1) In structural shapes and rails, the vertical curvature measured by the versed sine; (2) in plates, the lateral curvature, which in the case of structural material or rails is called sweep.

Cambier Converter.—See page 23.

Cammel's Process.—See page 9.

Campbell's Formulæ.—For tensile strength: see page 338.

Campbell (H. H.) Process.—See page 317.

Cancellated Structure.—See page 126.

Cannel Coal.—See Coal.

Cantilever Beam.—See page 468.

Cap.—To close the top of an ingot mold either with sand and an

iron plate, or else with a circular cast-iron or steel cap which fits in a corresponding hole in the top of the mold; to **stopper down** (Eng.).

Capillary Structure.—See page 125.

Car Casting.—See page 57.

Carbide Carbon.—See page 273.

Carbide Steel.—See page 443.

Carbo-allotropic Theory.—Of hardening: see page 280.

Carbon.—(1) Influence on corrosion: see page 366; (2) as a refractory: see page 398.

Carbon.—C; at. wt., 12; sp. gr. diamond, 3.5; graphite, 2.5; gas carbon, 2.35; charcoal, 1.57. Carbon occurs as three allotropic varieties: the **diamond**, which is crystalline and colorless or colored, occurring naturally, and rarely obtained in an electric furnace; **graphite**, which occurs naturally in black crystalline plates, or may be prepared artificially in an electric furnace; and **amorphous carbon**, which is deposited on cool surfaces when carbonaceous matter is burned with an insufficient supply of air. An amorphous form of graphite has been termed **graphitite**; a natural fuel, containing only traces of oxygen and hydrogen, has been called **schungite** or **graphitoid**, and it has been suggested that this name be used for fuels intermediate between graphite and anthracite. The carbon which separates out in plates from cast iron during solidification is called **graphite** or **kish**. A substance having the appearance of graphite is sometimes said to be **graphitoid**.

Carbon is the principal constituent of all common fuels, either solid, liquid, or gaseous, the most important of which are coal and coke, used for heating and reduction. It is the most important constituent of iron and steel, and is the chief factor in making its varied properties and conditions possible. In increasing amounts it raises the strength and the hardness, and also the brittleness. The last is not a desirable quality, but carbon causes less of this, combined with greater strength, than any other element. This statement may require slight modification in the case of some special steels. With increasing carbon content, the elongation and the reduction of area are decreased. With carbon, say, over 0.30%, iron can be hardened by rapid cooling from above the critical point.

In making a chemical analysis of cast iron or steel, the carbon is reported as **combined carbon**, **graphitic carbon**, and the two together, **total carbon**. **Combined carbon** is that which is combined directly with the metal or is dissolved in it, for which Howe has suggested the name **agraphitic carbon**. **Graphitic carbon**, **graphite**, or **uncombined carbon** is that which is simply mechanically mixed with the metal. When combined carbon is determined volumetrically, by comparing or matching the coloration of a solution of the sample with that of a known standard, it is termed **color carbon**, to indicate the method employed as distinguished from burning the carbon in oxygen and weighing the carbonic acid produced, called **carbon by combustion** or **combustion carbon**. Howe uses the term **missing carbon** to

denominate that portion of the combined carbon in rapidly cooled steel which is not shown by a color determination. The change of carbon from one condition to another, *i.e.*, from the combined to the uncombined, or *vice versa*, is sometimes referred to as **transcarburization**.

Carbon forms two very important oxides with oxygen, both of which are gaseous under ordinary conditions. **Carbon dioxide**, CO_2 , also called **carbonic acid** or **carbonic anhydride**, is the result of the complete oxidation (combustion) of carbon. When acted upon, at a high temperature, by additional carbon, it is partially reduced, forming **carbon monoxide**, CO , also termed **carbonic oxide** or rarely **carbon oxide gas**; this reducing action, in connection with solid fuel, being rarely called **carbon transfer**. It is valuable as a reducing agent but, in the case of iron, the action is never perfectly complete. Carbon monoxide acts as a radical to form compounds with certain elements, and is then termed **carbonyl**. Iron apparently forms two such compounds, called **ferro-carbonyl** or **iron carbonyl**, $\text{Fe}(\text{CO})_5$ and $\text{Fe}_2(\text{CO})_7$, when finely divided iron, at comparatively low temperatures, is allowed to remain in contact with the gas.

Carbon Additions.—See Recarburization.

Carbon of Annealing.—See page 272.

Carbon Bloom.—See page 138.

Carbon Brick.—See page 398.

Carbon of Cementation.—See page 272.

Carbon Change.—A change in the condition of carbon occurring in iron or steel.

Carbon by Combustion.—See Carbon.

Carbon Core.—See page 299.

Carbon Deposition, Zone of.—In blast furnace practice: see page 36.

Carbon Dioxide.—See Carbon.

Carbon Free.—A term used to designate metals and alloys practically free from carbon, which makes them more suitable for certain purposes.

Carbon Iron.—Iron (either steel or cast iron) in which carbon is the principal constituent.

Carbon Iron Company's Process.—See page 138.

Carbon-iron Diagram.—Iron-carbon diagram: see page 271.

Carbon Monoxide.—See Carbon.

Carbon of Normal Carbide.—See page 272.

Carbon Oxide Gas.—See Carbon.

Carbon Steel.—See page 443.

Carbon Theories.—Of hardening: see page 279.

Carbon Tool Steel.—See page 445.

Carbon Transfer.—See Carbon.

Carbon Value.—See page 87.

Carbonate.—(1) The combination of a base with carbon dioxide; to convert into a carbonate or to impregnate with carbon dioxide; (2) (obs.) to carburize or carbonize: see Carburize; (3) see Carbonization.

Carbonate Ore.—See page 244.

Carbonic Acid.—See Carbon.

Carbonic Acid Theory.—Of corrosion: see page 107.

Carbonic Anhydride.—See Carbon.

Carbonic Oxide.—See Carbon.

Carbonization.—(1) Of fuels, coking or driving off the volatile matter; (2) commonly used instead of carburization, meaning impregnation with carbon: see pages 66 and 393.

Carbonized Iron.—Usually a pig iron rendered brittle by excess of silicon (Raymond).

Carbonizing Process.—See page 66.

Carbonless.—A term used to designate metals and alloys practically free from carbon, which makes them more suitable for certain purposes.

Carbonyl.—See Carbon.

Carborundum.—(1) As a silicon addition: see Recarburization; (2) as a refractory: see page 398.

Carburet.—(1) Carbide; (2) to carburize (rare).

Carburite.—A name given to a mixture of about 50% each of carbon and iron, used for recarburizing, particularly in the electric furnace.

Carburize.—Also termed **carbonize**; to introduce carbon (1) while steel is molten by adding coke, coal, ferro-manganese, etc. (see Recarburization), or (2) while in the solid state, by heating it in contact with carbonaceous matter below its melting point (see Cementation).

Carburizing-fusion Process.—See page 113.

Carburizing Process.—See page 66.

Carburizing Varnishes.—See page 69.

Carinthian Process.—See page 76.

Carmont's Process.—Consists in piling, reheating, and rolling steel scrap with steel or iron turnings.

Carnelly & Burton's Pyrometer.—See page 210.

Caron's Cement.—See page 68.

Caron's Method.—Of hardening: see page 229.

Caron's Process.—See page 68.

Carpenter & Keeling's Equilibrium Diagram.—See page 272.

Carrier.—See page 406.

Cascade Furnace.—See page 146.

Case.—(1) In cementation: see page 67; (2) of a mold: see page 297.

Case Carbonizing.—Case hardening: see page 67.

Case Hardening.—See page 66.

Caspersson Process.—See page 60.

Cast.—(1) The act of tapping a blast furnace: see page 36; (2) the metal taken from a blast furnace at regular intervals; (3) a term for objects which are produced from the molten state.

Cast House.—See page 27.

Cast Iron.—(1) In general, usually called **pig iron** (*q.v.*), the product obtained by reducing iron ore or similar materials with carbon at a temperature sufficiently high to render it fluid (molten). It is made in the blast furnace, sometimes

in the electric furnace, and occasionally in the high bloomary when that was in use. It contains a considerable proportion of carbon (say, 2.20 up to about 7%—usually from about 2.5 to 4%) and variable percentages of other substances, such as silicon, manganese, phosphorus, sulphur, etc. It is hard and brittle, and cannot be rolled or forged at any temperature. (2) In a more restricted sense the above product cast in its final form, the metal for this purpose being usually first cast in pigs, and subsequently remelted, although it is sometimes used in the molten state as it comes from the blast furnace. Cast iron is defined by I.A.T.M. as "Iron containing so much carbon that it is not usefully malleable at any temperature."

Cast Iron Armor Plate.—See page 9.

Cast Iron Mold.—See page 296.

Cast Iron Pipe.—See page 489.

Cast Seam.—A fin formed in a casting when the mold has joints into which some of the metal runs.

Cast Steel.—(1) Crucible steel: see Crucible Process; (2) any object made from steel in the molten condition.

Cast-welding Process.—Pouring molten metal between objects to be welded or fastened together.

Casting.—(1) The operation of tapping a blast furnace; (2) melting cast iron in a cupola for foundry work (obs.), sometimes called **running down**; (3) a metal object which receives its shape from a mold (see Molding) into which the metal is poured while in a molten condition and there allowed to solidify; (4) the operation of filling molds, also termed **teeming** or **pouring**. A special kind of casting known as **ingots** is the form in which steel is cast for subsequent rolling or forging; these are usually rectangular, rarely round or hexagonal, in cross section; if more than twice as wide as they are thick they are termed **slab ingots**; the height is usually two to four times the thickness or diameter. Castings ordinarily as considered may be annealed or machined, or both, but do not receive any rolling or forging. The manufacture of castings is sometimes termed **founding**; and the plant or shop where they are made, a **foundry**.

Piping.—During the **solidification** of any casting, the action proceeds inward from the portion in contact with the walls of the mold. (In this connection a core or interior division of a mold is to be considered as a wall). As contraction proceeds, since the metal itself is of smaller bulk when solid than when molten, eventually a longitudinal cavity is left near the top, where solidification last occurs, since below this point any incipient cavity is immediately filled with molten metal. This cavity is known as a **pipe** on account of its shape (also termed **cavity**, **contraction cavity**, **void**, **vug**, **sink hole**, **shrink hole**, **draw hole**). **Liquid contraction** is that which occurs up to the point of solidification; used by Longmuir in connection with the formation of cavities in the heavy parts of castings when an outside skin had formed. **Solid contraction** occurs after solidification is complete. Howe points out (Am. I. & S. Inst., 1915) that during the early stages of solidification the exterior cools faster

than the interior (**pre-neutral period**), at some moment the rates are the same (**neutral moment**), and afterwards the rates are reversed (**post-neutral period**); that the relative rates of cooling of the different portions govern the piping. The **exterior or major shrinkage** is that which is measured by the external dimensions; the **interior or minor shrinkage** is that which occurs in an opposite direction in the interior of the casting tending to produce a pipe. The question is further complicated by the fact that owing to variations in composition, due to segregation or initial heterogeneity, the solidification does not usually occur at a single definite temperature but over a range (**solidification range**) giving rise to **progressive freezing**.

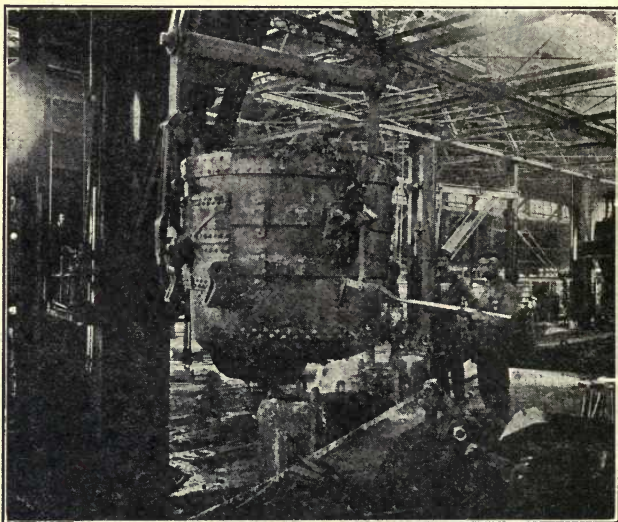


FIG. 9.—Pouring a heat of steel.

To facilitate the discussion of the phenomena of progressive freezing, H. M. Howe adopted provisionally certain terms for which he has given the following definitions: **Frozen continent**, the part of the alloy which at any given instant under consideration has already frozen; **shore layers**, those which have already in part solidified, and yet in part remain unfrozen with pool-lets or estuaries of still molten matter, or in other words the layers in which freezing is actually going on; **littoral region**, that part of the still unfrozen alloy immediately adjoining the shore layers, in other words, the layers which have not yet actually begun freezing but are about to; **open sea**, the still unfrozen mother metal beyond the littoral region. Freezing, during which pools of

metal are isolated (which he terms the **landlocking type**), proceeds by the outshooting of **pine-tree crystals** (so-called from the fancied resemblance; also **arborescent** or **dendritic**), the tangled branches of which lock up much of the impure metal of the littoral region, and thus prevent it from diffusing centerward or, in short, from segregating. But in the **onion-skin type** the successive deposition of smooth concentric layers does not thus obstruct the centripetal travel of the impurities.

Blowholes.—Metals also evolve more or less gas during solidification, and any which cannot escape is mechanically held in little pockets called **blowholes** (sometimes **gas holes**) which are generally arranged symmetrically to the axis.

Those occurring near the surface are called **subcutaneous** or **surface blowholes**; if open at the surface, **cutaneous blowholes**; those nearer the center, **deep-seated blowholes**. A casting

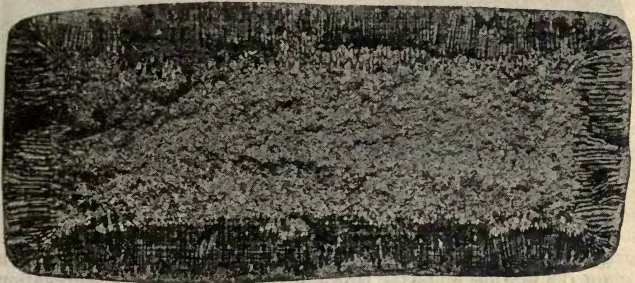


FIG. 10.—Ingot broken transversely showing subcutaneous blowholes.

containing an excessive number of blowholes, rendering it unsound, is said to be **honeycombed**, **porous**, **blown**, **blowy**, **spongy**, or **mushy**; in such cases the blowholes are rarely termed **shrink holes**. Since the space occupied by any blowholes corresponds to an equal amount of contraction cavity, it is evident that where there are many blowholes the pipe will not be so extensive as where they are absent; in other words, other conditions being similar, the space occupied by the blowholes and the pipe is equal to that of the contraction cavity. Steel from which the gases have been removed is sometimes referred to as **degasified steel**; it is correspondingly free from blowholes which necessarily means a large pipe, hence called **pipng steel**. Where the steel contains much gas it has a tendency to rise in the molds (**rising steel**) and the resulting casting contains numerous blowholes, sometimes termed **open steel**.

Segregation is the concentration of the carbon and impurities (in solution) into that portion of a metal casting which solidifies last. **Liquation** is also used in the same sense, but Howe suggests that segregation be used "to designate a concentration inward,

and liquation an expulsion of matter outward from the exterior of the mass, but without insisting on the propriety of the terminology. The metal other than the segregation is known as the **mother metal** (also called **segregans**): it is not closely analogous to mother liquor, for it is in general the first crystallized and purer substance, the segregation being the residue left from its crystallization, while mother liquor is the impure residue left by the early formed, relatively pure crystals." The term **segregate** is also used for the segregated portion expelled in the freezing of the earlier layers and usually found concentrated in the axis of the ingot (**axial segregate**). Segregation was the term used by Kosman (1903) to designate the separation of the constituents of an alloy by partial melting (*i.e.*, of one of them); in its usual sense,

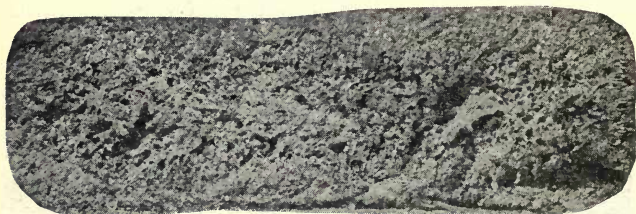


FIG. 11.—Ingot broken transversely showing deep-seated blowholes.

as described above, it means a **differentiation** or **purification** (of the mother metal). Howe introduced the terms **segregation excess** for the excess of the percentage of an element in the segregate over that in the segregans, and **segregation deficit** or **negative segregation** for the opposite condition resulting from the impoverishment of certain parts to provide the excess found in the segregate.

With an ordinary casting the mold is made to provide for an excess of metal above the casting proper. This extra metal serves to keep the body of the mold full, and to receive any dirt or scum (**sulage**) which rises (called **head metal**), and should also be large enough to contain all the pipe. This portion of the casting is called the **sinkhead**, **sinking head**, **shrinking head**, **settling head**, **feeder**, **feeding head**, **sullage piece**, **riser**, **rising head**, **head**, **deadhead**, or **header**; the top of an ordinary ingot is rarely called the **sand**. In the case of iron molds, if a lining of refractory material is used around the sink head, to retard solidification at that point, it is termed a **hot-top sink head**. The pressure resulting from the height of metal, as in the sink head, is sometimes referred to as **ferrostatic pressure**, similar to hydrostatic pressure for a head of water. If the rate of contraction is so unequal that the casting is distorted from **casting strains**, it is said to be **warped** or **sprung**; if the action is still more severe, so that surface cracks result, it is termed **checking** or **pulling**, also the latter if

actual rupture results. **Slag inclusions**, also called **cinder inclusions**, **dirt inclusions**, or simply **inclusions**, are particles of slag or dirt occurring in the metal due to being mechanically held so they could not escape to the top before solidification. **Casting boil** usually refers to a condition in blast furnace practice where the runners are damp and the hot metal generates steam causing explosions; in the same way with damp molds, particularly sand molds, dampness leads to the formation of steam which causes a more or less honeycombed or badly pitted surface on the casting. **Ingotism** is the name applied by Howe to designate the very coarsely granular condition of certain castings poured at a high temperature and slowly cooled; this structure tends to persist even after annealing or other heat treatment and may require mechanical working to destroy it. During the cooling, the cohesion between adjacent grains may not be sufficient to resist the contraction strains, so that there is a partial separation between them. Any subsequent heat treatment therefore has no more effect in uniting them than upon two pieces simply laid against each other; mechanical working will usually effect a reunion provided, of course, the surfaces are free from oxide or dirt. A **scorched ingot** (Eng.) is one which has a needle structure and is brittle, perhaps due to being poured too hot.

Pouring or Teeming.—The metal may be poured directly into the top of the mold (**top pouring**, **top casting**), practically always from some form of ladle (*q.v.*), but this method is generally restricted to iron molds for ingots, as the falling metal is likely to tear and destroy (**wash**) the surface of sand molds. In the latter case the metal is introduced through a hole at the side or bottom, by a separate channel called a **runner** which connects with the mold itself by a gate, the metal in the runner is also referred to by the same name, and the portion in the gate is called the **runner head**. This method is known as **bottom pouring** (**casting**) or **ascensional casting**, and the casting itself is similarly designated, sometimes also as a **rising casting**. In filling ladles from a furnace, or open top molds from a ladle, a split runner may be used sometimes called a **breeches runner**, to permit of **double pouring**.

Small molds are set on the foundry floor, but with larger sizes it is generally necessary to place them in a pit (**casting pit**, **foundry pit**, or **open pit**) so their tops will be readily accessible; also to save the use of flasks. With ingots, the latter method (**pit casting**) has been almost entirely abandoned, having been superseded by setting the molds on small cars or buggies (**car casting**, **buggy** or **bogey casting**) so they may be removed expeditiously to the **stripper** (a machine for **stripping** the ingots, *i.e.*, lifting off the molds), and thence to the heating furnaces for rolling or forging. The plate or base upon which an open bottom mold stands is called the **stool**. **Open sand castings** are those made in molds simply excavated in sand without flasks. When molten metal breaks through the mold the latter is called a **running mold**. An ingot which is rolled or forged while the interior is still liquid is termed a **green ingot**, and if it cracks so some of the

interior escapes, a **bled ingot**. **Chilled** or (rarely) **hardened castings** are usually of cast iron which have been set in metal molds, or where certain portions have been chilled by contact with metal pieces set the walls of the mold.

A casting is said to be **sharp** when it conforms accurately to the mold. **Veins** are irregular wavy markings on the surface of castings which occur when too much blacking, etc., has been used to coat the molds. **Feathers** are small fins or excrescences of metal which have run between the joints of the mold. **Scabs** are rough projections on a casting caused by the mold breaking or being washed by the molten metal. **Buckles** or **swells** on castings are caused by the mold being pushed out of shape by the molten metal. In an iron casting a **hot spot** is a place where segregation is high; such spots are sometimes porous or surrounded by porous metal. To prepare a casting for use, it is necessary to **clean it**,



FIG. 12.—Ingot split longitudinally showing pipe.

i.e., remove the gates, fins, scabs, and adhering sand. Smoothing up the surface with grinding wheels, etc., particularly where the runners and sinkhead have been broken off, is referred to as **dressing** or **fettling**. The sand adheres much more tenaciously to castings of steel than to those of cast iron; in the former case it may be necessary to use a chisel and sledge or a pneumatic chipper; in the latter case the castings, if small, are frequently put in a machine resembling a barrel in which they are rotated, usually with some sharp pointed pieces of metal, by means of which the sand is removed and the surface polished; this machine is called a **rumble**, **rattle barrel**, **tumbler**, **tumbling barrel**, or **shaking barrel**. Where castings have to be fitted to each other or to some object, the faces which are to come into contact are frequently provided with thin metal strips cast on, which can be cut until an accurate fit is obtained; these are called **chipping pieces** or **chipping strips**, and their faces **chipping faces**.

Steel castings may be regularly annealed after removal from the molds by reheating in a furnace to a cherry red for a certain length of time (*a*) to remove any cooling strains, and (*b*) to give a finer grain. Sometimes to avoid cooling-strains they are allowed to cool slowly in the mold, and this is referred to as **flask annealing**. In the case of cast-iron car wheels they are removed from the chill molds as soon as possible and are frequently piled, about six deep, in a circular pit provided with a cover, and there allowed to cool slowly (**pit annealing**).

Special methods of casting in some cases have for their object a cheaper or more rapid operation, but in most cases are concerned with the production of **sound steel**, *i.e.*, free from piping and blowholes or other interior defects, in which may be included segregation. Below are given certain processes which are usually based on one or more of the following principles:

1. **Mechanical methods:**

- (a) Applying pressure in the mold before complete solidification: fluid compression.
- (b) Applying pressure to the ingot after removal from the mold: Talbot's process.
- (c) Replenishment (**top replenishment**) of molten metal at the top.
- (d) **Slow pouring.**
- (e) Increasing blowholes to reduce pipe, and *vice versa*.

2. **Thermal methods:** Retarding the cooling of the metal at the top in relation to that below (Howe refers to retardation of cooling at the top as **top lag**).

- (a) **Top heating:** Applying molten slag, fuel, etc.
- (b) **Top insulation:** A refractory lining at the top of the mold (**dozzle**); sand, lime, etc., thrown on top of the casting, or even contact with the air. An ingot is **dozzled** (Eng.) when the mold has a refractory top.
- (c) Increasing cooling effect at the bottom by inserting metal pieces (for sand molds) or increasing the section (for metal molds).
- (d) The addition of a substance such as thermit to increase the temperature at the top.
- (e) **Inverted molds** (large end up).
- (f) Charging ingots hot in the soaking pits.

3. **Chemical methods:** The addition of aluminum, silicon, etc., to remove gases or cause them to remain in solution after solidification.

Piping is increased by 1 (e) if blowholes are decreased; by 3. Blowholes are increased by 1 (e) if piping is reduced.

Special methods of pouring.—Pouring or teeming is the operation of filling molds with molten metal, while the production of castings in general is termed casting. With cast iron, the ladle is practically always top pouring (see Ladle), the small amount of slag floating on top of the metal being kept back with bars. With steel, the bottom pouring style of ladle is almost universally employed on account of the large amount of slag which must be prevented from entering the molds, and also the necessity for avoiding splashing the sides of the molds. Ordinarily the same ladle into which the steel is run from the furnace or converter is used for pouring. To insure better mixing (particularly of small charges) the steel is sometimes poured from one ladle into another (**repouring process**), and if this is done through the bottom of the first ladle, instead of over the top, it will eliminate almost entirely the slag, and so permit additions to be made

in the second ladle without any danger of rephosphorization. In **Caspersson's method** of pouring, the steel is run into a vessel with a number of perforations in the bottom (**colander funnel**) which divide it up into a number of fine streams with the object of giving the contained gases a better opportunity to escape. **Sauveur's overflow method** of pouring was devised for the prevention of pipes in ingots, by having each mold overflow into the next, and thus have a quantity of molten steel constantly on top of each ingot until the ingot had almost completely solidified. Owing to early chilling of the stream, it was found applicable only to small ingots, and there were also difficulties in handling from having to break the ingots apart. In the **Beardmore and Cherrie process** a shallow mold with a large surface is employed instead of the ordinary deep type, with the idea of promoting the escape of gases, and so reducing the number of blowholes. **Van Riet** claimed to avoid the formation of blowholes by placing on top of the mold a box with a small hole in the bottom arranged to prevent the slag from running in; it would not appear to be of much value unless a top-pouring ladle were used. To shorten the fall of the steel, and so prevent the entraining of air, **Billing** employed a mold with a piston forming the bottom and so arranged that, starting at the top of the mold, it could be lowered as the mold was filled. In **Hainsworth's method** the steel from a converter is poured into a deep stopperless runner which discharges into the molds, preferably through an intermediate stopperless funnel with several nozzles, one over each mold. To prevent splashing the sides of the mold, **Posnikoff** suspends in the mold a thin sheet-iron tube through which the steel is poured; this melts as the steel rises over it.

Regulating the Rate of Cooling.—The **Ansaldo process** is on the same principle as an electric induction furnace. The metal in the mold is heated by a secondary current induced by the primary current in a coil of wire surrounding the mold. This coil can be moved vertically so that when the mold has been filled it occupies a position at the top of the mold to keep the metal molten there as desired. The **De Laval feeding head (De Laval ring)** consists of a conical or funnel-shaped crown lined with refractory material heated to at least a red heat. This is placed on top of the mold during pouring, and afterward helps to keep the steel liquid at that point so it will fill any pipe which tends to form. The **Gathmann process** consists in casting ingots in inverted molds, the bottom portion having much thicker walls, the object sought by both these means being to decrease the rate of cooling at the top and increase it at the bottom of the ingot. In the **Hadfield process** the ingots are cast with the large end up. On top of the mold is placed a cast iron box lined with refractory material, the mold being filled with steel to within a few inches of the top of this box. A small amount of fusible crushed slag is thrown on, and, when this is melted, charcoal is also added. A weak blast, in a series of jets, impinges on the charcoal to promote its combustion, the temperature secured being sufficient to keep the steel in the hot top fluid and so fill up any pipe forming beneath. In **J. Munton's**

method attainment of the same object is sought by pouring molten slag on top of the ingot before the steel has solidified. **J. B. Nau** attempts the same thing in a somewhat different manner: the ingot mold constitutes the bottom or hearth of a heating furnace, and is arranged so it can be lowered; the bottom of the mold is cooled by a series of water pipes so the cooling of the ingot will proceed from the bottom upward. **Riemer's method** is to use a gas flame for heating the top of the ingot. **Thermit** (see **Goldschmidt Process**), also called **anti-piping thermit**, has been employed to reduce piping, a can of the thermit attached to an iron rod being thrust into the steel near the top, after the mold has been filled, so that the heat generated by the reaction will keep it molten. A later development is to thrust the can down as near the bottom of the mold as possible so the reaction will stir up the metal and thus give the gases a better chance to escape; fresh metal from a ladle may also be added to keep the mold full.

Group casting is where a number of molds on one bottom plate are bottom poured simultaneously by means of a central runner (**git**) or mold (**git mold**) into which the steel is run. This is sometimes referred to as the **hen and chickens method**. In the **Pink method**, the molds are supported on a turntable. A modification of group casting, usually termed **multiple casting**, is where a number of molds are superposed and fed through a common runner. In **Scott's method** (intended for tire ingots) the molds are built up with cast-iron rings and fire-brick slabs with a small central hole interposed to make several **cheeses** (round slabs for forging into railroad tires) which are readily broken apart after solidifying. The pouring is done from the bottom. **Turner** combines several molds in one larger mold, and also piles several on top of each other, separated by division bricks provided with small holes. They are fed at the bottom of the lowest mold by a runner. **J. B. D'A. Boulton's method** consists in employing ingot molds without bottoms which are superposed; they are filled successively, and the shrinkage in each is compensated by fluid metal from the ingot above; an asbestos washer with a small aperture is placed between the ingots so the bottom one can be easily removed. The operation is intended to be continuous, the ingots being sheared off at the bottom (the molds are split longitudinally so as to be easily removed), and fresh molds set in position on top of those already filled; the lowering of the molds is performed by hydraulic mechanism. **A. Kurzwernhart** and **C. Bertrand** have suggested a method with several modifications: the ingot mold consists of two portions, a lower, divided into several smaller molds, and an upper undivided one. The sides of the two main portions are kept separate by means of a slab of fire-brick inserted between them. By this means the portions may be easily separated after the casting of the ingots. The upper portion of the mold is comparatively shallow, and is lined with refractory material, termed the **gas collector**, and it is claimed its use permits of very small and sound ingots being produced. In **R. Smith-Casson's method** a split mold is em-

ployed with divisions nearly coming together so the ingots are connected at the two opposite edges by small webs of metal, and can later be separated by a blow of a sledge or else sheared off; they are bottom cast. **J. Parkes** causes metal to rise upward through a series of slab molds of different and gradually diminishing sizes with the idea of producing pieces of steel of nearly the size desired for plates, etc., free from blowholes by the pressure of the long column.

Mechanical treatment for producing solid castings.—See also Fluid Compression. **Vacuum casting** consists in creating a partial vacuum in the mold after pouring the steel, to remove the dissolved or occluded gases, and so prevent the formation of blowholes. **Forsyth** rapidly hammers the mold after pouring, the jarring of the steel interfering with coarse crystallization. **F. Kapfl** gives slight vertical jerks to the mold and its contents during the progress of solidification. **Chernoff** agitates the metal during solidification by rotating the mold at varying speeds with occasional reversals. **R. W. Hinsdale** has devised two methods. In the first he uses a single stationary, bottomless, water or steam-cooled mold. The ingot is drawn down by mechanism as soon as its crust has solidified, till only its upper end remains in the mold, when a second is cast upon it, uniting with it in the center, and feeding its pipe, yet readily detached later. There must be little or no taper to the mold, so there is danger of the ingot cracking and bleeding. In the second method the mold is mounted on trunnions; after pouring, the top of the ingot is chilled, and the mold turned upside down with the purpose of having the pipe entirely enclosed by steel, so the interior of the pipe will not be oxidized, and will weld up on subsequent working. A method which may be mentioned here consists in stirring up the steel in the ladle with a machine known as **Allen's agitator**. This has two arms fastened to a revolving shaft which can be raised or lowered. It was primarily intended for mixing the additions with the steel, but was also found to effect a considerable evolution of gas and so reduce the number of blowholes in the ingots. An operation termed **poling** is sometimes employed for nearly the same purpose: a pole of green wood is thrust into the steel in a ladle, and the gases distilled off serve to stir up the contents, and also exert a certain amount of reducing action on any oxides present. This method has also been tried with cast iron for foundry work with the idea that a certain amount of purification will result. **Centrifugal casting** consists in rotating or revolving the molds after pouring, and while the steel is still molten. The pressure exerted, which is much less than with fluid compression, tends to remove the occluded gases and produce sound castings. **L. Sebenius** pivoted the ingot molds on swinging arms which were rotated at a rate of about 125 revolutions per minute, so that the molds were caused to take a horizontal position. In **Stridsberg's modification** the mold was rotated about its longitudinal axis instead of having it as the radius. **P. Huth's method** was devised especially for producing wheels, etc., with a hard rim or face and a soft interior. The

mold was caused to rotate about its center as an axis, and hard steel was poured in first and thrown to the circumference of the mold; soft steel was then run in to complete the center. Of course any other combination could be made.

Fluid Compression.—Also called **liquid compression** or **plastic compression**, has for its object the treatment of ingots to make them perfectly solid throughout by the elimination of blowholes and pipe. It consists in applying pressure in some form to the steel while it is solidifying. In the earlier methods gaseous pressure was applied between the top of the ingot and the top of the mold (closed after pouring). **Bessemer's process** consisted in the combustion of gas-yielding substances, and in the vaporization of certain liquids. In **W. A. Jones' process** steam under considerable pressure was introduced. In **Krupp's process** liquid carbonic acid gas was used. The **La Chaléassière process**, like Jones', consisted in casting under a steam pressure of 88 to 147 pounds to the square inch. In the **Galy-Cazalet process** a mixture of charcoal and saltpeter (similar to gunpowder with the sulphur left out) was used.

In the **Whitworth process** the steel is cast in a cylindrical mold with vertical walls, and a hydraulic plunger is forced down on top of the ingot. **Hinsdale's process** is somewhat similar to Whitworth's: a plunger with a hollow end is brought down on top of the ingot and breaks through the upper crust; the liquid steel which enters this hollow is stated to be the only scrap; it was employed for small, high-carbon ingots. In **G. W. Billing's process** a common mold was used, its bottom being replaced by a piston which was forced upward as soon as pouring was completed, the top of the ingot being pressed against a resistance plate which had meanwhile been slipped in (Howe). In **Daelen's process** the steel was cast in a powerfully clamped iron mold. If top cast, a plunger was driven through a hole in the top of the mold, its cross-section being only a small part of that of the ingot. If bottom cast, a plunger was driven in horizontally into the runner which was larger at that point, the top of the mold being closed (Howe). In the **Neuberg process** the steel is cast in tapered molds, reinforced by steel hoops which are shrunk on. The inside is hexagonal in section except for about 6" at the top which is circular to admit the plunger of a hydraulic press which exerts a pressure of 400 to 700 tons for about half a minute to a minute. In **S. T. Williams' process** the ingot is cast in an ordinary tapered mold, one side of which is removable; when the walls of the ingot are sufficiently thick, a convex liner is slipped inside the removable side of the mold and forced against the ingot. **Lilienberg's process** is somewhat similar: Ingots are cast in the ordinary manner, which, after removing the molds, are pressed between two walls, one of which is movable and the other stationary. **Illingworth's method** was to employ a split mold with a metallic filler which was removed when the ingot had partially set and pressure was applied. **H. D. Hibbard's method** was similar to Illingworth's except a refractory filler was employed and the ingot

was cast with the large end up. In **Harmet's process** (also called **St. Etienne process**, **compression by wire drawing**, or **draft fluid compression**) a tapered ingot is driven upward in a tapered mold by means of a hydraulic plunger, the wedge action exerting enormous pressure on the sides. **Talbot's process** consists essentially in removing the ingot from the soaking pit before the central portion has solidified, reducing it partially in a blooming mill with the object of closing up any cavities, and then restoring it to the soaking pit until it is in the usual condition for rolling, after which the rolling is finished in the regular way. The term **liquid squeezed** has been applied to steel treated in this manner.

Compound or composite castings (ingots) are those made by combining together different grades of steel, sometimes with wrought iron, so that certain parts of the casting will be hard, while others will be soft and tough. This method is intended principally for ingots to be rolled or forged into various articles such as armor plate, etc. Where the center is soft while the outside is hard, the term **soft centered (mild centered) steel** is applied; in the reverse case, **hard centered steel**. In the **Wild process** ingots were to be formed of wrought iron and steel by taking a piece of iron of the desired shape, heating it to a welding heat, placing it in the mold, and pouring steel around it; there was trouble from oxidation of the iron, and also the iron was found to roll out faster than the steel. **Von Nawrocki** divided the mold into two or more parts by thin sheets of wrought iron, when steel and iron (soft steel?) were run into the separate compartments. **Congreaves patent composite steel**, or **compo**, intended for axles, boiler plate, etc., was produced by placing in the mold a cage of wrought-iron bars separated by perforated plates, around which steel was poured. **Sibut's process** is very similar to the above. In the process devised by **Marel Brothers** (for armor plate) a ribbed plate of wrought iron was first made. This was heated to a white heat, sprinkled with borax, and in this condition put in a mold, and molten steel run around it or merely against one face; the ingot was subsequently worked down. **Wm. Siemens** poured hard steel upon softer, or divided up the ingot mold in some way. **B. Lauth** proposed a very similar method. In the process devised by **Evans and Spencer** for producing suitable material for axles and shafts, a central core of wrought iron was placed in the mold, and around this a harder grade of steel was run, and the ingot subsequently worked down. **Elbridge Wheeler** used two grades of steel from two converters; metal of one grade was poured into a mold provided with a core which was then removed and the other grade run into the cavity. **Charles Saunderson's process** consisted in making blooms of wrought iron containing grooves over which iron strips were welded, and the holes thus formed were filled with steel. In a modification, he surrounded a bloom with a tube, and filled the space with steel. In either case the product was heated and worked down.

Miscellaneous methods.—The **Szekely method** consists in employing metal molds, one of the chief points being to coat the molds with chalk and paraffin. **Shaw** also employs metal molds. **Slavianoff's electric casting method** appears to be simply a method of melting steel by connecting it to one terminal of a strong electric circuit, the crucible in which it is to be melted, or the plate on which it is to be cast being attached to the other. In the so-called **sand core process**, a sand core is cast in the ingot which is afterward worked down as usual; it was claimed that the sand did not injure the material, but this, as well as any advantage, is extremely doubtful. In **Norton's fluid rolling process**, fluid steel was to be worked direct into sheets by pouring it through revolving rolls properly adjusted, with the idea of preventing blowholes, and reducing the usual amount of scale. **Bessemer's method** for making continuous sheets consisted in running molten steel between two water-cooled steel rolls, separated a suitable distance; the speed of the rolls was regulated according to the thickness of the sheet. In **Whiteley's process** for the production of plates, molten steel was run into a revolving cylinder and formed a shell which was taken out, cut open by a saw, and then rolled down. **Pielsticker and Mueller's process** was devised for producing bars, rods, and similar material direct from fluid steel by first passing it through dies, and then finishing the resultant material in a rolling mill or under a hammer. The **Mellen rod casting process** employs a special machine for the continuous production of rods; molten metal is poured into the molds arranged in an endless chain.

Malleable or cast-iron castings are sometimes united by heating in contact to a high temperature; this is termed **burning together**. It is sometimes necessary to make an addition to a casting to complete or to replace a portion which has been broken off. For this purpose the casting already made is placed in a mold of the proper shape and molten metal poured in. The solid metal must be heated up to a sufficiently high temperature, and there are two methods which are usually distinguished as (a) **casting on**, where the solid metal is heated with a flame, and (b) **burning on**, where the molten metal is first caused to run into and out of the mold until the solid portion has been sufficiently heated, when the outlet hole is closed, and the mold allowed to fill up. **Wm. Chalk's method** for uniting a sleeve or boss of cast iron, etc., on a wrought-iron shaft consists in heating the shaft to a welding temperature, putting it in a suitable mold, and pouring around it the molten metal. **Falk's method** is somewhat similar, and is intended for uniting the ends of rails; an iron mold is placed around the ends, and extremely hot metal is then poured around them until they are partially fused and will unite readily.

Casting Boil.—See page 57.

Casting Box.—See page 297.

Casting On.—Form of soldering: see above.

Casting Pit.—See page 57.

Casting Shoe.—The fore-hearth for an open hearth furnace.

Casting Strains.—See page 56.

Catalan Forge; Process.—See page 138.

Catalysis; Catalyst; Catalytic Agent.—See page 87.

Catalysis Theory.—Of passivity: see page 364.

Catch the Carbon on the Way Down.—See page 315.

Catcher.—See page 430.

Catcher's Side.—See page 415.

Cathode.—See page 89.

Cation.—See page 89.

Cat's Eyes.—See page 114.

Caustic Potash; Soda.—The commercial hydrate or hydroxide of potassium and sodium respectively.

Cave.—Crucible furnace: see page 114.

Cavity.—Pipe or gas pocket: see page 53.

Celite.—See page 396.

Cell.—See page 121.

Cell Wall.—See pages 121 and 126.

Cellular Deformation.—See page 126.

Cellular Theory.—Of steel: That when solid it consists of a network of grains or crystals.

Celsius Scale.—Of temperature degrees: see page 204.

Cement.—(1) In cementation: see pages 67 and 70; (2) binding the grains of metals: see page 281.

Cement Bars.—See page 71.

Cement Carbon.—See page 272.

Cement Steel.—See page 71.

Cement Theory.—See page 281.

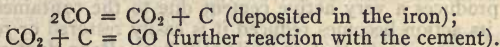
Cementation.—(1) In the metallurgy of iron and steel the carburization, or impregnation with carbon, at a temperature below the melting point of the metal. The iron must be in intimate contact with the carbonaceous matter, and air must be excluded. While the general principles are the same, there are three modifications which are readily classified in accordance with the depth and the nature of the carburization: (a) bars carburized throughout or nearly so to a varying degree—referred to specifically as the **cementation process**—used in the crucible process and also in the manufacture of cutting tools; (b) armor plate (*q.v.*), deeply impregnated but on one side only; (c) where the depth of penetration is very slight, usually called **case hardening**, for objects or parts of objects which must be superficially hard to resist wear. (2) **Metallic cementation** (see also Protection, page 370), a term used to denote impregnation with a metal or alloy in much the same manner as with carbon, resulting in a metallic coating for the purpose of resisting corrosion. **Siliciuration** indicates impregnation with silicon, as when platinum is heated in contact with silicious material and hydrogen. (3) Rarely used in the sense of treating solid cast iron with oxides to effect its decarburization (see Malleable Castings, page 257). (4) Rarely the reduction, without fusion, of iron ore by means of carbonaceous material (see Direct Processes, page 134).

For the general process of cementation the terms **carbonization**, **carbonizing process**, and **carburizing process** are also used.

Cementation which is wholly or almost complete is sometimes called **total cementation** to distinguish it from case hardening which is also known as **partial cementation**, **surface cementation**, **superficial cementation**, **case carbonizing**, rarely **burning in**, and sometimes (especially in the case of gears and pinions) **armored** or **armorized**. The term **supercarburized** has been applied to armor made by the Harvey process. Where the cementation is partial, the (outer) portion affected, the **cemented zone**, is called the **case**, and the inner unaffected portion the **core**, **heart** or **nucleus**. These two last terms are more usually restricted to blister bars not completely cemented, otherwise they would be distinguished as **core cemented**.

The carbonaceous material used is the **cement**. Depending upon its state it may be **solid**, **liquid**, **gaseous**, or, if a combination of two or all, **mixed**. It may be further classed, according to its rate of action, into **mild**, **slow** or **gradual**; **quick** or **rapid**; and **violent** or **sudden**. In general the velocity of cementation depends upon the rate of penetration of the carbon. This in turn is differently affected by different elements which may be present in the metal. On the basis of certain experiments Guillet considers it proved that the substances which retard cementation are those which are found in solution in the iron (nickel, titanium, silicon, and aluminum); and that the substances which accelerate cementation are those which seem to exist in the state of double carbides, replacing a part of the iron of the cementite (manganese, chromium, tungsten, and molybdenum—Giolitti). In determining the rate of penetration of carbon, **cementation curves** may be employed, which are plotted with one of the coördinates as the depth (measured in mm. or in.) and the other as time (hours).

The temperatures ordinarily employed are 850° to 1100° C. (1560° to 2010° F.) and the rate of cementation increases with increase of temperature. However, with carbon monoxide and carbonaceous matter the amount of carbon deposited will be greater at a lower temperature, say around or below 700° C. (1290° F.). In this latter case the bulk of the carbon may be deposited in the free state, that is, without combining with or dissolving in the iron, by the same reaction as occurs in the blast furnace, thus:



The equilibrium of the system $\text{CO} : \text{CO}_2 : \text{C}$ according to these reactions, that is, the carbon concentration, is proportional to the concentration of carbon dioxide, and varies inversely as the temperature. According to Boudouard while it is only 0.7% at 1100° C. (2010° F.) it increases to 42% at 700° C. (1290° F.—Giolitti). These reactions also take place in regular cementation. If, owing to the loss of CO_2 the efficacy of the cement is impaired (**exhaustion**) it may be restored by a short exposure to the air or by the introduction of a limited supply of oxygen while still hot (**regeneration**).

In certain cases four different **zones** may be observed under the microscope: (*a*) the central portion of untouched metal (hypo-eutectoid steel), (*b*) where the carbon gradually increases to the eutectoid content (also hypo-eutectoid), (*c*) eutectoid steel, and (*d*) a hyper-eutectoid region; there might also be included (*e*) the case where, owing to subsequent oxidizing influences, the outer portion has been more or less decarburized. It is desirable to avoid any sharp changes in structure as these prevent the proper continuity and gradation of the physical properties. Where the outer layer is high in carbon, say 1 to 1.5%, it usually presents a coarsely crystalline appearance (**pig face**) which is objectionable owing to its lack of coördination with the interior, causing it to flake off (**exfoliation** or **splitting**). The separation or segregation of cementite so that it exists in the free state is sometimes called **liquation**. According to Giolitti, the elimination of a first series of discontinuities—those due to liquation of cementite—can be obtained by avoiding the formation of a hyper-eutectoid layer containing free cementite. This can be done by the use of carbon monoxide acting as an equalizer with other cements. Further, to avoid or reduce in the cemented and hardened zones, sudden variations in the concentration of carbon, to which are due the phenomenon of exfoliation: (1) avoid effecting the cementation at too low a temperature, and in every case cement above Ar_3 ; (2) avoid slow cooling after cementation and before quenching (to prevent separation of cementite and ferrite and so cause greater discontinuity). Cyanides are not necessary under the conditions for ordinary cementation, as the transportation of carbon to the metal is effected, at least for the most part, by carbon monoxide (Giolitti).

Of the **solid cements** wood charcoal has been, and still is, the most widely used particularly for total cementation. For this purpose the temperature is usually kept at about the melting point of copper, say $1085^{\circ} C.$ ($1985^{\circ} F.$), and old and new charcoal is employed; if the charcoal is all new, a lower temperature is necessary to prevent local **overcarburization**, and the time extended correspondingly to get the required depth. Hard wood charcoal is more effective than soft but more costly. **Caron's process**, still used, was to mix about 40 parts of barium carbonate with 60 parts of wood charcoal (**Caron's cement** or **hardenite**). This produces a very active cement due to the contained CO_2 ; when its action becomes reduced it is easily restored or regenerated by exposing to the air while still hot. **Bone dust** or **bone ash** is a solid cement which evolves a certain amount of hydrocarbons; after repeated use it is termed **spent bone**. Charred leather, horns or hoofs, etc., are all used, principally in mixtures. Coke saturated with a heavy oil is sometimes employed. For the purpose of increasing the effect by the action of cyanides, **Eaton's process** consisted in mixing ferrocyanide of potash with wood charcoal. In **Bates' process** the mixture consisted of carbon, cryolite, spent lime, rosin, and soda, with the later addition of oxide of nickel which he claimed was reduced and formed an alloy with the iron. There are various mixtures,

some sold under trade names, which are usually more rather than less complicated and not always better than some of the standard substances.

Carburizing varnishes are mixtures which can be painted on special parts, and in addition to being capable of imparting carbon must also be adherent without cracking or melting off.

The use of liquid or fusible cements for cementation by immersion has been practised for some time, usually where only a very thin case is desired, hence sometimes called **skin hardening**. Leaving aside the use of cast iron which has been proposed several times but at present is not applied, the only liquid cements consist of pure salts or saline mixtures (hence **chemical hardening**); most commonly simple or complex salts of prussic (hydrocyanic) acid, either alkali or alkaline earth cyanides, ferrocyanides and ferricyanides. The substance most frequently and almost exclusively used as a liquid cement for cementation by immersion is potassium cyanide (**potash hardening**). In general the pieces are immersed in the already fused bath, kept between 850° and 900° C. (1560° and 1650° F.), and left in 3 to 15 minutes, according to the depth of cementation desired. If the piece is of medium size, say about 1 to 6 pounds., and not too irregular in form, the rule can be followed to immerse cold, and remove when the temperature has exceeded 850 to 880° C. (1560° to 1615° F.). Zones of uniform thickness are obtained from 0.03 to 0.10 mm. (0.0012" to 0.004"), according to the temperature and the time. The content of carbon near the surface reaches 0.9% C or higher, sufficient to render it, after quenching, inattackable by a file. It is not advisable, by this process, to try to obtain deeper than 0.15 to 0.20 mm. (0.006" to 0.008") by prolonging the operation or using a higher temperature, since then zones are obtained in which excessive percentages of carbon and sudden variations give rise, after quenching, to intense brittleness and exfoliation (Giolitti).

Salts derived from the radical CN exercise a specific carburizing action which has not yet been studied with precision. At 700° C. (1290° F.) nitrogenous cements furnish a thin cemented zone with less than 0.55% carbon but very rich in nitrogen, the percentage of which may exceed 0.5%. In these cemented zones J. Kirner observed a special constituent which he designated by the name **flavite**, the proportion of which increased with increase in the percentage of nitrogen.

A patented method termed **infusion method of hardening** was similar to the above, claims being made that owing to the special ingredients used the action proceeded to a greater depth and that the change from the treated to the untreated parts was very gradual.

Partially fusible cements consist of a mixture of an infusible base with a fusible constituent and have been proposed for use in a similar manner.

The gaseous cements may consist of various hydrocarbons or carbon monoxide, the advantage being the uniformity secured particularly where the pieces treated are of complicated shape.

Carbon monoxide as the base in mixed cements acts as an equalizer in securing uniformity and avoiding sharp changes in content. The gas employed may be diluted by an inert gas when it is desired to restrain its action. Carbon monoxide, for example, is said to be isolated when it is caused to act alone.

Electrical processes for cementing (termed by Sang **electrocementizing**), as in the manufacture of steel, consist principally in the use of the current for heating purposes. There are also methods proposed (and patented) from time to time by which it is claimed the current is employed directly for securing better results, the current acting as a carrying agent.

An **anti-cement** is a coating which prevents or impedes cementation and is employed for the protection of a certain part which is not to be cemented; for example, in the **DeDion-Bouton process** copper is deposited from a solution of copper sulphate.

The theory of cementation is based on the observed fact that certain elements (in this particular case, carbon) have the power of diffusing through iron. Arnold and McWilliam have divided the elements most commonly found in steel into those which are **migratory** and those which are **fixed**. **Leplay's hypothesis** was that carbon monoxide was formed by a reaction of carbonaceous matter with air and that this alone acted as the carrier of, and deposited, carbon. **Laurent's hypothesis** was that the cementing action was due to a vapor of carbon and not to solid carbon. It has been proved, however, that solid carbon, as such, has the power of diffusing into iron; the usual action is due to both gases and to solid carbon.

Cementation Carbon.—See page 272.

Cementation Curve.—See page 67.

Cementation Furnace.—See below.

Cementation by Immersion.—See page 69.

Cementation Process.—Also called **converting process**. This process, in its special sense, consists in impregnating bars of wrought iron or soft steel with carbon, at a temperature below its melting point, and is used (chiefly in England) for the production of high carbon bars to be employed in the manufacture of crucible steel or shear steel. The bars are usually of pure Swedish iron made by the Walloon process (see page 79), $2\frac{1}{2}$ " to 3" wide, $\frac{5}{8}$ " to $\frac{3}{4}$ " thick, and about 12 feet long, 8 to 13 tons constituting a charge (Harbord and Hall). They are packed in layers, separated by charcoal (sometimes called **cement**) in fire-brick chambers (**converting pots**) heated externally by flues, and forming part of the **cementing furnace**. The top of the pot is closed with an arch of wheel swarf, which later frits and forms an airtight cover. The furnace attains its full temperature in about 3 to 4 days, at which it is maintained about 7 to 8 days for mild heats, about $9\frac{1}{2}$ days for medium heats, and about 11 days for high carbon heats; the cooling down requires about 4 to 6 days. To test the progress of the operation, **trial bars** (**test bars**, **tap bars**, **spies**, or **regulator test pieces**) are drawn at intervals through a special, small aperture, provided for the purpose, and examined. If wrought iron has been employed, the finished bars

will be found covered with blisters (also rarely called beads and bubbles) formed by the reaction between the contained slag and the carbon, from which comes the name blister bar or blister steel; at one time this was sometimes termed German steel. This phenomenon is absent when steel bars are treated; both products are known as converted bars, cement (cemented) bars or cement steel, at one time also called artificial steel because not made direct from the ore.

Bars desired of very high carbon may be retreated, and are known as doubly converted bars or glazed bars. Since the carbon penetrates from the outside inward, the percentage will decrease progressively to the center. In very mild bars there is an unaltered core of mild steel called sap, and very hard bars are easily distinguished by being what is known as flaked, as on fracture they present bright cleavage planes. Two examples of this are: (a) bar $\frac{1}{2}$ " thick, outside, 0.98%, center, 0.10%, average, 0.45%; (b) bar $\frac{1}{2}$ " thick, outside, 1.50%, center, 1.15%, average, 1.33%. In Sheffield the six grades of cement steel have the following names:

1. Spring heat.....	carbon about	0.50%
2. Country heat.....	" "	0.63%
3. Single-shear heat.....	" "	0.75%
4. Double-shear heat.....	" "	1.00%
5. Steel-through heat.....	" "	1.25%
6. Melting heat.....	" "	1.50%

The sap or soft center of No. 1 has a dull appearance (killed) and does not stare or look raw, *i.e.*, have a bright fracture. It is important to have the transition from one grade to the other as gradual as possible: when the line of demarkation is too abrupt, the process has been carried out too rapidly, and the bars are said to be flushed. If, owing to a leak in the pot, air has entered, the outside of the bars will be somewhat oxidized, and are called aired bars. If the temperature has been a little too high, so the outside has fused slightly, they are called glazed bars. Blister bars rolled or hammered down at a yellow heat are known as plated bars or bar steel. The following are various methods suggested or tried from time to time:

In Bink's process compounds of cyanogen were specified, and currents of nitrogen, carbonic oxide, and ammonia, or ammonia alone, were to be passed through decarburized molten iron.

In Boulet's process iron was to be cemented with a substance consisting of sugar, horn dust or shavings, animal fat or blood, and wood charcoal dried and pulverized.

In Brooman's process iron was to be melted in pots with compounds of cyanogen; such compounds might consist of charcoal, salt, brick dust or oxide of manganese, sal ammoniac, and ferrocyanide of potash.

Henry Brown's process consisted in cementing iron in a granulated condition in close pots with carbon: iron which was being puddled was taken out of the furnace as soon as it became granulated, and before it was pasty; it was then broken up until

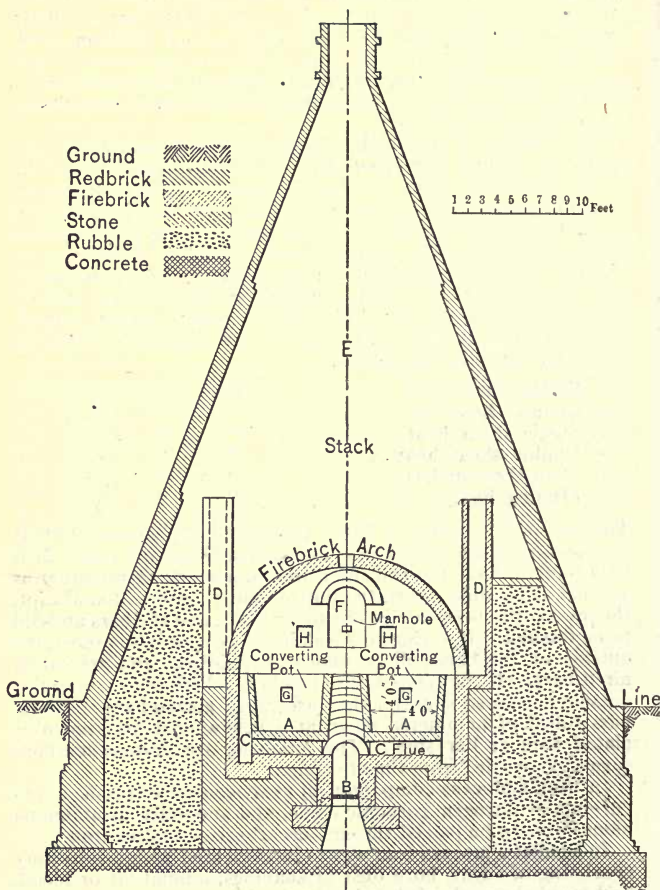


FIG. 13.—Transverse section of cementation converting furnace—A, converting pots; B, firegrate; C, flues for distributing heat; D, short chimneys communicating with stack; E, conical hood or stack; F, manhole for introducing or withdrawing charge; G, holes for removal of trial bars; H, charging holes. (Harbord and Hall, "Metallurgy of Steel".)

it would pass through a 20-mesh screen, after which it was put in long pots with wood and cemented as usual.

James Boydel's process was to cement the product obtained by puddling wrought iron melted in a cupola.

In **Holland's process** silk waste of every kind was to be torrified, *i.e.*, dried at a high temperature without being carbonized, and then ground to a fine powder, and used for cementing.

Kimball's process consisted in cementing bars with a special mixture prepared from sal ammoniac, borax, alum, salt, vinegar, urine, soot, burnt leather, and horsehoofs.

Kraff and Sauve's process consists in employing charcoal, etc., previously heated to about 50° C. (122° F.) and dipped in some liquid hydrocarbon.

Charles Macintosh heated wrought iron to a white heat in closed pots, and then introduced carburated hydrogen or carbonaceous gases through suitable openings.

A. V. Newton's process consisted in melting pig iron in a special furnace, and blowing on it jets of hydrocarbon gases and atmospheric air.

Moses Poole specified the use of prussiates and ferrocyanides.

G. C. Thomas claimed the decided novelty of a cementing (?) mixture consisting of salt, ferrocyanide of potash, bichromate of potash, and animal charcoal.

In **Arthur Wall's process** iron was to be cemented by embedding bars, in an ordinary cementing furnace, in a mixture of charcoal and chalk and zinc filings; electric currents were to be passed through the bars for a certain period.

J. J. W. Watson claimed the use of electricity for carburizing iron; he also employed sulphate of manganese with carbonaceous matter and lime, either with or without the application of an electric current.

Cemented Armor Plate.—See page 8.

Cemented Bars; Steel.—See page 71.

Cemented Zone.—See page 67.

Cementing Furnace.—See page 70.

Cementing Fusion Process.—See page 113.

Cementite.—See page 272.

Cementite Carbide.—See page 273.

Cementite Point.—See page 273.

Cementitic Steels.—See page 445.

Cementito-Austenitic Steel.—See page 276.

Centigrade Scale.—Of temperature degrees: see page 204.

Centrifugal Casting.—See page 62.

Centrifugal Extrusion.—See page 121.

Chafery (obs.).—A sort of blacksmith's forge.

Chalcopyrite.—See page 245.

Chalk Method.—See page 65.

Chalut and Clouet Process.—See page 113.

Chalybeate.—Containing iron, usually applied to water.

Chalybite.—See page 244.

Chambered Core.—See page 299.

Chamotte.—Powder of old clay crucibles: see page 396.

Champin Pneumatic Process.—See page 21.

Champlain Forge.—See page 137.

Channeling.—See page 35.

Chapelet Furnace.—See page 154.

Chaplet; Chaplet Block; Nail.—See page 299.

Chappuis Gas Pyrometer.—See page 207.

Char.—(1) To carbonize; (2) coke or charcoal (Eng.).

Charcoal.—The carbonaceous residue resulting from the dry distillation of wood, amounting to about 26%. Owing to its ease of preparation and its comparative freedom from sulphur and ash, it has long been used in certain metallurgical processes. Ledebur gives the approximate composition of good air-dried charcoal as:

Volatile matter.....	4%
Fixed carbon.....	84
Ash.....	2
Sulphur.....	under 0.05
Phosphorus.....	“ 0.05
Moisture.....	10

Red Charcoal is the name given to the product obtained by charring wood at a low temperature and which is of intermediate composition between wood and charcoal.

The wood was formerly charred exclusively in piles (sometimes called **meilers**) covered over with earth or turf, small openings being provided for the entrance of the air and for the escape of the gases. The most usual method is to employ a **charcoal kiln**, which is a stall consisting of two side walls and a back wall, the front and top being covered with earth and turf as in the case of the pile. It is now frequently prepared in **charcoal ovens** or **charcoal retorts**, similar in principle to those used in the manufacture of coke; in the former case, combustion of the gases takes place inside the chamber, while in the latter, the chamber is externally heated by flues or a fire.

Charcoal Bars.—(1) Wrought iron rods or flats; (2) wrought iron bars made by some charcoal hearth process, or from charcoal pig, to be rolled into sheets: see page 75.

Charcoal Blacking.—See page 298.

Charcoal Finery.—See page 383.

Charcoal Furnace.—See pages 39 and 181.

Charcoal Hearth; Charcoal Hearth Cast Iron.—See page 383.

Charcoal Hearth Processes.—Rarely called **forge process**; **bustling** and **buzzing** are very obsolete terms (Percy). These processes are designed for the production of wrought iron (charcoal iron), usually by refining cast iron, occasionally by melting scrap before a tuyere with charcoal for fuel, the product being obtained in a pasty condition, and containing a certain amount of slag, but less than puddled iron. Only the latter method is at present employed in this country.

In general the furnaces or hearths are (Howe) like the Catalan and bloomary hearths (see Direct Processes), for reducing iron

from the ore, low, rectangular chambers, sometimes roofed, and with one or more tuyeres. The chief difference is that in refining cast iron much more strongly oxidizing conditions are brought about, chiefly (1) by melting the metal down in drops before the tuyere, repeatedly, if need be, so that it passes in a state of minute subdivision and with great surface exposure through a part of the hearth where the atmospheric oxygen is in excess; and (2) by the action of the basic ferruginous slag with which the metal is mixed during the earlier stages, and with which it is covered during the later stages, to ward off the strongly carburizing tendency of the charcoal. Only a good quality of pig iron (nearly always charcoal pig) is used, as the process is expensive, and is employed only for a high grade of wrought iron. The pig iron is often given a preliminary refining to eliminate most of the silicon.

The hearths are usually built of unlined cast-iron plates, at least in part water-cooled. Brick-work is avoided as the silica would enter the slag.

The processes may be classified (Howe) according to the number of times the metal is melted down before the tuyere, (1) into single melting, double melting, and triple melting (or German or breaking up); (2) into Walloon and non-Walloon.

The hearth may be covered or uncovered; if the latter it is called an open fire or open hearth; if the former, a closed hearth. The bloom, after rolling, is called finer's bar (corresponding to muck bar in puddling), and after piling and rerolling, finished charcoal bar. German steel is an obsolete name for the product obtained by melting white or refined pig in a charcoal hearth; it may also be made of poorer quality in a very hot puddling furnace.

Product.—"From given cast iron the charcoal hearth process yields better wrought iron than puddling, perhaps in part because the charcoal lacks the sulphur which the mineral fuel of the puddling furnace contains, and of which a little may enter the metal, but chiefly for the following reason. In both processes we can decarburize the pasty metal throughout its mass only by stirring it vigorously, exposing fresh surfaces to the action of the atmosphere and of the strongly decarburizing basic slag, and this stirring intentionally mixes slag with metal to effect decarburizing. We thus get a ball of stiff pasty wrought iron mixed with much slag. In some of the charcoal hearth processes we get rid of most of this slag by remelting this ball; holding it aloft we allow its metal to fall drop by drop, and collect it in a new ball, which we carefully avoid touching, and which is thus relatively free from slag. In the puddling process we cannot do this, and must content ourselves with squeezing out as much of the slag as we can in hammering or rolling. Charcoal iron, then, is in a manner intermediate between common wrought iron and ingot iron (fluid-cast steel, see Classification) in that it is remelted and cast while molten into a malleable mass; but instead of being cast into a slagless mold as in true ingot-metal-making processes, it is poured upon a bath of slag of which a very

little inevitably becomes mixed with the metal. Charcoal iron is raised but slightly above its melting point and for a few minutes only; is cast drop by drop through an atmosphere rich in carbonic oxide and carbonic acid into a white-hot bath of slag, falling in all but a few inches; ingot iron is held for a very considerable length of time far above its melting point, is cast in a thick stream, through a cold atmosphere of oxygen and nitrogen, usually into a cold cast-iron mold, often falling several feet. In the charcoal hearth, drop of metal follows drop in such a way that neither pipe nor blowhole nor microscopic cavity seems to form; ingot metal is so cast that pipes or blowholes or microscopic cavities or all three arise. Charcoal hearth iron is purposely kept as free as possible from slag, ingot metal is purposely kept practically absolutely free from slag" (Howe).

In the **Bohemian process**, mottled or even gray pig is used, and the blooms are reheated in the same hearth. Charcoal is first charged, and on top of this some slag and the pig which is melted down slowly, the iron cake which is formed being frequently raised up. The cinder is tapped at intervals. Finally the bloom is welded to the end of a rod and taken to the hammer; any particles of iron that remain in the hearth are retreated.

Carinthian process: The pig used is white, and is cast in thin disks about 3 to 6 feet in diameter and $\frac{1}{4}$ " thick, which are given a preliminary heating or roasting for about 30 hours, which removes some of the carbon as well as the silicon. The disks are broken up and piled on charcoal in the hearth, which is of about the usual type. The metal is gradually melted down, care being taken that no pieces of unmelted metal drop into the melted portion. The bloom is divided into two pieces, and each of these into six, which are reheated in the same hearth. A charge takes about $2\frac{1}{4}$ hours.

The **Carinthian raw steel process** is very similar to the preceding, except that the removal of the carbon is not carried so far. Mottled, rarely gray, pig, or the round disks described above, are used. The bottom is made of charcoal and binding material rammed hard in layers. The pig is melted down with addition of cinder. The cinder is then taken off, the iron piled up in the middle of the hearth and melted down again, when it reposes on the bottom under a layer of slag. The slag is again removed, and the bloom taken out, hammered, etc. The product is apt to be very heterogenous; about three-quarters of it is good steel. The process takes about $2\frac{1}{2}$ hours. The blooms are cut in two, and reheated separately in the same hearth.

Fosberg's Swedish hearth is very similar to the ordinary Lancashire hearth, except it has three tuyeres (one at the back) instead of two, and also an adjustable bottom whose height can be regulated as desired.

Franche-Comté process: The hearth is nearly rectangular, and is composed of cast-iron plates; it is closed, and the bottom may be cooled between heats with water underneath. It is provided with one or two tuyeres, and the blast is preheated

by the products of combustion. Pigs of gray cast iron are melted down as in the Swedish Wallon process, *i.e.*, are gradually pushed forward as their ends melt off. This continues for about 90 minutes or less, during which the bloom from the preceding charge, having been cut in two, is reheated in the same hearth, and forged, three heatings and forgings being needed for each half bloom. The pasty mass, which has meanwhile accumulated on the hearth bottom, is now lifted above the tuyeres and gradually melted down, falling drop by drop past the tuyeres. This occupies some 20 to 25 minutes more. Those parts of the mass resulting from this second fusion which are still imperfectly decarburized must be raised up and melted down a third time (Howe).

The **J. J. Hudson process**, recently employed in this country, consists in melting the charge between layers of charcoal in a specially designed furnace of the open hearth type. The furnace is preheated by means of oil or gas, and a thick bed of charcoal is provided upon which the charge of pig is made. By the introduction of blasts of cold air through tuyeres, the metal is melted and boiled, filtering through the charcoal which consumes the impurities, eliminating them from the molten mass. Charcoal may be added at any time during the heat and is generally added near the end to dispel any injurious gases that may arise, thereby insuring complete purification of the metal. The method has the effect of purifying and refining the iron by decarburization and oxidation. It is stated that it may be applied to the manufacture of charcoal steel (higher in carbon) with equally valuable results. (*Iron Age*, 4/18/12).

In the **Lancashire process**, **American Lancashire process**, and **Swedish Lancashire process**, all of which are about the same, the hearth consists of unlined, water-cooled, cast-iron plates, and is provided with two (sometimes only one) tuyeres. The blast is somewhat preheated by the products of combustion. If not enough slag remains from the last operation to cover the bottom, some is added, and charcoal is piled up to above the tuyeres. On top of this is placed the pig in lumps (sometimes previously heated in the same hearth), which is covered with charcoal and the blast turned on. The pig melts in drops which, in passing the tuyere area, become partially decarburized and collect on the bottom. When it is all melted, it is worked with bars so it will become mixed with the slag and be thoroughly purified. When this has taken place, as shown by the fact that it is stiff and pasty the mass is raised above the tuyeres and melted down again to free it from the intermingled slag, care being taken that this remelted lump is not cut by the working bars, as this would introduce fresh slag. The lump is then taken from the furnace and hammered, etc. The operation takes about $1\frac{1}{4}$ to $1\frac{1}{2}$ hours. About 275 to 300 pounds of pig are used for a charge. A modification of this process consists in simply melting soft scrap, which is practically the last stage in the method where pig is employed. This is used to some extent in this country for making charcoal sheets, etc.

The **Lombardy process** has the peculiarity of subjecting the pig to a special refining before the process proper commences. The pig is charged in the hearth on top of charcoal, and melted slowly in about $2\frac{1}{2}$ hours, with only a small amount of blast. During this period charcoal is thrown on occasionally, and each time this is done the pig is raised up. The charcoal is then taken out, the slag chilled with water and removed, and hammer slag mixed with the molten metal, which becomes pasty and is taken out and broken up into six pieces. The hearth is then cleaned and filled with powdered charcoal which is thoroughly stamped down. Each of the pieces of metal is then melted down separately with slag or charcoal, and subsequently refined as usual. The time required for the entire charge is not less than 18 hours, and the charcoal required amounts to about $2\frac{1}{2}$ times the weight of the pig (Percy).

The **Paal steel process** is very similar to the Carinthian. The pig is melted down to form a cake, while pieces of the previous bloom are reheated in the cinder and hammered. The bottom cake is then exposed, and, if already hard and steely, is finished, but if otherwise, it must be further treated. For this purpose the charcoal is removed from the hearth, and rich scale or oxides are stirred into the iron until it begins to get hard, when the charcoal is put back and the metal melted down; after this the bloom is hammered, etc. Some of the metal remains in the hearth, and forms part of the next charge (Percy).

The **Rohnitz process** resembles the Bohemian most nearly. Reheating and refining operations take place simultaneously in the same hearth. Mottled or even gray pig is used, and the metal after melting down is treated as in the Lombardy process (Percy).

In the **Salzburg process** gray pig is used, which is subjected to some preliminary treatment as in the Lombardy process. Reheating and refining are conducted in the same hearth, but the former is finished before the latter begins. A considerable amount of cinder is formed, and it must be tapped out frequently.

In the **Siegen process** the bottom of the hearth is formed of a mixture of crushed cinder and hammer slag. Mottled or white pig, in long pieces, is treated exactly as in the Walloon process.

In the **Siegen raw steel finery process** the hearth is much as usual, with the bottom composed of pieces of fine-grained sandstone; there is usually one tuyere. The blooms are cut in pieces and reheated in the same hearth, one piece being melted down with the next charge. The pig is melted down in successive portions, on top of the charcoal, and rich cinder is thrown in to oxidize the carbon; if this action has gone too far, spiegel is added. The excess of cinder is tapped off, and when the ball is of the proper size and consistency, it is removed, hammered, cut up, and graded by fracture, the product being heterogeneous. One charge requires about 7 to 8 hours.

In the **slag bottom process**, practised in Styria, the hearth is similar in construction to the Franche-Comté, etc. The

bed is composed of rich finery cinder, broken up small and stamped down carefully. White pig iron is used in small pieces, which are melted down on charcoal. The bloom is divided into eight pieces, which are reheated in the slag in the same hearth. A charge takes about $1\frac{1}{2}$ to 2 hours (Percy).

In the **South Wales (South Welsh) process**, pig iron is first melted down in a coke refinery, and there part of its silicon and carbon are removed by the action of the blast. It is then tapped out into a pair of charcoal hearths, the relatively acid slag being held back, and any which runs into the charcoal hearths being carefully removed. The partly solidified metal is broken up and piled near the tuyere. After melting down, it is repeatedly raised slightly from the bottom, apparently as in the Lancashire process. The slag is tapped off from time to time. As soon as the metal has come to nature, it is withdrawn and hammered (Howe). When the metal melts down, after being piled up in front of the tuyere, the operation of working it is termed **sinking a lump** or **sinking**. The last cinder solidifies into a more or less cylindrical piece, hollow in the center, due to chilling around the point of a bar inserted through the cinder hole, and is called a **fox tail**. The ball is hammered into oval slabs which are nicked in seven or eight places, quenched in water; and broken into pieces called **stamps**, which are graded according to their fractures. These are reheated in a furnace called a **hollow fire** which has two chambers, in one of which coke is burned, and in the other the iron is heated so it does not come in contact with the fuel, but only with the gas. The stamps are laid on a peel (**staff**), the blade of which is of the same quality of iron. After heating, they are welded together, then nicked and bent over so the staff material forms the top and bottom.

The **Knobbling process** is practically identical with the South Wales.

Stridsberg's hearth is provided with four tuyeres and two working doors on opposite sides, and is practically a double Lancashire hearth.

The **Styrian charcoal process (Styrian open hearth)** employs the ordinary type of hearth. The bed is formed of small pieces of charcoal, mixed with a small amount of cinder from the previous heat. Reheating and refining are performed simultaneously in the same hearth. White pig iron, in small pieces, is slowly melted down on charcoal in two portions; this is arranged so that the second portion shall begin to melt about 10 minutes after the commencement of the first. A small amount of hammer slag is thrown on the melted metal which has previously been denuded of charcoal. The bloom is cut into four pieces for subsequent hammering, etc. A heat lasts about 2 hours (Percy).

The **Styrian raw steel process**, according to Tunner, bears such a close resemblance to the preceding that it is difficult to distinguish between them, and frequently soft iron is made by this process.

The **Tyrol process** closely resembles the Styrian.

The **Walloon process**, or **Swedish Walloon process**, is used

in Sweden for making bars to be converted into blister steel. The hearth is rectangular, and is built of unlined, water-cooled, cast-iron plates, and is provided with one tuyere. One or two very long pigs of white or mottled cast iron are melted down drop by drop, being pushed forward as their ends melt off, till enough to yield a bloom of from, say, 84 to 93 pounds has been melted. This may take some 20 minutes, during which the pasty metal, gradually reaching the bottom of the hearth, is worked constantly. The pasty mass is now broken up, raised above the tuyere, and melted a second time, apparently much as in the Lancashire method. During this time the bloom from the preceding charge is heated in this same hearth, held steeply inclined (Howe).

The **Eifel Walloon process** and the **Styrian Walloon process** appear to have no essential differences from the above.

Charcoal Iron.—(1) Pig iron smelted with charcoal: see page 343; (2) wrought iron made by some charcoal hearth process (*q.v.*), or from charcoal pig: see page 379.

Charcoal Kiln.—See Charcoal.

Charcoal Pig.—See page 343.

Charcoal Plate.—See page 433.

Charcoal Refinery.—See page 383.

Charcoal Retort.—See Charcoal.

Charcoal Sheet.—See page 433.

Charcoal Steel.—See page 77.

Charcoal Wrought Iron.—Wrought iron produced by some charcoal hearth process, or from charcoal pig.

Charge.—(1) In a blast furnace, the amount of material composing a round; (2) in other furnaces, the total amount of material for a heat.

Charger.—In the crucible process: see page 114.

Charging Box.—See page 314.

Charging Door.—Of a furnace: see pages 182 and 183.

Charging Machine.—See page 314.

Charging Tray.—Charging box: see page 314.

Charkt. (obs.).—An old English name for a kind of charcoal.

Charles's Law.—See Gas.

Charpy Pendulum Hammer; Test.—See page 482.

Check Analysis.—See page 82.

Checkers; Checkerwork.—See pages 203 and 311.

Checking.—Cracking: see pages 56 and 110.

Cheek.—See page 297.

Cheese.—See page 61.

Chemical Action; Affinity.—See page 84.

Chemical Analysis.—See pages 82 and 284.

Chemical Bond.—See page 86.

Chemical Compound.—See page 83.

Chemical Energy.—See page 84.

Chemical Equation.—See page 87.

Chemical Equivalent.—See page 87.

Chemical Formula.—(1) Meaning: see page 86; (2) for physical properties: see page 337.

Chemical Hardening.—See page 69.

Chemical Hardness.—See page 331.

Chemical Impurity.—See impurity.

Chemical Metallurgy.—See Physical Metallurgy.

Chemical Methods of Etching.—See pages 286 and 287.

Chemical Passivity.—See page 364.

Chemical Purity.—See page 89.

Chemical Reaction, Reagent.—See page 86.

Chemical Solution.—See pages 88 and 107.

Chemical Symbol.—See page 86.

Chemically Dissolved.—See page 107.

Chemistry.—Matter is anything which occupies space. It is considered made up of very small particles called **molecules** or **atomic aggregates**, which again are composed of **atoms**. A molecule is the smallest particle of matter which can exist in the free state, and an atom is a smaller particle which enters into chemical combination. This constitutes the so-called **atomic theory** upon which chemistry is based. Physics is concerned principally with the relations of molecules, and chemistry with the relations of atoms. Quite recently the **electron theory** or **electronic theory** has been advanced that the atom is not, as formerly assumed, the smallest possible unit, but is itself a system consisting of a nucleus charged with positive electricity and **electrons**, each of which carries the minimum unit charge of negative electricity. **Meta-element** was the name suggested by Crookes for a supposed variety of an element whose existence was indicated by spectrum analysis.

There are three states of matter: the **solid**, the **liquid** and the **gaseous**. The solid state is due to the strong attraction or cohesion between the particles; with liquids the attraction is much less, while with gases there is a repulsion. Different, more specific, terms have been adopted to indicate changes affecting the state or condition of matter. **Transformation** signifies a change of the same substance from one form to another without change of state, as in the case of allotropy; a special case of transformation is sometimes known as **transmutation**, a term employed by the alchemists to signify the change of one metal into another, as lead into gold; **conversion** is still used in this latter sense, as in the conversion of pig iron into steel. **Transition** is a change of state as solid to gaseous. **Transference** is the change of place of substances or forces, as the point at which a force is applied. **Translation** is the bodily removal of a substance from one place to another. Martens uses the following terms to indicate how solid material may be brought by physical means to possess the desired shape or form: (1) **division**: the separation into different parts, as by cutting; (2) **transformation**: changing the original shape without separation, as by hammering; (3) **agglomeration**: uniting various parts into one whole, as by welding. By state of aggregation is understood the different conditions in which matter may exist.

Chemistry is divided into **theoretical** or **pure**, which deals with the underlying laws and relations, and **applied** or **technical** which,

as the name implies, relates to its commercial application. It is usually further divided into **organic** (the chemistry of compounds containing carbon) and **inorganic chemistry** (the chemistry of compounds which do not contain carbon), but the line is not sharply drawn. These again are divided into **synthetic (synthetical)** and **analytical (analytic) chemistry**, the former having to do with the building up of more complicated from less complicated substances, while the latter deals with the determination of the components of a substance. **Chemical analysis** indicates that the analysis is by chemical methods as distinguished from mechanical or microscopic methods, etc. **Analytical chemistry** is subdivided into **qualitative analysis** (determining only the constituents but not their respective percentages) and **quantitative analysis**, where both the constituents and their respective percentages are determined. **Quantitative analysis** may be further divided into **proximate** and **ultimate**, the former determining the percentage of the compounds of which a substance is made up, while the latter determines the percentage of the elements; e.g., the proximate analysis of coal (that almost always made) shows the percentages of volatile matter, fixed carbon, moisture, sulphur, and ash; the ultimate analysis of the same sample would show the percentages of hydrogen, oxygen, carbon, nitrogen, etc. If an analysis is performed with the aid of liquid solvents and reagents, it is called **wet** or **humid analysis (process)**, while if dry reagents and heat are employed, it is called **dry analysis (process)**, and this latter branch of chemistry, including the relations of reactions to the evolution (**exothermic reaction**) or the absorption of heat (**endothermic reaction**), is termed **thermochemistry** or **thermal chemistry**; the corresponding branch of metallurgy, **thermometallurgy**; **thermolysis** is the analysis or dissociation of a substance by the application of heat alone. The analysis of ores is usually termed **assaying**, which is divided into **wet assaying** and **fire assaying**. In the manufacture of steel a **ladle analysis** is that made from drillings from a small test ingot or ingots (**ladle test**—in England termed a **pit sample**) taken during the pouring of each melt. A **finished material analysis** is one made on a sample of material after being rolled or otherwise worked; a **check analysis** properly means a duplicate determination to ascertain or confirm a previous result, but is also commonly used in the same sense as finished material analysis and as distinguished from a ladle analysis. A **residue analysis** is one made on what remains after the other portion of a substance has been dissolved away—the method followed in determining the composition of cementite after the iron matrix has been dissolved. **Spectrum analysis** is the determination of a substance or of its constituents by the color of its "flame" when heated to a point of incandescence; the instrument used in this work is termed a **spectroscope**. **Microchemistry** is where chemical methods are employed on minute substances or portions of matter in conjunction with microscopical methods. In some cases, particularly in the study of alloys, it is desirable (owing to differences in atomic weight) to express composition

as atom percent instead of actual weight percent; this is arrived at by a proportion between the respective percentages by weight and the atomic weights, *e.g.*:

	Weight, %	Atom, %
Copper (atomic weight, 63.5)	90	94.4
Tin (atomic weight, 118.0)	10	5.6

If the molecules of a given substance are composed of similar atoms, the substance is called an **element**; if of two or more different kinds, a **compound** (chemical compound). A **mechanical mixture** (intimate mixture) is where two or more substances are in a very fine state of division, and very intimately mixed, but can be separated by purely mechanical means, *e.g.*, a mixture of iron filings and powdered sulphur can be separated by the aid of a magnet. A compound is said to be **semi-combined** when the constituents are only loosely held together, as in the case of water of crystallization. While atoms are too small to be measured or weighed directly, it is possible to compare their properties with each other, and their relative weights are called **atomic weights**. Formerly these weights were based on that of hydrogen, the lightest atom, as 1; the present standard is based on a weight of 16 for oxygen as this gives numbers which are somewhat easier for calculations. The molecular weight in grams is called the **gram molecular weight** (**G. M. W.**) usually abbreviated to **molar weight** or simply **mole**. In chemical work it is frequently useful to make up what are known as **standard solutions** which contain a definite amount of some reagent; a **molar solution** contains one mole of solute (dissolved substance) per liter of solvent; a **normal (N) solution** is one which contains, per liter, an amount of the substance equal to the mole divided by the valence or basicity; a **decinormal** or tenth normal (**N/10**) solution, for example, contains one-tenth this amount. The percentage of the solute is often referred to as the **concentration**. From Avogadro's law (see below) it is evident that a mole of any gas will occupy the same volume (22.4 liters under standard conditions of temperature and pressure); this is known as a **gram-molecular volume** (**G. M. V.**) or **molar volume**.

There are now 83 **elements** recognized, but not over about half are of common occurrence or application; these, together with their symbols and atomic weights are listed in the accompanying table. Elements are classed as **metals** and **non-metals**, while certain ones occupying an intermediate position are called **metalloids** (of the nature of metals). Metals have a bright appearance or **metallic luster**, at least when freshly polished, and in varying degrees the properties of malleability, ductility, etc., and their oxides are generally basic; the non-metals have not these physical properties, and their oxides are generally acid; metalloids, as a rule, resemble the metals in their physical properties or, as in the case of carbon, in their ability to form alloys with metals, and the non-metals in their general chemical properties. Following the classification of the alchemists, metals are still referred to as noble or base (ignoble); the

International Atomic Weights (1917)

Oxygen = 16

Element	Sym- bol	Atomic weight	Element	Sym- bol	Atomic weight
Aluminium.....	Al	27.1	Molybdenum.....	Mo	96.0
Antimony.....	Sb	120.2	Neodymium.....	Nd	144.3
Argon.....	A	39.88	Neon.....	Ne	20.2
Arsenic.....	As	74.96	Nickel.....	Ni	58.68
Barium.....	Ba	137.37	Niton (radium emanation)	Nt	222.4
Bismuth.....	Bi	208.0	Nitrogen.....	N	14.01
Boron.....	B	11.0	Osmium.....	Os	190.9
Bromine.....	Br	79.92	Oxygen.....	O	16.00
Cadmium.....	Cd	112.40	Palladium.....	Pd	106.7
Cæsium.....	Cs	132.81	Phosphorus.....	P	31.04
Calcium.....	Ca	40.07	Platinum.....	Pt	195.2
Carbon.....	C	12.005	Potassium.....	K	39.10
Cerium.....	Ce	140.25	Praseodymium.....	Pr	140.9
Chlorine.....	Cl	35.46	Radium.....	Ra	226.0
Chromium.....	Cr	52.0	Rhodium.....	Rh	102.9
Cobalt.....	Co	58.97	Rubidium.....	Rb	85.45
Columbium.....	Cb	93.1	Ruthenium.....	Ru	101.7
Copper.....	Cu	63.57	Samarium.....	Sa	150.4
Dysprosium.....	Dy	162.5	Scandium.....	Sc	44.1
Erbium.....	Er	167.7	Selenium.....	Se	79.2
Europium.....	Eu	152.0	Silicon.....	Si	28.3
Fluorine.....	F	19.0	Silver.....	Ag	107.88
Gadolinium.....	Gd	157.3	Sodium.....	Na	23.00
Gallium.....	Ga	69.9	Strontium.....	Sr	87.63
Germanium.....	Ge	72.5	Sulphur.....	S	32.06
Glucinum.....	Gl	9.1	Tantalum.....	Ta	181.5
Gold.....	Au	197.2	Tellurium.....	Te	127.5
Helium.....	He	4.00	Terbium.....	Tb	159.2
Holmium.....	Ho	163.5	Thallium.....	Tl	204.0
Hydrogen.....	H	1.008	Thorium.....	Th	232.4
Indium.....	In	114.8	Thulium.....	Tm	168.5
Iodine.....	I	126.92	Tin.....	Sn	118.7
Iridium.....	Ir	193.1	Titanium.....	Ti	48.1
Iron.....	Fe	55.84	Tungsten.....	W	184.0
Krypton.....	Kr	82.92	Uranium.....	U	238.2
Lanthanum.....	La	139.0	Vanadium.....	V	51.0
Lead.....	Pb	207.20	Xenon.....	Xe	130.2
Lithium.....	Li	6.94	Ytterbium (Neoytterbium)	Yb	173.5
Lutecium.....	Lu	175.0	Yttrium.....	Yt	88.7
Magnesium.....	Mg	24.32	Zinc.....	Zn	65.37
Manganese.....	Mn	54.93	Zirconium.....	Zr	90.6
Mercury.....	Hg	200.6			

base metals were those which were readily dissolved by ordinary acids or solvents, while the noble metals resisted all but the most powerful, such as aqua regia ("royal water") a mixture of about 3 parts of hydrochloric acid and 1 part of nitric acid.

The attraction between atoms which causes them to combine to form a molecule is called **chemical affinity** (such an aggregation of atoms and their mutual attraction is sometimes termed **association**), and the cause, **chemical attraction** or **chemical energy**. It is always assumed that a molecule is made up of whole atoms, and not of fractions of an atom. The following are the fundamental laws with regard to combinations of atoms: **constant proportions** or **definite proportions**: A given compound always

contains the same elements combined together in the same proportion by weight. **Multiple proportions (Dalton's law):** When the same two elements combine together to form more than one compound, the different weights of one of the elements which unite with a constant weight of the other bear a simple ratio to one another. **Reciprocal proportions, or equivalent proportions:** The weights of different elements which combine separately with one and the same weight of another element are either the same as, or are simple multiples of, the weights of these different elements which combine with each other. **Gaseous volumes (law of Gay-Lussac):** When chemical action takes place between gases, either elements or compounds, the volume of the gaseous product bears a simple relation to the volumes of the reacting gases. Other basic laws are: **Avogadro's law:** Under the same conditions of temperature and pressure, equal volumes of all gases contain the same number of molecules. **Dulong and Pettit's law of atomic heat (only approximately true):** The product of the atomic weight of an element by its specific heat is a constant quantity (approximately 6.4).

In 1863-64 Newlands found by arranging the elements (omitting hydrogen) in the order of their atomic weights that there was a recurring similarity in their characteristics; what is known as **Newlands' law of octaves** is that each element closely resembles the eighth element (counting the element itself as one) above or below it in the scale. There is some difficulty in making out the scale above chlorine (35.5), which was largely corrected by Mendelejeff in 1869: **Mendelejeff's periodic law** is that all the properties of the elements are periodic functions of their atomic weights. He was able to predict certain elements unknown at the time, and to foretell with an astonishing degree of accuracy what properties they would possess; which predictions were notably confirmed in the cases of scandium, gallium and germanium.

Isomerism.—All bodies of identical molecular weight were originally termed isomeric; but it is now found convenient (Thorpe) to restrict this term to bodies which not only possess identical molecular weights, but are also of similar chemical type, and possess different physical and chemical properties. Professor Howe proposes the following definition: **Isomerism** is a change in the properties of a compound without change of state or of ultimate composition. It is habitually accompanied by a change in internal energy, and it is supposed to be due to a change in the number or in the arrangement of the atoms in the molecule. It is to compounds what allotropy is to elements (I. A. T. M.).

Metamerism is where compounds have not only the same percentage composition but also the same molecular weight. **Polymerism** is a case of the same percentage composition but different molecular weights.

One atom does not necessarily combine with only one other atom; it may combine with several, or several of the same kind may be needed to combine completely (saturate) another.

Hydrogen and certain other elements which have the smallest combining power (**valence, valency, or atomicity**) have assigned to them a value of 1; they are said to be **monovalent** or **univalent** atoms, or simply a **monad**. To make this clearer it is assumed that such an atom has a single bond which can become attached only to a single bond of another atom. Thus, if an atom has two such bonds, it can become attached to the bonds of two monovalent atoms, or of one divalent atom. Valences are expressed as follows:

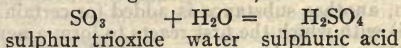
Valence	(noun)	Name (adjective)
I	monad	monovalent or univalent
II	dyad	divalent
III	triad	trivalent
IV	tetrad	tetravalent or quadravalent
V	pentad	pentavalent
VI	hexad	hexavalent

To avoid writing the name of an element in full each time, abbreviations of the name (or the Latin or Greek name), called **chemical symbols**, are employed. The symbol for an element denotes not only the name, but also one atom, the atomic weight, and all the various properties which it possesses. The composition of a substance or compound represented by symbols is called its **formula (chemical formula)**. Where there is more than one atom of a given kind in a molecule, it is indicated by a figure written just below and to the right of the chemical symbol; thus, Fe_2O_3 shows that a molecule of ferric oxide is composed of two atoms of iron (Fe) and three atoms of oxygen (O). A number written immediately in front of such a formula, and on the same line, applies to the formula as a whole; thus, $3\text{Fe}_2\text{O}_3$ represents three molecules. There are different kinds of chemical formula. The one described above is that ordinarily referred to and is the simplest; it is known specifically as an **empirical** or **composition formula**. A **rational** or **constitutional formula** indicates the manner in which a compound is made up; thus calcium carbonate (CaCO_3) may be written $\text{CaO}\cdot\text{CO}_2$ or $\text{Ca}\left\langle\begin{array}{c} \text{O} \\ \text{O} \end{array}\right\rangle\text{C}=\text{O}$. This latter form indicates the valence of and manner of joining the several atoms, and hence is termed a **structural, graphic, linkage, or valence formula**. To indicate wherein lies the difference in properties of certain compounds (**isomers** or **stereo-isomers**) which have the same composition formula, it is necessary to resort to three-dimension space, and hence they are termed **stereo-formulæ**; the special branch dealing with this subject is termed **stereo-chemistry**.

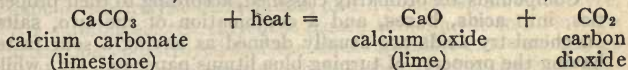
Chemical Reactions.—When two or more different molecules are brought together, the atoms will rearrange themselves, provided, under the given conditions, they have not a greater affinity for the atoms with which they are already combined. This rearrangement is called a **reaction**. A substance which, when added to another, causes a reaction is called a **reagent**

(chemical reagent); this term is commonly restricted to certain substances, such as acids and standard solutions, constantly in use in a chemical laboratory, particularly those used in analytical work. The following types of reactions may occur:

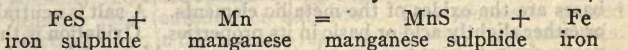
1. **Synthetic reaction:** Where two or more different substances combine to form a single substance, as



2. **Analytical reaction:** Where one substance is split up (by heat or otherwise) into two or more different substances, as



3. **Metathetical reaction:** Where two or more substances react to form two or more entirely different substances, as



Catalysis is where a chemical reaction is promoted by the presence of another substance (catalytic agent or catalyst) which does not itself take part directly, but remains the same throughout, or is only temporarily affected.

The **combining weight** or **chemical equivalent** is the atomic weight divided by the valence, *e.g.*,

Name	Atomic Weight	Valence	Combining Weight
Sodium	23	I	23
Calcium	40	II	20

The **atomic volume** is the value obtained when the atomic weight is divided by the specific gravity. It is sometimes desired (in considering volume, etc.) to ascertain what is known as the value of one or more elements in terms of another; for example, the **carbon value** of phosphorus is obtained by dividing the given percentage of phosphorus by 31 (its atomic weight) and multiplying by 12 (the atomic weight of carbon).

That portion of a molecule which enters into a chemical reaction is termed a **radical**; if it is a single atom, such as Ca or Na, it is a **simple radical**; if composed of two or more atoms, acting like a simple body, such as SO_4 or NH_4 , it is a **compound radical**.

A molecule consisting of a single atom is said to be **monatomic**; a molecule or a radical consisting of two or more atoms is **polyatomic**, or specifically **diatomic** (two), **triatomic** (three), **tetraatomic**, (four), etc. With regard to the atoms of hydrogen which are replaceable in an acid by basic atoms or radicals (its **basicity**) the terms **monobasic** (one), **bibasic** or **dibasic** (two), **tribasic** (three), etc., are used, or where there are two or more, the general term **polybasic**.

A substance, usually a gaseous element, at the instant of its formation, is said to be in the **nascent condition**, and exerts a stronger action than when in its ordinary state, probably because it is in its atomic and not in its molecular form. **Solution**

(**chemical solution**) is where one substance is dissolved or merged in another without completely losing its identity, *i.e.*, undergoing a reaction whereby a new compound is formed. Thus, common salt is dissolved by water, forming a solution, but it still answers to the regular tests for salt, and, upon evaporating it to dryness, the salt is found to be the same as before. If, while a substance is in solution, another substance is added (or certain conditions are changed) with which the first reacts to form a new insoluble compound, the action is known as **precipitation** (throwing out of solution,) and the insoluble compound is called a **precipitate**.

Compounds are ordinarily classified, according to their properties, into **acids**, **bases**, and a combination of the two, **salts**. In chemistry **acids** are usually defined as having a sour taste, having the property of turning blue litmus paper red, etc., while the **bases** have opposite properties; but in metallurgy, acids may be considered to be the oxides of the non-metallic elements, while bases are the oxides of the metallic elements. A salt is neutral, or either slightly acid or basic in its properties. **Oxidation** is the name given to any process where oxygen combines with an element or substance; the opposite of this, or the removal of oxygen, is **reduction**.

The combination of two different elements is called a **binary compound**; of three, a **ternary compound**; of four, a **quaternary compound**, etc. In a binary compound, usually formed of a metallic and a non-metallic element, the name of the latter ends in **-ide**, thus, sodium sulphide, calcium oxide, etc. Where two elements combine in more than one proportion, it is necessary to indicate the ratio by giving the number of atoms of the variable (in some cases of both):

SO ₂	Sulphur dioxide
SO ₃	“ trioxide
S ₂ O ₃	“ sesquioxide or disulphur trioxide.

Some elements have two or even three different valences, and it is essential to show which one exists in a given compound. To do this, the suffixes **-ous** and **-ic**, for the lower and the higher respectively, are used, and where there are more than two arrangements, the prefixes **hypo-** for the lower and **per-** or **hyper-** for the higher, are also employed. Acids are designated thus, and the salts which they form have the suffix **-ous** changed to **-ite**, and **-ic** changed to **-ate**, the prefix (if any) remaining unchanged. Examples of the above are:

Acid		Salt (of sodium)	
Formula	Name	Formula	Name
H ₂ S ₂ O ₄	hyposulphurous acid	Na ₂ S ₂ O ₄	sodium hyposulphite
H ₂ SO ₃	sulphurous	Na ₂ SO ₃	“ sulphite
H ₂ SO ₄	sulphuric	Na ₂ SO ₄	“ sulphate
H ₂ SO ₅	persulphuric	Na ₂ SO ₅	“ persulphate

While an acid does not necessarily contain oxygen (as was at first believed), the majority do. Those oxides which combine with water to form acids are called **anhydrides**; thus, SO₂, sulphurous anhydride, SO₃, sulphuric anhydride, CO₂, carbonic

anhydride (also called carbonic acid, but really incorrectly), etc.

Dissociation (dissociation theory is (1) the temporary decomposition of a substance by the application of heat, the original substance being again formed upon cooling; the temperature at which this occurs is called the **dissociation point**. (2) In a liquid or molten solution it is the separation of the dissolved substance (or a part of it) into electrically positive and negative particles or radicals, termed **ions** (**ionic theory**) which remain loosely bound together by their mutual attraction; this is called **ionic** or **electrolytic dissociation**, and the solution an **electrolyte**. If a suitable electric current is passed through the solution, this attraction is destroyed and the **electronegative ions** (**anions**) go to the positive pole (**anode**) where their negative charge is neutralized and they appear in the free state (no longer as ions); similarly the **electropositive ions** (**cations** or **kations**) go to the negative pole (**cathode** or **kathode**). This process is termed **electrolysis** or, in the cases of a fused electrolyte, **pyroelectrolysis**. E. D. Campbell suggests the term **ionid** in place of ion in the case of metallic solutions. Electrolysis is based on the following laws or assumptions: **Faraday's laws**: the amount of an electrolyte which is decomposed is proportional to the quantity (number of coulombs) of electricity which passes through it; (2) the weight of any ion liberated by a given quantity of electricity is proportional to the chemically equivalent mass of the ion. The **electro-chemical equivalent** of an element or substance is the amount set free per coulomb of electricity. According to **Arrhenius' theory**, the passage of an electric current through an electrolyte is by means of the motion of the ions. The **binary** or **dualistic theory** is that every definite compound is possessed of equal amounts of positive and negative electricity. **Decomposition** is the splitting up of a compound by heat or some other means; it is broader than dissociation in that decomposed compounds need not necessarily recombine if the former conditions are restored.

To indicate the **purity of chemicals**, various designations have been adopted (as shown on the labels or elsewhere) which are generally rated in the following decreasing order of excellence: (a) strictly chemically pure: guaranteed to contain not over . . . percent of . . . (substance); (b) strictly or absolutely pure; (c) chemically pure (**c.p.**); (d) pure; (e) commercial; (f) no qualification. It should be noted that in technical writings it is usually understood that only high quality substances are intended, or else the particular grade is indicated by the context or the purpose in question.

Chenot Process.—See page 139.

Chernoff Process.—Of treating castings: see page 62.

Cherry-red Heat.—Color temperature: see page 210.

Chesterfield Process.—See page 229.

Chestnut.—See page 315.

Chestnut Coal.—See Coal.

Chestnut Coke.—See Coke.

Chill Cast Pig.—See page 342.

Chill Mold.—See page 300.

Chill (Chilled) Roll.—See page 403.

Chill Test.—For charcoal iron: see page 350.

Chilled Casting.—See page 58.

Chilled Heat.—See Ladle.

Chipping.—Employed to remove seams and other surface defects occurring on billets, etc. The conditions to be observed are that the depth shall not be too great, that the opening shall be flared, *i.e.*, much wider than deep, and that no sharp cuts shall occur, so that after rolling or forging no laps or lap seams will result. **Spot Chipping** is chipping at intervals along a seam, etc., to test its depth, but where the defect need not be removed by those means, as when the material is to be machined.

Chipping Face; Piece; Strip.—See page 58.

Chisel Temper.—See Temper.

Chock.—See page 406.

Choking.—In a rolling mill with grooved rolls, overflowing a pass.

Chondrite, Chondrule, Chondrus.—See page 292.

Chromate Ore.—See page 244.

Chromated Steel.—See page 451.

Chromatic Protection.—See page 364.

Chromatic Thermometer.—See page 205.

Chrome.—See Chromium.

Chrome Brick.—See page 398.

Chrome Iron Ore.—(1) As an ore: see page 244; (2) as a refractory: see page 398.

Chrome Steel.—See page 451.

Chromeisen.—See page 352.

Chromic Iron.—See page 244.

Chromite.—(1) As an ore: see page 244; (2) as a refractory: see page 398.

Chromium.—Also called **chrome**; Cr; at. wt., 52; melt. pt., 1515° C. (2759° F.); sp. gr., 6.92. It is not found free in nature; its chief occurrence is as an oxide in combination with iron, etc., called chrome iron ore (see page 244). The pure metal is hard, of a steel-gray color, and is not readily oxidized. It alloys with iron in all proportions, and is obtained principally as ferro-chrome (see page 352). Steel of which it is a constituent is called chrome steel (see page 451). It raises the saturation point of iron for carbon even more powerfully than manganese does, and, like manganese, prevents the separation of graphite. For influence on corrosion: see page 367.

Chromium Carbide.—See page 279.

Chromium Steel.—See page 451.

Chromo-ferrite.—See page 272.

Chromometer.—An apparatus used in chemical analysis for determining percentages by the color method. It consists essentially of two graduated tubes containing respectively solutions of the standard and the test similarly treated. From the relative lengths of the two columns when they have the same color, the percentage is found.

- Chubb's Method.**—Of percussive welding: see page 504.
- Chuck.**—See page 406.
- Chute.**—See Billet Chute.
- Chute Process.**—See page 385.
- Cinder.**—See Slag.
- Cinder Bottom.**—See Lining.
- Cinder Dump.**—A place for the disposal of waste cinder.
- Cinder Fall (obs.).**—In an old-style blast furnace, the plate over which the cinder runs from the cinder notch.
- Cinder Heat.**—See Wash Heat.
- Cinder Inclusion.**—See page 57.
- Cinder Iron; Pig.**—See page 343.
- Cinder Notch.**—See page 32.
- Cinder Pit.**—See page 312.
- Cinder Plate.**—See page 135.
- Cinder Pocket.**—See page 311.
- Cintring.**—Sintering.
- Circular Inch.**—The area of a circle of 1" diameter = 0.7854 sq. in.
- Circular Mil; Circular Mil Gage.**—See page 187.
- Cire Perdu Process.**—See page 301.
- Cito-ductile.**—See page 331.
- Clamps.**—(1) Of a crucible furnace: see page 114; (2) of a testing machine: see page 469.
- Clapp-Griffith Converter.**—See page 23.
- Class.**—Of steel: see page 455.
- Claudius Process.**—See page 368.
- Clay.**—See page 396.
- Clay Crucible.**—See page 111.
- Clay Dinas Brick.**—See page 395.
- Clay Ironstone (Eng.).**—See page 244.
- Clay Process.**—See page 139.
- Clayband; Clayband Ironstone (Eng.).**—See page 244.
- Clean.**—(1) To remove the scale from a reheated piece of steel; (2) a surface free from scale; (3) of castings: see page 58.
- Clean Gas.**—See page 33.
- Clear (verb).**—See page 376.
- Clearer.**—See page 415.
- Cleavage; Cleavage Brittleness.**—See page 123.
- Cleavage Foliation.**—See page 124.
- Cleavage Plane.**—See pages 123 and 282.
- Cleavage Structure.**—See page 127.
- Cleavage in Traces.**—See page 124.
- Cleavage Weakness.**—See page 123.
- Clémandot Process.**—See page 229.
- Clinker.**—See Slag Cement.
- Clinkering.**—See page 44.
- Clinking (Eng.).**—See page 223.
- Clinks (Eng.).**—Fractures (cracks) due to uneven contraction or expansion of large masses.
- Clinorhombic (Clinorhomboidal) System.**—Of crystallization: see page 120.
- Close Annealing.**—See pages 232 and 431.

Close-grained Iron ; Close Iron.—See page 343.

Close-jointed Skelp.—See page 489.

Close Order in Line.—See page 283.

Close Pig.—See page 343.

Close-top Mold.—See page 299.

Closed Front.—See page 32.

Closed Guide.—See page 416.

Closed Hearth.—See pages 32 and 75.

Closed Pass.—See page 405.

Closed Top.—(1) Of a blast furnace: see page 33; (2) of a mold: see page 299.

Closer.—See page 405.

Clot (Eng.).—Rabble.

Clotting.—The sintering or semi-fusion of ores during roasting (Raymond).

Coagulation.—Incipient fusion of ores which are being roasted or calcined (something to be guarded against).

Coal.—A stratified, combustible, carbonaceous mineral resulting from the decomposition of wood, usually accompanied by heat and pressure. Coals are usually classified according to (a) the amount of volatile matter they contain, and (b) the purpose for which they are suitable.

Lignite or brown coal is the softest variety, somewhat resembling peat, and is high in volatile matter and water. It is not much used for metallurgical purposes. It kindles easily, has a long smoky flame, low calorific power, and does not coke. Following is the usual range in composition:

Volatile matter.....	40 to 54%
Coke.....	60 to 46
Fixed carbon.....	51 to 36
Ash.....	1 to 10
Sulphur.....	up to 3
Moisture.....	1 to 25

A variety of brown coal, altered by faulting of igneous rocks, varying in composition from that of ordinary brown coal to that of anthracite, is known as **glance coal**.

Bituminous coals, sometimes called **soft coals**, are easily the most important variety, as either in their natural condition, or as the basis of artificial fuels, they are the kind usually employed for heating purposes. They burn with a yellow, luminous, smoky flame. If, upon distillation of the volatile matter, they melt down and yield a hard, strong, coherent, carbonaceous residue, they are termed **coking or caking coals** (rarely **binding coals** or **fat coals**); otherwise, **non-coking or non-caking coals** (rarely **dry coals**). To which variety a coal belongs is determined by making a practical test, as the composition or appearance is not a sufficient indication. **Gas coals** are those which contain a large amount of volatile matter, and yield up to 10,000 or 12,000 cubic feet of gas per ton. **Cannel coal** (the name is a

corruption of "candle") is valuable for this purpose, but differs somewhat in structure and appearance; the volatile matter may amount to over 70%; on heating, it splits with a decided cleavage, and as it emits a cracking sound, it is sometimes called **parrot coal**. **Furnace coal** is any sort suitable for heating purposes, and the term **manufacturing coal** (Eng.) is used in the same sense. **Forge coal** or **smith coal** is the kind used for smiths' forges; when freshly put on it is sometimes termed **green coal**. **Bituminous shale** is a grade containing a large amount of ash and occurring in laminated masses. A coal very low in volatile matter is sometimes called **lean** or **meager coal**; the term is usually applied relatively to bituminous coal. **Splint coal** is a variety of non-caking coal used to a limited extent in blast furnaces in Scotland.

Following is the approximate range in the composition of bituminous coals:

Volatile matter.....	20 to 35%
Coke.....	80 to 65
Fixed carbon.....	60 to 75
Ash.....	1 to 10
Sulphur.....	1 to 7
Moisture.....	0 to 7

Anthracite (hard coal), as found in eastern Pennsylvania, is very low in volatile matter; **anthracite coals** (sometimes termed **anthracite** in England) are usually somewhat higher in volatile matter. This variety is hard to ignite, and it burns with very little flame. Its composition is approximately:

Volatile matter.....	3 to 7%
Fixed carbon.....	85 to 90
Ash.....	3 to 7
Sulphur.....	up to 1.5
Moisture.....	0 to 4

Occasionally specimens of anthracite are found in spheroidal masses, termed **coal apples**.

Coal as mined, occurring in large and small lumps, is called **run-of-mine coal**. After washing and crushing, it is sorted into sizes which receive various names (according to their size) such as **buckwheat**, **pea**, and **chestnut** or **nut**. The fine material containing a little dirt, which is removed from the larger pieces by screening, is termed **slack**. In the anthracite regions, such coal thrown on the dump is called **culm**.

Pit coal is an old English name for mined coal (in contradistinction to charcoal); if transported on vessels, it was known as **sea coal**. Coal high in sulphur is sometimes called **sulphur coal** or **stinking coal**.

Coal Apples.—See Coal.

Coal Furnace.—See pages 39 and 181.

Coal Gas.—The gas obtained by the distillation of bituminous coal in closed retorts, and used principally for illuminating purposes.

Sexton gives an average analysis (by volume) as:

Hydrogen.....	48%
Carbon monoxide.....	8
Methane.....	36
Ethylene.....	3.8
Non-combustible.....	4.2

Coalescence.—See page 120.

Coalite.—A trade name for a product obtained by filling flat rectangular retorts with bituminous coal, and heating vertically in a gas-fired furnace at 800° F. (425° C.), the coal swelling, and the resulting pressure giving good density to the product. It resembles coke in appearance, but is higher in volatile matter, and its calorific power is stated to be close to that of coal; it is also claimed to be smokeless.

Coarse-grained Fracture.—See page 178.

Coating.—(1) For protection: see page 370; (2) in wire drawing: see page 507.

Cobalt.—Co; at. wt., 59; melt. pt., 1464° C. (2667° F.); sp. gr., 8.72. It is not found in the uncombined state, and is usually associated with nickel. It is a hard white metal having a slight bluish tinge. For influence on corrosion: see page 366.

Cobalt Steels.—See page 453.

Cobbing.—See Ore.

Cobble.—(1) In puddling: see page 377; (2) in rolling: see page 415.

Cod.—See page 299.

Coddle.—Of blast: see page 35.

Codonoid.—See page 290.

Codorus (obs.).—Or silicon ore: a silicious iron ore formerly sometimes used in puddling.

Coefficient of Corrosion.—See page 108.

Coefficient of Distribution.—See Solution.

Coefficient of Elasticity.—See page 334.

Coefficient of Impact.—See page 481.

Coefficient of Restitution.—See page 478.

Coffee-mill Squeezer.—See page 377.

Coffin Bend.—See page 265.

Coffin Joint; Weld.—See page 503.

Coffin Process.—For axles and rails: see page 233.

Cogging.—See pages 115 and 407.

Cogging Hammer.—See Hammer.

Cogging Mill.—See page 411.

Cohenite.—See page 292.

Cohesion.—See page 81.

Coil.—A roll or bundle of wire, hoop, etc., made up in this form for convenience in handling and shipping. If the material is bent

backward on itself, like a flattened letter "S," it is called a **scroll bundle** or **hoop**. If one length is wound up on itself, like a clock spring, it is known as a **single coil** or **single strand (strip) coil**; if several lengths are thus wound up simultaneously, a **standard** or **regular coil**; **continuous coils** are made up of several strips, one being coiled up before the next is put on, with a short lap, so that one length can be used without disturbing the remainder of the coil. Coils are sometimes called **strips**. A **hank** is a bundle of wire; a **stone** is a name rarely applied to a bundle of small wire weighing about 12 pounds. The term **stone wire** is usually applied to fine wire suitable for wire cloth and similar purposes.

Coke.—Grade of tin plate: see page 433.

Coke.—(1) The residue obtained by driving off all, or nearly all, the volatile matter from solid or liquid fuels; (2) as generally understood, such residue obtained from certain kinds of bituminous coals, which is hard, strong and porous, and hence can support a heavy burden without crushing. This latter is particularly valuable for heating by contact, as it has practically no flame. As its specific gravity is about 0.9, while that of carbon is 2, over 50% of its volume must be air space which enables it to burn more readily. It is stated (*Bull. No. 382, U. S. Geol. Sur.*) that the coking properties of a coal are determined by the ratio of hydrogen to oxygen in the composition of the coal. Experiments indicated that with H:O over .50% it will coke. Practical tests should, however, be made.

An average analysis of Connellsville coke, and the coal from which it is made, is as follows:

	Coke, %	Coal, %
Moisture.....	—	1.33
Volatile matter.....	1.50	28.36
Fixed carbon.....	88.00	62.64
Sulphur.....	0.90	1.111
Phosphorus.....	0.077	0.013
Ash.....	10.50	7.68

At the present time coke is made in either beehive or retort ovens, the product being termed, respectively, **beehive coke**, and **retort coke** or **by-product coke**.

Beehive ovens are of the shape which their name indicates, and are built either in a single row against a hillside (**bank ovens**), or in a double row back to back (**block ovens**). They are of fire-brick, faced with stone, and each has an opening in the top for charging (**trunnel head**) and another at the bottom for drawing (**door**). They are usually 10½ to 12 feet in diameter. The charge amounts to about 4½ tons for **forty-eight hour coke**, and 6 tons for **seventy-two hour coke**, these two names indicating the length of time required for the operation. After dumping in the ovens, the coal is leveled off, and the door bricked up except for small openings to admit the air for combustion. The oven, hot from a previous charge, or heated with fuel, causes the volatile matter to

be driven off; this burns and supplies the requisite amount of heat; the coking proceeds from the top downward. When the process is complete, the red-hot mass is **quenched** with water, broken up and removed from the oven either by hand with rabblers or by a machine termed a **coke extractor** or **coke pusher**. Properly burned coke usually has a whitish deposit extending downward from the top a couple of inches, called **whiskers**, which is supposed to be an indication of its good quality.

In **retort ovens** the coal is placed in vertical, or horizontal, closed brick chambers externally heated by flues. The volatile matter consisting of hydrocarbons, tar, and ammonia is saved, for which reason this type is known as a **by-product oven**. The **by-product recovery** operation is briefly as follows (Meissner, *Am. I. & S. Inst.*, 1913): In the **indirect process** (**indirect recovery process**) the gas leaves the ovens through the **foul gas main**, located above the ovens, and is taken to the by-product plant where it is cooled, the tar extracted, the naphthalene thrown down as far as possible, and the ammonia scrubbed out of the gas by passing through water towers or other apparatus. The weak ammonia liquor is passed into lead-lined saturators containing sulphuric acid, and ammonium sulphate formed, or the distilled ammonia is placed in tanks and shipped as strong ammonia liquor. In the **direct recovery process** the scrubbing of the ammonia from the gases is avoided by passing them through the saturator after the separation of the tar. In some of the so-called **direct processes** tar is separated by cooling the gases, and in this case a certain proportion of ammonia is precipitated with the tar and must be distilled. In others, tar is separated without the precipitation of ammonium salts. These latter are more properly called **direct** than those where some of the ammonia is precipitated, which should be called **semi-direct processes**. The **thio-sulphate process** is the name usually given to a process for utilizing the sulphur contained in the gases; *e.g.*, in the **Burkheiser** process a special oxide purifier removes hydrogen sulphide from the gas and employs it to make an acid solution for the recovery of ammonia as sulphate and sulphite. Where the surplus gas (after extraction of the by-products and the heating of the retorts) is used for generating power, it is called a **waste heat oven**; otherwise, where gas is sold, as much as possible is generally desired for that purpose.

Foundry coke.—This coke is selected from ovens which have burned 72 hours. It is always made on Mondays and Tuesdays, as no work is done at the ovens on Sundays. It may be made on other days of the week by shutting down another day. It is hard and large, and has a bright appearance caused by the carbon condensing on the surface. This coke is used in cupolas for melting iron, and also for heavy forging work.

Furnace coke (blast furnace coke).—This is coke that is burned 48 hours, and is used in smelting ores in blast furnaces. It is sometimes used in cupola practice.

Standard foundry and furnace coke.—Sulphur under 1%: the lower the better. Ash not over 13%; the quality improves

with the reduction in ash until the percentage is brought to a point where the structure is weakened.

Smelter coke is either of the above running, say, over 1.20% in sulphur. While this higher sulphur renders it undesirable for smelting or melting iron, it does not harm it for the smelting of most other non-ferrous ores.

Stock coke is that stocked on the oven yard instead of being loaded direct into cars. If care is used in selecting, when loading, it is as good as if freshly drawn, with the exception that it is somewhat broken up by the double handling, and is discolored.

Soft coke, heating coke, or jamb coke is the cullings from the above classes, and is made up of the backs, fronts, and that around the oven doors; this is often incorrectly called stock coke.

Crushed coke is crushed and graded according to size into the following classes: **egg, large stove, small stove, chestnut, 7/8-inch pea, 1/2-inch pea, dust coke, coke dust, or coke breeze.** The first four grades are used for house heating, small forgings, etc., the pea size for chemical works, etc., and the dust for covering the bottoms of soaking pits and crucible furnaces to protect the brick-work from melted scale.

The coke obtained as a by-product from the distillation of coal for illuminating gas is called **gas coke or gas-house coke.** It is very hard, and is largely used for electric light carbons and the electrodes of electric furnaces, for which purposes it is ground, mixed with a little tar, molded and heated. **Retarded coke** is coke which has been mixed with milk of lime or other inert substance to reduce the rate of combustion.

The **Diehl-Faber process** consists in introducing limestone into a charge of raw coal containing sulphur. It was claimed that calcium sulphide was formed during coking, and that the physical properties of the product, termed **neutral coke,** were much improved.

Coke Bars.—See page 411.

Coke Bottom.—See Lining.

Coke Breeze; Dust.—See above.

Coke Extractor.—See page 96.

Coke Finery.—See page 383.

Coke Furnace.—See pages 39 and 181.

Coke Hole.—See page 114.

Coke Malleable.—See page 346.

Coke Ovens.—See page 95.

Coke Pig.—See page 343.

Coke Plate.—See page 433.

Coke Pusher.—See page 96.

Coke Refinery.—See page 383.

Coke Sheet.—See page 433.

Coke Tin; Tin Plate.—See page 433.

Coking Coal.—See Coal.

Colander Funnel.—See page 60.

Colby Furnace.—See page 154.

Cold Bend Test.—See page 476.

Cold Bending.—See Cold Working.

Cold Blast.—See Blast.

Cold Blast Charcoal Iron.—See page 343.

Cold Blast Cupola.—See page 182.

Cold Blast Furnace.—See page 39.

Cold Blast Iron.—Pig iron smelted with a cold blast.

Cold Blowing Iron, Metal, Pig.—See page 20.

Cold Bottom.—See page 376.

Cold Cracks.—See page 223.

Cold Crystallization.—See page 179.

Cold Cupping; Dishing.—See Cold Working.

Cold Distortion.—See Cold Working.

Cold Drawing.—(1) General: see page 101; (2) of tubes: see page 492; (3) of wire: see page 507.

Cold Ductility.—See page 331.

Cold Etching.—See page 286.

Cold Flanging.—See Cold Working.

Cold Galvanizing.—See page 371.

Cold Hammering.—See Cold Working.

Cold Hanging.—See page 35.

Cold Iron; Metal; Pig.—(1) In foundry work, cast iron which is thick and sluggish and does not pour readily on account of being at too low a temperature; (2) cast iron at a low temperature in the blast furnace and hence usually higher in sulphur than normal; see page 343; (3) in Bessemer practice iron which is low in silicon: see page 20.

Cold Junction.—See page 209.

Cold Lap.—See Seam.

Cold Pot.—See page 432.

Cold Pressing.—See Cold Working.

Cold Punching.—See Cold Working.

Cold Rolls.—See page 431.

Cold Rolling.—See pages 101 and 431.

Cold Saw.—A circular power saw for cutting metals while cold.

Cold Scaffold.—See page 35.

Cold Set.—Of metal: chilling.

Cold Shearing.—See Cold Working.

Cold Short; Shortness.—See Brittleness.

Cold Short Ore.—See page 243.

Cold Shut.—(1) The freezing over of the top surface of an ingot before the mold has been filled, due to an interruption of the stream of metal; this is most likely to happen in the crucible process (see page 115), or where very small ingots are made; (2) the name for certain defects: see pages 426 and 502; (3) a special link for repairing broken chains which is closed up cold; it must not be confused with (1) or (2).

Cold Stable State.—See page 327.

Cold Straining.—See Cold Working.

Cold Twisting.—See Cold Working.

Cold Wild.—Wildness due to the temperature of the steel having been too low for the purifying reactions to take place; perhaps on account of infusibility of the metal due to oxides.

Cold Working.—Straining metal cold (**cold straining**) beyond its

elastic limit with a corresponding effect upon the physical properties; this is the same as plastic deformation (see Metallography, p. 281) and overstrain (see Physical Properties, p. 334). Depending upon its nature, and upon the further use or treatment of the material, it may be beneficial or harmful. The effect is due to the permanent deformation of the crystals or grains from their normal shape which, on account of the rigidity of the material when cold, they can completely regain only by annealing (see Heat Treatment, p. 231), which restores the original properties if the cold working has not been excessive. If the cold working has been unequal, this leads to severe internal strains which may develop so-called **season cracks** (occurring sometimes years afterward), or may cause cracking on annealing, owing to the different rates of recrystallization in the portions differently strained. If the cold working has been excessive (**overwork**), **spontaneous cracking** may result; in the case of bars this may take the form of splitting or flaking, and in the case of sheets exfoliation may result, thin layers peeling off or crumbling away. Rosenhain states that as a general rule cold working may be continued without permanent damage as long as the tensile strength continues to rise. "When this **strain hardness** is merely to afford stiffness and does not involve the general question of resistance to serious and continued stresses, it is perfectly logical and rational. In some cases, particularly wire, the artificially induced strength appears more or less permanently reliable, although with wire ropes subjected to repeated bending, fatigue failures occur, as against alternating stresses strain hardness is of no avail. This is more serious with rods of hard-drawn or cold-drawn alloys employed for bolts or where called on to carry important loads. Practical experience in such cases confirms conclusions drawn from research data that the extra strength from strain hardness cannot be safely relied upon for continued resistance, particularly where stresses are alternating or intermittent. The best recent practice shows a strong and highly rational tendency to avoid the use of any material which has been severely cold-worked, unless subsequently annealed to remove strain hardening more or less completely" (Rosenhain). As opposed to this statement of Rosenhain's may be cited the use of hard-drawn wire for cables, etc., and the data in the following table offers evidence that a careful distinction must be made between **cold-drawn** and **cold-rolled** material when subjected to repeated transverse stresses (see next page).

Heyn states that since cold rolling and cold hammering are apt to produce tension strains in the core, whereas cold drawing, on the contrary, causes tension strains in the superficial layers, it is possible to reduce strains by alternating these processes. This difference would also serve to account for the results in the table. As regards electrical and magnetic properties, cold working decreases the magnetic permeability and the remanence and increases the coercive force and the resistance. The solubility in acids is increased but the specific heat does not appear to be affected.

Endurance of Alternating Equal and Opposite Stresses before Rupture
(In hundreds of thousands)¹

Deflection, inches..... Fiber stress, lb. per sq. in.	15/16 28,100		13/16 24,300		11/16 20,600		Tensile strength aver., lb. per sq. in.	Yield point, aver., lb. per sq. in.
	Repetitions of stress before rupture, in hundreds of thousands							
	Max.	Min.	Aver.	Max.	Min.	Aver.	Max.	Aver.
Cold-drawn.....	2.3	1.0	1.6	3.4	2.5	2.9	4.3	3.8
Cold-rolled.....	5.8	4.7	5.4	20.3	12.5	15.8	244.0	121.5
Turned.....	2.9	1.6	2.3	9.3	3.7	6.7	24.2	13.4
Cold-rolled, turned.....	.....	.....	2.35	.....	.....	2.36	10.1	9.07

¹ For instance, the maximum number of repetitions before rupture endured by the first cold-drawn bar was 227,897 = 2.3 hundred thousand.

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Cold working usually consists in (a) slightly reducing the cross-sectional area by rolling, hammering or drawing; (b) distorting the material by bending, flanging, cupping or twisting; and (c) punching or shearing.

Cold rolling, cold hammering, and cold drawing are employed for one or more of the following reasons: (a) the effect upon the physical properties; (b) where extreme accuracy as to size is required; (c) to obtain a very smooth, even surface; (d) in the case of cold drawing, to produce certain thin, complicated sections, such as cornice molding, which could hardly be obtained commercially by any other method. The hole in a die through which material is drawn is frequently called the **reduction ring**. The material (usually round, square or hexagon bars) is first pickled to remove all the scale. Round bars for shafting, etc., are made perfectly straight after rolling by passing them through a revolving straightening machine called a **flyer**. A curious action takes place in this machine: open hearth steel bars, over about 0.15% carbon are increased slightly in diameter (**swelling**), while those of Bessemer steel, not over 0.10% carbon are reduced slightly (**shrinking**). The reduction is very slight on account of the resistance of the material to being worked, and the very much higher cost in comparison with hot working; an exception to this is wire drawing (see Wire).

In drawing large rounds, say over 3" in diameter, breakage sometimes occurs from too heavy reduction without proper annealing. With such large sizes, the outside is worked more than the interior, producing a skin or **shell** around an inner core. Sometimes only this shell is broken, called **skin breakage** or **shelling**.

By cold working the tensile strength may be increased about 20 to 40%, and the elastic limit 60 to over 100%.

Cold twisting is applied to certain bars, to be used in reinforced concrete construction, to increase their elastic limit (about the same as by cold rolling) and also to afford better bonding with the concrete. **Cold bending and cold pressing (cupping, dishing and flanging)** are resorted to more to obtain some desired form; also to obtain greater stiffness, but rather from this form than from any effect on the metal due to the cold working involved. An application of cold working made use of by bell hangers to increase the elastic limit of the wire is known as **frigo-tension**. It consists in subjecting the metal to repeated tensile stresses somewhat above the elastic limit.

Cold shearing and cold punching affect the metal to a slight depth (about $\frac{1}{16}$ to $\frac{1}{8}$ " or even more) from the sheared or punched surface, the effect being proportional to the thickness of the piece and to its percentage of carbon or other hardening elements. This is liable to cause cracking if the piece is bent across a sheared edge or where there is a punched hole, the danger being much greater if the upper surface (the entering side for the punch or the shear blade) is on the outside of the bend, probably due to the fin on the lower side, and also to the fact that at the upper side the affected metal is in compression. This

effect may be removed by annealing or by machining off the embrittled portion. First punching a small hole and then reaming it out to the desired size is known as **sub-punching**.

Machining is "essentially the action of an edged cutting tool and consists in bringing to bear upon a very small area of metal a stress sufficiently intense to produce rupture. Obviously, however, although actual rupture is confined to a single line or surface, severe strain will be produced in the immediate vicinity, so that in an ordinary machined or filed surface the visible grooves are accompanied by corresponding sub-surface regions of strained material. This region will be deeper, the deeper the "cut" which has been taken and the greater the force which has been employed, and also the blunter the tool, *i.e.*, the larger the area to which the intense pressure of the tool has been applied." With a grinding wheel or with emery paper the cutting is exceedingly sharp and the depth is very slight (Rosenhain).

Cole (obs.).—Coal.

Collar.—See page 404.

Collaring.—See page 415.

Collins (W. W.) Process.— See page 380.

Collodion Coating.—See page 365.

Colloid.—See Solution.

Colloidal Metal.—See page 128.

Colony.—See page 123.

Color Carbon.—See Carbon.

Color Identity; Names; Scale.—Of temperatures: see page 210.

Column.—See page 468.

Columnar Crystals.—See page 125.

Columnar Fracture.—See page 178.

Columnar Granulation, Structure.—See page 125.

Comb.—See page 291.

Combination Induction Furnace.—See page 153.

Combination Pot.—See page 432.

Combination Steel.—See page 443.

Combination, Water of.—See Water.

Combined Arc and Resistance Furnaces.—See page 153.

Combined Carbon.—See Carbon.

Combined Carbon Dioxide.—See page 107.

Combined Water.—See Water.

Combining Weight.—See page 87.

Combustible Matter.—See Fuel.

Combustion.—See page 202.

Combustion Carbon.—See Carbon.

Comby.—See Pit.

Come to Nature.—See page 376.

Commercial Annealing.—See page 231.

Commercial Elastic Limit.—See page 470.

Commercial Ore.—See page 243.

Comminute.—To bring to an extremely fine state of division.

Common Calorie.—See page 199.

Common Iron.—See page 379.

Common Lines.—Of deformation: see page 283.

- Compact Grained Pig Iron.**—Pig iron whose fracture shows fine grains or crystals.
- Comparator.**—See page 483.
- Complete Combustion.**—See page 202.
- Complete Corrosion.**—See page 106.
- Complete Crystal.**—See page 122.
- Complete Fusion, Zone of.**—In blast furnace practice: see page 36.
- Complete Heterogeneous Equilibrium.**—See page 327.
- Compo.**—See page 64.
- Component.**—See page 326.
- Composite Casting.**—See page 64.
- Composite Fracture.**—See page 179.
- Composition Face.**—See page 124.
- Composition Formula.**—See page 86.
- Compound.**—Chemical compound: see page 83.
- Compound Armor Plate.**—See page 8.
- Compound Casting.**—See page 64.
- Compound Cell.**—See page 121.
- Compound Couple.**—See page 209.
- Compound Crystal.**—See page 124.
- Compound Cupola.**—See page 182.
- Compound Gas.**—See page 33.
- Compound Ingot.**—See page 64.
- Compound Microscope.**—See page 285.
- Compound Radical.**—See page 87.
- Compound Steel.**—(1) Steel made by casting layers of hard and soft material together: see page 64; (2) alloy steel: see page 443; (3) a name rarely given to steel made by the duplex process: see page 317.
- Compound Stress.**—See page 332.
- Compound Twin.**—See page 124.
- Compression.**—See page 336.
- Compression Figure.**—See page 126.
- Compression Test.**—See page 476.
- Compression Hardened (Tempered) Steel.**—See page 229.
- Compression Theory.**—Of hardening: see page 280.
- Compression by Wire Drawing.**—See page 64.
- Compressive Resilience.**—See page 331.
- Compressive Strain; Strength; Stress.**—See pages 330 and 332.
- Compressometer.**—See page 476.
- Concentrated Load.**—See page 468.
- Concentration.**—Percentage composition: see page 83.
- Concentric Converter.**—See page 17.
- Concentric Load.**—See page 332.
- Conchoidal Fracture.**—See page 178.
- Conduction.**—See page 200.
- Conductometer.**—See page 483.
- Cone, Fusible.**—See page 209.
- Cone Test.**—For hardness: see page 478.
- Cone Washer.**—See Ore.
- Configuration.**—See page 126.
- Congealed Solution.**—See page 270.

- Congenital Malleableness.**—Malleable as produced.
- Congenital Twin.**—See page 124.
- Conglomerate Structure.**—See page 125.
- Congreaves' Composite Steel.**—See page 64.
- Congredient (Tiemann).**—Suggested as a general term to include elements, impurities, or constituents of a substance.
- Congruent Freezing.**—See page 267.
- Conley-Lancaster Process.**—See page 140.
- Conley Process.**—(1) Direct: see page 140; (2) electric: see page 155.
- Conoid.**—See page 290.
- Consolute (rare).**—Miscible in all proportions.
- Constant Angles.**—Law of: see page 120.
- Constant Heat Sums.**—Law of: see page 201.
- Constant Pressure Thermometer.**—See page 205.
- Constant Proportions.**—Law of: see page 84.
- Constant Sum Theory.**—Of passivity: see page 364.
- Constant Volume Thermometer.**—See page 205.
- Constantan.**—See page 203.
- Constituent.**—See pages 264 and 326.
- Constituents of Iron Alloys.**—See page 272.
- Constitution of Special Steels.**—See page 444.
- Constitutional Diagram.**—See page 271.
- Constitutional Formula.**—See page 86.
- Constitutive Freedom, Degree of.**—See page 327.
- Contact, Angle of.**—See page 407.
- Contact Confusion of Orientation.**—See pages 127 and 282.
- Contact Heating Furnace.**—See page 181.
- Contact Twin.**—See page 124.
- Contact Welding.**—See page 503.
- Continuous Acting Press.**—See Press.
- Continuous Beam.**—See page 468.
- Continuous Coil.**—See Coil.
- Continuous Combustion.**—See page 202.
- Continuous Curve.**—See Curve.
- Continuous Furnace.**—See page 184.
- Continuous Galvanizing Process.**—See page 509.
- Continuous Heating Furnace.**—See page 184.
- Continuous High Bloomary.**—See page 144.
- Continuous Mill.**—See page 412.
- Continuous Producer.**—See Producer.
- Continuous Stückofen.**—See page 142.
- Contracting Chill.**—See page 300.
- Contraction.**—See page 204.
- Contraction of Area.**—See page 336.
- Contraction Cavity.**—See page 53.
- Contraction Crack.**—See Crack.
- Contraction Pyrometer.**—See page 209.
- Contraction Pyroscope, Wedgwood's.**—See page 209.
- Contraction Rule.**—See page 296.
- Contraction of Section.**—See page 336.
- Convection.**—See page 200.

- Conversion.**—See page 81.
- Conversion Process.**—Where a desired change in the properties are effected by purification, as of cast iron into steel.
- Converted Bar.**—See page 71.
- Converted Gray Castings.**—A grade between gray and malleable castings, obtained by heating white cast iron to about 1010° C. (1850° F.) for a few hours.
- Converted Steel.**—Blister steel: see page 71.
- Converter.**—See page 15.
- Converter Steel (rare).**—Bessemer steel.
- Converting Furnace.**—Cementing furnace: see page 70.
- Converting Pot.**—See page 70.
- Converting Process.**—(1) Bessemer process; (2) cementation process.
- Convex Pass.**—See page 405.
- Cooling.**—(1) General: see page 227; (2) law of: see page 200.
- Cooling Bed.**—See page 414.
- Cooling Crack.**—See Crack.
- Cooling Curve.**—See pages 129 and 267.
- Cooling Curve Method.**—Of determining critical points: see page 265.
- Cooling Plate.**—See page 27.
- Cooling of Solid Solutions.**—See page 270.
- Cooling Table.**—See page 414.
- Cooper Process.**—See page 140.
- Coördinate.**—See Curve.
- Cope.**—See page 297.
- Copper.**—Cu; at. wt., 63.6; melt. pt., 1050° C. (1922° F.); sp. gr., electrolytic, 8.945, hammered, 8.95. It is found both free and combined. It is a reddish-colored metal, very malleable and ductile, possessed of great tenacity, and is one of the best conductors for both heat and electricity. Its occurrence in steel usually results only from its presence in the ores (see also page 371). Up to at least 0.5% it does not seem to have any bad effect upon steel, but with 1%, in conjunction with high sulphur, it may cause some red shortness; it tends to hinder welding. In amounts up to 0.5% (commonly 0.10 to 0.30%) it has recently come into extensive use in the manufacture of steel, particularly thin sheets and ordinary plates owing to its effect in greatly reducing corrosion (*q.v.*, page 366). In these amounts and even up to 1.00% (unless perhaps when accompanied by abnormally high sulphur) its effect on the physical properties appears to be a slight increase in the elastic limit and the tensile strength with, if anything, a little better ductility; with heavy plates it somewhat resembles nickel in preventing as good a surface as usual. For influence on corrosion: see page 366.
- Copper-clad Steel.**—See page 372.
- Copper Coating.**—(1) For protection against corrosion: same as plating: see page 371; (2) in wire drawing: see page 508.
- Copper Plating.**—See page 371.
- Copper Pyrites.**—See page 245.
- Copper Steel.**—See pages 372 and 453.

Copperas.—See page 245.

Coppered Steel.—See page 508.

Coppered Wire.—See page 508.

Copperizing (rare).—Coating with copper.

Core.—(1) In case hardening: see page 67; (2) in molding: see page 299.

Core Bar; Barrel; Binder; Box.—See page 299.

Core Cemented; Cementation.—See page 67.

Core Gum; Nail; Plate; Print.—See page 299.

Core Steel.—See Edge Steel.

Cored Structure.—See page 125.

Corey Reforging Process.—See page 8.

Coring.—See page 299.

Corroding Agents.—See page 107.

Corrosion.—(See also Protection, page 365). The slow oxidation and wasting away of metal, usually at ordinary temperatures; it may also be extended in meaning to cover the more rapid action at high temperatures, generally called oxidation or scaling, also loss resulting from other chemical reactions either at ordinary or high temperatures. (Contrast with **erosion**, the loss occurring in gun barrels when a film on the surface is melted by the temperature generated in the explosion of the powder and blown out by the force of the gases generated; and **abrasion**, the mechanical removal of particles by the rubbing action of another substance.) Its commonest manifestation is **rust** which is the oxide of iron formed on the surface of corroded iron. Dr. Rideal has defined corrosion as follows: "Corrosion may be said to result from an irreversible chemical change proceeding with a small velocity and taking place on the common surfaces between two or more phases, the products of which change are continually removed from the sphere of action."

Different types of corrosion may be classified as follows: (Some of the following definitions were devised particularly for non-ferrous alloys, but also apply to steel alloys). **Complete corrosion** (Corrosion Comm., *Inst. Met.*, 1916) in which both constituents of the alloy dissolve at approximately the same rate and uniformly over the surface of the metal. **Selective corrosion** (Cor. Comm.) in which only one constituent dissolves. In the case of a brass it is usually the zinc that dissolves selectively, a process termed **dezincification**. Distinction should also be made between **general selective corrosion**, which occurs over the whole surface uniformly, and **localized selective corrosion**, which occurs in spots, also called **pitting** or **tubercular corrosion**; of this last type is also the case where pipes or other objects of cast iron are long subjected to corrosive action, such as guns sunk for a century in sea water, termed **graphitic corrosion**, **graphitization**, **sponge-like decay** or **iron cancer**, the surfaces being apparently sound but are readily penetrated by a sharp-pointed instrument and in place of the original metallic substance is found a mass of oxide of iron mixed with flakes of graphite. Corrosion occurs when iron is exposed to moist air or to water

containing acids or certain substances (**corroding agents**). The ratio of the corrosion produced by a given set of conditions to that of pure water is termed the **corrosion factor**. In order to agitate a solution as well as introduce oxygen in making corrosion tests a jet of air is sometimes employed. The Corrosion Committee of the Institute of Metals recognizes two kinds of **aeration**: **gentle aeration** in which the mechanical agitation of the water or solution by the stream of air is reduced to a minimum; and **violent aeration**, in which the air impinges directly upon the surface of the metal, or in any other way produces considerable agitation of the liquid which is in immediate contact with the metal.

According to the **carbonic acid theory** this gas must be present. It is pointed out by Gibbs that sea water from which all carbon dioxide has been removed is alkaline because it contains an excess of basic over acid substances. In contact with air this alkaline solution will absorb carbon dioxide until its alkalinity is neutralized. The solution will then be neutral. At this stage all carbonic acid in sea water will be present in chemical equilibrium with the dissolved salts. This is the **combined carbon dioxide**. It might be called **chemically dissolved carbon dioxide**. The atmosphere contains free carbon dioxide, consequently it would continue to dissolve in this neutralized sea water until equilibrium is established between the sea water and the atmosphere. This small additional quantity of carbon dioxide is **physically dissolved** in the sea water and is known as the **free carbon dioxide**.

The **acid theory of corrosion** "depends on the simultaneous presence of oxygen, moisture, and an acid, and mere traces of acidity are sufficient to start the reaction. As generally understood, the primary attack is due to carbonic acid, a ferrous salt resulting, which in turn is acted upon by oxygen and water with the formation of rust and the liberation of the acid. In this manner the process is continuous, and a comparatively small amount of acid may exercise a vast influence" (Longmuir).

Since, as previously stated, corrosion is a slow process, various methods of testing have been suggested to expedite matters and thereby obviate tedious delays by intensifying conditions. Such **accelerated tests** are frequently of value as indicating the probable results to be secured from different substances, but as it is not possible to intensify all the conditions in the same degree, some must be vitally changed in their relation to the others and hence too much reliance must not be placed upon the net results without first making a careful comparison with those secured under the actual conditions of service which it is sought to determine. An accelerated test sometimes employed in this country was devised by the Committee on Corrosion of the American Society for Testing Materials. A piece of the metal to be tested machined to $2'' \times \frac{1}{2}'' \times \frac{1}{16}''$ is suspended by a small hole near one end on a glass rod or other inactive and non-conducting substance for 2 hours in an aqueous solution of 20% (by weight) of sulphuric acid at ordinary temperatures. The percentage of loss in weight is used as the **index**.

In general, the addition of small amounts of an inorganic salt

in water increases the corrosive action of the solution until a maximum effect is reached, termed the **critical concentration**. Further addition decreases the "corrosive action of the solution and at the saturation point (**limiting concentration**) corrosion is inhibited. Certain experiments have shown that concentrated solutions of most salts are less corrosive than pure water, some of the exceptions, within different temperature ranges, being ammonium chloride, sodium sulphate, potassium nitrate, and barium chloride. The corrodibility usually increases with increase of temperature. Changes in action may take place at a definite temperature (**inversion temperature**): Thus above 14°C . (57°F .) solutions of sodium chloride have greater corrosive effect on iron than distilled water; below this temperature the reverse is the case" (Friend).

According to the **electrolytic theory**, when iron (or a given substance) is in contact with a more electro-positive substance, or, due to heterogeneousness of composition, when certain particles or constituents are more electro-negative than others, in the presence of moisture or of water containing dissolved substances and acting as an electrolyte, a current is set up which causes oxidation or solution of the iron or of the more electro-negative constituent. According to Longmuir it "depends upon the solubility of iron in pure water, or, expressed in another form, upon the pressure of free hydrogen ions in the purest water." This action may also be increased or diminished by the flow of a current of electricity generated outside of the couple, depending upon its direction.

The Bureau of Standards has used the terms **electrolytic corrosion** when the damage is caused by stray electric currents, and **self-corrosion** for the **natural corrosion** (also termed **autoelectrolysis** or **autogenous electrolysis**) when structures in the ground decay unaccelerated by an external e.m.f. In this theory it is stated that it takes place at ordinary temperatures only in the presence of water through the reaction $\text{Fe} + 2\text{H}' \rightarrow \text{Fe}'' + 2\text{H}$. This means that a metallic iron atom, electrically neutral, interacts with two hydrogen ions present in water and which carry electrical charges; the result is the production of an iron atom which takes up the two electric charges from the hydrogen ions, and the deposition of two atoms of hydrogen. "All have agreed up to the present in regarding carbides as being electro-negative (that is, having positive **electro-affinity** or a greater tendency to exist in the molecular than in the ionic form). Hence this action should be cathodic, and they should not be attacked by corrosive liquids. That this is so may be seen by microscopical examination" (Aitchison). **Coefficient of corrosion** is sometimes used in connection with the corrosion of an anode, and is the ratio of actual corrosion observed to that which would have occurred if all of the electrode reactions determined by Faraday's law had been concerned solely in corroding the anode; this has also been termed **efficiency of corrosion**. The experiments of J. N. Friend and of Heyn have shown that, although absence of electrolytic cells in a very pure steel does retard the commencement of corro-

sion, it does not affect the rate of corrosion once the process has begun (Rosenhain).

Certain substances produce marked reactions at high temperatures at which they may even be melted. An example is the method of etching with calcium chloride introduced by Saniter (See Metallog., page 287). Iron is slightly soluble in molten zinc. In the case of galvanizing pans it appears advantageous to keep the silicon and phosphorus low, while the content of manganese or carbon does not seem to have much effect. The temperature of the bath is of much greater importance, the effect increasing gradually up to about 490° C. (915° F.), and above this very rapidly being about 30 times greater at 530° C. (985° F.) than below 490° C.

The relative corrodibility of cast iron and steel depends on given conditions. Thus, in ordinary air cast iron is usually more resistant, also when completely submerged in water; but in sulphuric acid the reverse is true.

Certain conclusions drawn by Aitchison (*J. I. & S.*, 1916-1-90-91) are as follows:

(1) That corrosion of steel takes place purely by the action of ferrite on the solid solution.

(2) The action upon pure ferrite may be due entirely to the potential difference set up in consequence of the different solution pressures of the grains of metal, and the inter-granular cement, it being probable that the latter is possessed of greater e.m.f.

(3) The percentage of a third element added to iron and carbon must be sufficiently great to produce a fairly high percentage in the solid solution, if there is to be any beneficial effect.

(4) The electromotive force of the solid solution with respect to the corrosive liquid is the deciding factor.

(5) Pearlite as a whole does not corrode as a whole, but as a mixture of ferrite and cementite, the disappearance of the latter being due to mechanical, and not to chemical, action.

(6) Carbides are not decomposed by ordinary corrosive agents, and act merely as the cathode to the anode of ferrite or solid solution. Stead says (*ibid.*, p. 99): "On long etching polished sections of any aggregate of iron crystals in dilute nitric acid, cupric ammonium chloride, etc., the crystals with cube faces parallel to the surface are always the slowest to be attacked and stand out in bold relief above the surfaces of the other crystals of different orientation. Further sections of the same crystal of iron cut parallel to and at an angle to the cube face if immersed in acid and connected by wires to a galvanometer give an electric current, proving that the cube face is electro-negative to the other face. The assumption of Aitchison that the solution pressure of iron crystals varies with the orientation is therefore fully justified, and it is proved that strains produced by forcing a needle into a cube face are not the cause leading to the development of square etching pits."

Corrosion Factor.—See page 107.

Corrosion Test.—See page 107.

Corrugated Sheet.—See page 433.

- Corsican Process.**—See page 140.
- Cort Mill.**—See page 409.
- Cort Process.**—See page 374.
- Coruscation.**—The emission of sparks or flashes.
- Cotton Tie Mill.**—See page 415.
- Counter-current Principle.**—See page 204.
- Country Heat.**—See page 71.
- Couple.**—See page 208.
- Coupling Box.**—See page 407.
- Coupon.**—(1) In shearing plates, a piece of suitable size and shape for physical tests not quite detached from the piece it is to represent; (2) in forgings, an extension left to be cut off and turned down for testing.
- Course.**—Of bricks, a layer or row.
- Cover.**—(1) The lid of a crucible; (2) in the puddling process, manganese is said to cover the carbon in the bath when the former is high enough to prevent the latter from being oxidized for some time.
- Cowper-Coles Process.**—(1) For electrolytic iron: see page 166; (2) sherardizing: see page 371.
- Cowper (E. A.) Process.**—See page 380.
- Crab.**—See page 407.
- Crack.**—A fissure which has opened up to a certain extent due to strains or brittle material. Those produced by rolling and forging are known respectively as **rolling cracks** and **forging cracks**. Where cracks are formed on the outside, due to the rapid heating of cold material, they are called **heating cracks** or **expansion cracks**. **Cooling cracks** or **contraction cracks** are due to the outside not being able to contract uniformly during cooling; in castings this is termed **checking**. **Thermal cracks**, **hot cracks** or **heat cracks** are those produced by repeated, alternate, sudden heating and cooling of the surface as in the case of the rolls for rolling hot steel which are subjected to the hot metal followed immediately by cooling from the water spray; this also occurs at times with railroad wheels and brake shoes, due to their mutual action—often referred to as **wheel burns** and **brake burns** respectively. An **internal crack** or **fissure** is one which has formed in the interior, but does not (usually) extend through to the outside; this is due to excessive longitudinal strains, either from cold working or from too rapid cooling from the outside. In shearing hot billets, etc., particularly those high in carbon, fine cracks may be formed at the ends where the water drops on them; they are called **water cracks**.
- Cradle.**—See page 431.
- Crafts Furnace.**—See page 155.
- Cremer Process.**—See page 30.
- Cramp Bar.**—See page 415.
- Creeping.**—(1) In rolling: see page 408; (2) in testing; see page 472.
- Cricoid.**—See page 290.
- Crimped Sheet.**—A sheet, one corner or a portion of which has been doubled or bent upon itself during rolling.
- Crith.**—See Hydrogen.]

- Critical Concentration.**—See page 108.
Critical Cooling Velocity.—See page 447.
Critical Deformation.—And grain growth: see page 216.
Critical Interval.—See page 265.
Critical Mechanical Temperature.—See page 331.
Critical Points.—(1) General: see page 264; (2) determination of: see page 265.
Critical Range.—Of temperature: see page 265.
Critical Strain.—See page 216.
Critical Temperature.—See page 264.
Crocodile.—See page 489.
Crocodile Hammer.—See page 196.
Crocodile Shears.—See Shears.
Crocodile Skin.—See page 229.
Crocodile Squeezer.—See page 377.
Crook.—A distortion in castings produced in cooling.
Crookes' Radiometer.—See page 207.
Crop; Crop End.—See Discard.
Cropping Shears.—See Shears.
Cross Breaking Rupture.—See page 336.
Cross Breaking Strength.—Of cast iron: see page 484.
Cross Pane.—See Pane.
Cross Piling.—See page 378.
Cross Rolls; Rolling.—(1) of plates, etc.: see page 414; (2) of tubes: see page 490.
Cross-section; Cross-sectional Area.—See page 468.
Cross Welding.—See page 502.
Crossed Twinning.—See page 124.
Crova's Pyrometer.—See page 203.
Crown.—Of plates: see page 414.
Crown Bar.—Merchant bar of wrought iron.
Crucia Steel.—See page 451.
Crucible.—The hearth of a blast furnace: see page 27.
Crucible.—Also called **pot**, is used for melting small amounts of various materials, but more particularly for the manufacture of crucible steel. For this industry crucibles are made of a high quality of clay mixed with a little powdered coke (**clay crucible** or **white pot**), or of a mixture of clay and graphite (**graphite, plumbago, or blacklead crucible**).
 Graphite crucibles can be made to contain a heavier charge, and also a greater number of heats. They are made of a mixture of Ceylon graphite, German clay and pure sand, the final composition being approximately:

Carbon.....	50%
Silica.....	35
Alumina.....	11
Iron oxide, etc.....	4

The clay is dried, ground, made into a paste with water, and the sand and graphite thoroughly mixed in, after which the mass is allowed to remain for a few days in a damp place to

season or **temper**, *i.e.*, be in a better condition for working. The amount of crucible material prepared at one time is called a **batch**. A lump of the proper size is cut off, kneaded slightly to insure its uniformity, and put inside a mold which is placed on a potter's wheel, and the mass **spun up** (by revolving the wheel) to fill the mold. The proper thickness of the wall is obtained by means of an arm or profile iron which descends and shapes the inside of the crucible. The excess at the top of the mold is sliced off and the mold removed. Spinning up gives better results than simple pressing because it causes the flakes or plates (in which natural graphite occurs) to take a tangential direction and intermesh, thereby binding the material together. Artificial graphite is rarely if ever used as it does not occur in these plates.

The crucibles are now dried, first for about 24 hours, at about 20° to 25° C. (70° to 80° F.), after which they are smoothed up; and then for about three weeks at a temperature high enough to drive off the hygroscopic moisture. They are then heated (**annealed** or **burned**) in an oven (**annealing oven**) for about three days at a temperature of about 815° C. (1500° F.) to drive off all the combined water. The crucibles are stacked up in a number of tiers, and, as they are still very tender, they are placed in loose-fitting clay molds (**seggars** or **saggars**) which keep them from being crushed, and also prevent excessive oxidation. When crucibles of different sizes are being made they are usually **nested**, *i.e.*, the smaller are placed inside the larger. The slight oxidation of carbon on the surface, which always occurs, gives the crucibles, originally black, a brownish color (the color of the clay). The covers are made and treated in a similar manner.

Clay crucibles, used chiefly in England, are manufactured from a high grade of fireclay (Burton, Stourbridge, etc.), usually mixed with about 5% of good ground coke. The mixing is done very carefully, frequently by **treading** the mass with the bare feet on the **treading floor**. A lump is then placed in a flask or mold, and a plunger having the shape of the interior is forced down, being centered by a pin passing through a hole in the bottom. The flask is removed and the top of the crucible forced inward, by means of another conical mold, to give it a shape like a barrel. After drying for a few days in the **pot house** (where they are made), the crucibles are further dried at a somewhat higher temperature near the flues of the melting furnaces. The hole left in the bottom is closed when the crucible is set in the furnace for use by throwing in a little sand which frits the crucible to the clay stand on which it rests.

Crucibles are generally supposed to improve with age, and for this reason they are frequently kept for some time to **season**. If they have not been dried thoroughly before use, the moisture is likely to cause portions to crack off, called **scalping**, when they are heated. In some cases fine cracks (**alligator cracks**, because they give the outside the appearance of alligator skin) may develop after a crucible has been in service some time; they are probably due to hot gases and improper annealing. Another defect of

infrequent occurrence is where small fissures (**pin holes**) are formed, allowing drops of metal to run out. Generally they do not appear until the crucible has been used for a few heats, and are originated in the drying or the annealing. A crucible is said to **run** when it cracks and the contents leak out.

Crucible Cast Steel.—Crucible Steel.

Crucible Furnace.—See pages 114 and 183.

Crucible Fusion.—See below.

Crucible Process.—Also called **pot melting** a process for the production of steel, consisting in melting down in closed crucibles various grades of iron or steel with or without the addition of carbon, ore, or other materials, the resultant product being cast in a fluid condition. As ordinarily practised, it is essentially a melting operation, there being little if any purification, except perhaps as regards oxides or gases. The process was invented by Robert Huntsman about 1740. The most important modifications are (Howe):

1. **Huntsman's**, the original method (sometimes called **crucible fusion**), in which small pieces of blister or other highly carburized steel are melted alone or with a slag-making flux (*e.g.*, glass).

2. **Josiah Marshall Heath's modification** of adding manganese, either previously reduced by heating its oxide with carbonaceous matter or reduced in the process itself by the action of charcoal on oxide of manganese. Huntsman's method thus modified, it is said, is now the prevalent one in Sheffield.

3. The **carburizing fusion** (or **cementing fusion**) method, in which the percentage of carbon in the product is regulated by the addition of carbonaceous matter (practically charcoal), is said to have been used in the last century by **Chalut and Clouet**, and is the prevalent method in this country.

4. **Uchatius**, or the **pig and ore method**, of melting granulated cast iron with iron ore.

5. The **pig and scrap method** of melting wrought iron or steel, or both, raising the proportion of carbon by adding cast iron.

In all the above methods the molten metal is tranquilized by **killing**, *i.e.*, holding it molten so as to yield sound ingots.

6. The **Mitis method**, in which the charge originally constituted in any of the above ways, is tranquilized by the addition of ferro-aluminum (or aluminum) immediately after fusion, and is teemed a few minutes later.

7. The **basic method**, or fusion in basic instead of silicious crucibles, to permit of the elimination of phosphorus and sulphur, does not appear to have had any practical application.

In **Bajault and Roche's process** powdered ore and pig iron were put in cast-iron molds and heated in a furnace. The pig iron and the mold reacted with the ore, the whole forming one ingot which was to be broken up and used in the crucible process. The materials would have to be pure, and the advantage to be gained from conducting the pig and ore process in two separate operations is not evident. **Kern's process** appears to be a modification of the carburizing fusion method, being conducted in two stages: (*a*) soft open hearth steel was melted with charcoal

in graphite crucibles, (b) the highly carburized product thus obtained was then used in place of cement steel, mixed with wrought iron, etc.

Graphite crucibles (see Crucible) are used in this country and principally on the Continent; clay crucibles chiefly in England; in this latter case the process is sometimes referred to as the **white crucible process**. The **crucible furnace** may be heated by gas, coal, or coke. If the former, it is regenerative in principle, and consists of a number of chambers or **holes (melting holes)**—about 6 to 15 holes to each furnace, each hole holding 6 crucibles—in which the combustion of the gas takes place. The bottoms of the holes are covered with coke dust to protect the brick-work in case a crucible is broken, and provided with a hole to permit of cleaning. The covers for the holes are sometimes called **clamps** or **bungs**. In coal or coke furnaces (**pot hole, coke hole, fire hole**—rarely called **shaft furnaces**) the crucible is set directly in the fuel, which is supported by grate bars, a chamber being provided underneath for cleaning, called the **cave**. Poking the fuel around the crucible is sometimes called **pottering down** (Eng.). Principally on the Continent and in a few cases in this country what is termed a **Krupp Furnace** is employed; this resembles a small open hearth furnace and the pots are charged and drawn horizontally through the doors. In contradistinction to this the other type of furnace, in which the pots are charged and drawn vertically, is referred to as a **hole furnace**. In this country the charge is ordinarily 100 pounds, and the graphite crucible weighs about 50 pounds when new. The material employed is usually wrought iron or soft-steel scrap, together with a certain proportion of charcoal and oxide of manganese; occasionally blister steel is used, in which case the charcoal is omitted. The larger pieces are put at the bottom by the **pot packer**, the charcoal and oxide of manganese on these, and the smaller pieces at the top; the cover is put on and the crucible set in the furnace by a man called the **setter in**. The charge is occasionally introduced into the crucible (while in the furnace) by means of a **funnel** or **charger**. Depending on the composition of the charge (low carbon heats take much longer than high carbon) the melting, which is the first stage of the process, takes about 2 to 4 hours, and when it is judged that this has taken place, the man in charge, or **melter**, **looks over the heat**, *i.e.*, uncovers certain of the pots to determine with his eye the condition of the contents; if necessary, he stirs them with a small rod to detect unmelted pieces. When this period is completed, the charge is allowed to remain a further period until the steel becomes tranquil, *i.e.*, does not evolve gas. This result is probably effected by silicon, reduced by carbon acting on the wall of the crucible, combining with the gases. This tranquilizing period is known as **killing**, and the steel when perfectly quiet is said to be **dead**. The bubbles of gas which form and break slowly toward the end of the killing period are sometimes called **cat's eyes**; they are larger than when the charge is first melted. Killing takes from about $\frac{1}{4}$ to $1\frac{3}{4}$ hours—usually from $\frac{1}{2}$ to 1

hour—and if unduly prolonged the metal when cast is hard and brittle (also called **dead**), probably on account of excessive absorption of silicon. The total time required for a heat is about 3 to 4 hours, three heats being made each turn of 12 hours. When ready the crucibles are **drawn** from the melting hole by the **puller out**, set on the floor and the covers removed. In some cases they may be set temporarily in an iron-lined hole (**teeming hole**) in the floor. The slag (**scum** or **flux**) floating on top of the steel is removed (**swabbed up**) by means of a light iron rod with a ball of slag on one end (**mop**) against which it chills. Drawing by some mechanical device, instead of by hand, has not proved satisfactory as the crucibles are liable to slip or else be crushed. The steel is now **teemed** (poured) into molds, and any slag remaining is kept back by holding a bar (**flux stick**) against it. Each mold receives the contents of one crucible, or, if of larger size, several cruciblefuls are used, care being taken in every case that the stream does not strike the sides, and also that it is not momentarily interrupted, the latter causing the metal to freeze over (**cold shut**). Several cruciblefuls may also be poured into a ladle and the molds filled from this. The ingot after cooling is **topped** (the top broken off) to determine the grade by the appearance of the fracture (chemical analysis is now largely employed for this), and also for the purpose of removing the piped portion. Graphite crucibles were formerly allowed to cool between heats, but now are usually charged hot, *i.e.*, returned to the furnace immediately without cooling after being inspected for cracks. After about nine heats they are allowed to cool completely for more careful inspection, their average life being six to nine heats. In English practice, where clay crucibles are used, the life of a crucible is about three heats, and the charges are reduced successively on account of the **slag line** or **flux line** which is left after each operation. The first charge is about 56 pounds, the succeeding ones being about 44 and 38 pounds respectively. Owing to the fact that the crucible is cold for the first heat, this takes about 4½ to 6 hours, the subsequent heat taking less, as then the crucible is returned to the furnace immediately; three heats are obtained in 12 hours. When solid fuel is used, care must be taken that none falls into the crucible, as the steel is thereby rendered red short, and its fracture, which is brilliant, is said to **stare**. The store room in which the raw materials for the charge, particularly the ingredients for special steels, is sometimes called the **medicine room**.

“In hammering crucible ingots for tool steel it used to be customary to heat them first to a comparatively low temperature, not high enough to produce scale, and then **cog** (forge) them under a steam hammer by very light blows, not sufficient to reduce materially the dimensions of the ingot but merely to smooth and slightly “compact” its surface. The ingot was then replaced in the heating furnace, brought to as high a temperature as its composition would permit, being rolled from time to time in a welding mixture, and then quickly returned to the hammer where it was roughly brought to the required **cogged bar** size. The

first operation was known as **saddening**, and the low, non-scaling temperature was spoken of as a **saddening heat**. The idea was to smooth the rough surface of the ingot as such a surface was less likely to be burned at the subsequent temperature. It was also believed that blowholes lying close to the surface would thus be closed before a scaling heat had a chance to open and expose them to oxidation" (G. Aertsen). "In crucible steel works practice it is sometimes the custom to heat the steel to, and forge from, what is called the **wash-welding temperature** (sufficiently high to cause the scale to run and also to promote welding), and it is assumed that if the material initially contains cavities or blowholes, they will be welded up" (Stead).

General Principles.—The charge contains initially a moderate quantity of oxygen as rust, scale, and the slag of wrought iron. This, as well as the trifling quantity of atmospheric oxygen originally present, and free oxygen and the oxygen of any carbon dioxide of aqueous vapor which may enter by leakage or by diffusion, should tend to form oxide of iron and (if the charge contains spiegeleisen or ferro-manganese) of manganese. This tendency is opposed by the carbon of the crucible walls, which, especially in the case of new graphite crucibles, tends to take up the free oxygen and to reduce the carbon dioxide present.

The metallic oxides, melting first to a very basic slag, should collect at the bottom of the crucible and react on its walls, and later, on the bath of molten steel. The first action of the slag on the metal should be strongly fining, tending to oxidize carbon, silicon, and manganese. As the slag level is gradually raised by the accumulation of the molten steel beneath, the slag corrodes ring after ring of the crucible wall, exposing the graphite or coke to the rising underlying metal, which absorbs carbon voraciously. The fining action should thus weaken rapidly as the slag grows acid through absorption of silica from the crucible, and through the reduction of its oxides, partly by the metal's carbon and silicon, partly (in the case of strongly graphitic crucibles chiefly) by the carbon of the crucible. This fining probably soon gives way to carburization, the carburized metal reducing and absorbing silicon from the now acid slag and from the acid crucible wall. The net result, under usual conditions, is that in graphite crucibles the metal gains in carbon (usually by from 0 to 0.25%) and in silicon (usually by from 0.05 to 0.20%); that if spiegel or ferro-manganese is charged before melting, much of its manganese is slagged, and the absorption of carbon and silicon is increased; and that if oxide of manganese is charged, part of its manganese is sometimes, if not usually, reduced and absorbed by the metal. The more highly carbureted the crucible wall, the greater will be the net absorption of carbon, manganese, and silicon.

In clay crucibles, the charge either loses carbon (say up to 0.25%) or gains but slightly (say up to 0.06%), while gaining but slightly in silicon, unless manganese or its oxide be present.

If the charge contains charcoal or graphite, this both carburizes the metal during heating to the melting point (probably most

of its carbon is absorbed by the steel), and greatly shortens and weakens, if it does not eliminate, the fining period by protecting iron and manganese from oxidation, and by reducing at least a part of their oxides.

If, on the other hand, oxide of manganese is charged, it tends to intensify and prolong the fining, to postpone and enfeeble the carburization, opposing the action of the charcoal.

The silicon absorbed during the killing period probably tranquilizes the steel, principally by removing any oxides or free oxygen present, although in addition it is supposed to give the steel the property of retaining gases which it contains, such as nitrogen.

Sulphur increases gradually but constantly, being taken up perhaps from the pyrites of the clay or graphite, perhaps from that of the fuel, very small quantities of sulphur dioxide entering the crucible.

Phosphorus, in like manner, increases slightly when clay or graphite crucibles are used, but is eliminated gradually in basic crucibles.

Comparative Quality of Crucible Steel.—As already stated, in the United States it is generally customary to use wrought iron (sometimes basic open hearth steel) in contact with charcoal in the crucible itself. In Europe blister steel is usually employed. This latter method necessitates a separate, very lengthy treatment previous to the melting down in crucibles. It is claimed (and also disputed) that as good steel is produced by the American method as by the English. Crucible steel is better than open hearth or Bessemer steel for the following reasons:

- (a) The materials used are more carefully selected.
- (b) Smaller units are handled which receive greater attention.
- (c) It is not exposed to the atmosphere.

The relative qualities are:

1. Crucible,
2. Open hearth,
3. Bessemer,

and taken in the same order, the crucible steel has least contact with the atmosphere, and the Bessemer most.

It is claimed that it is possible to produce in the electric furnace steel of crucible quality or even better. The electric furnace with a basic hearth permits of refining not possible in the acid crucible. It also operates without furnace gases in contact with the charge and can be made to exclude nearly all circulation of air. Electric steel is made in larger units and for this reason cannot receive the same meticulous care; for the same reason its uniformity should be greater especially for large ingots. However, the most expensive tool steel is still manufactured in crucibles.

A number of early processes or modifications did not possess any particular novelty or value, as will be seen from the following: **Charles Atwood's process** consisted essentially in melting together wrought iron and cast iron (spiegel preferred). **George**

Brown's process consisted in melting wrought iron, cut up into small pieces, with charcoal pig iron, in the proportion of about three parts of the former to one of the latter. **Victor Gallet** coated puddle bar with a paste consisting of certain proportions of limestone, vegetable mold or clay, carbonate of potash, oxide of manganese, resin, soot, wood charcoal, etc., and melting in a crucible. **Charles Low** devised a truly remarkable process in which wrought iron was to be melted in crucibles with a mixture of manganese dioxide, plumbago, charcoal, and niter. **A. V. Newton's process** consisted in heating crucibles and their charge of blister bars in an auxiliary furnace before putting them in the regular melting furnace, by which means he claimed a considerable reduction in the time required. **William Onions' process** consisted in melting in a crucible two parts of hematite ore, four parts of steel, and 94 parts of pig iron, the resulting metal being poured directly into molds, and the castings subsequently annealed. **D. S. Price and E. C. Nicholson's process** consisted simply in melting refined pig with suitable proportions of wrought iron. **Obersteiner** fused pig with wrought iron. **Sudre's process** consisted in melting steel (blister steel) in a reverberatory furnace, instead of in a crucible, and the employment of bottle glass for flux. In **J. L. Talbot and J. D. M. Stirling's process** various proportions of oxides were added to blister bars during melting in crucibles to get steel with different percentages of carbon. **John Thompson** proposed to produce refined cast steel by melting it in a furnace (instead of in crucibles) of peculiar construction, resembling a puddling furnace, in which were placed troughs or other vessels containing the metal. **Wm. Vickers' process** consisted in melting wrought-iron scrap with ground charcoal and oxide of manganese; cast-iron scrap might also be used.

Crucible Steel.—Steel made by the crucible process; also called cast steel, **Huntsman steel** (obs.), **pot steel** (Eng.).

Crude Iron (obs.).—Untreated pig iron.

Crude Steel.—See page 343.

Crumble.—Of the cutting edge of a tool which breaks away in small particles because it is too hard or has not the proper shape.

Crushed Coke.—See page 97.

Crushed Steel.—An abrasive material usually made by quenching high-carbon steel from a high temperature and crushing, followed by tempering to a straw color.

Crushing.—Breaking up into a smaller size, for such material as ore, limestone, etc.

Crushing Strength.—Compressive strength: see page 330.

Crux.—An abbreviation sometimes used for crucible.

Cryocarbide.—See page 273.

Cryohydrate.—See page 266.

Cryosel.—See page 266.

Cryptocellular Structure.—See page 126.

Cryptoclastic Structure.—See page 126.

Cryptocrystalline.—See page 126.

Cryptodimorphism.—See page 122.

- Crystals.—(1) General: see below; (2) laws of: see page 120; (3) properties of: see page 121; (4) structure of: see below.
- Crystal-boundary Etching.—See page 127.
- Crystal Centers.—See page 120.
- Crystal Cleavage.—See page 123.
- Crystal Debris.—See page 125.
- Crystal-field Etching; Crystal-figure Etching.—See page 127.
- Crystal Grain.—See page 122.
- Crystal Growth.—See page 121.
- Crystal Plane.—See page 123.
- Crystal Size.—See page 121.
- Crystal Skeleton.—See page 122.
- Crystal Thrust.—See page 121.
- Crystal Unit Slipping.—See page 281.
- Crystalliform.—See below.
- Crystalline.—See below.
- Crystalline Aggregate.—See page 125.
- Crystalline Antimony.—See Antimony.
- Crystalline Boron.—See Boron.
- Crystalline Carbon.—See Carbon.
- Crystalline Deformation.—See page 126.
- Crystalline Force.—See page 121.
- Crystalline Fracture.—See page 178.
- Crystalline Grain.—See page 122.
- Crystalline Growth.—See page 213.
- Crystalline Magnesite.—See page 397.
- Crystalline Movement.—See page 281.
- Crystalline Slip.—See page 282.
- Crystalline Solid Solutions.—See page 270.
- Crystalline State.—See below.
- Crystalline Structure.—See below.
- Crystalline Tin.—See Tin.
- Crystallite.—See page 122.
- Crystallization.—(1) General: see below; (2) systems of: see page 120; (3) water of: see page 499.
- Crystallization by Annealing.—See page 213.
- Crystallographic Amorphizing.—See page 282.
- Crystallographic Axis.—See below.
- Crystallographic Plane.—See below and page 123.
- Crystallography.—The study of crystals which are solid bodies bounded by plane surfaces or faces at definite angles to each other, and formed by the arrangement of the molecules, which arrangement is symmetrical to certain imaginary lines or axes (crystallographic axes) intersecting at the center, or to certain planes (crystallographic planes or planes of symmetry) intersecting the crystallographic axes. The relative inclination of the axes to a certain plane or line is called the orientation of the crystal. This regular structure (and a body possessing it) is termed crystalline or crystalliform (crystalline state); a body in which these properties are absent, amorphous or non-crystalline. The measurement of the angles of a crystal is performed by the aid of an instrument called a goniometer.

Systems of Crystallization.—Crystals may be classified according to their form or **crystallization**, into six different systems which are (Moses and Parsons, "Mineralogy, Crystallography, etc.," 6):

1. **Isometric (cubic, monometric, regular, tesserai, or tessular) system:** Three interchangeable axes at right angles to each other.

2. **Tetragonal (dimetric, monodimetric, pyramidal, quadratic, or quarternary) system:** Three axes at right angles, of which two are interchangeable.

3. **Hexagonal (rhombohedral, rhombohedric, or monotrimetric) system:** Four axes, three of which lie in one plane at 60 degrees to each other and are interchangeable; the fourth is at right angles to the other three.

4. **Orthorhombic (anisometric, orthosymmetric, prismatic, rhombic, or trimetric) system:** Three axes at right angles but not interchangeable.

5. **Monoclinic (clinorhombic, hemiprismatic, monoclinohedral, monosymmetric, or oblique) system:** Three non-interchangeable axes, two of which are oblique to each other; the third is at right angles to the other two.

6. **Triclinic (anorthic, asymmetric, clinorhomboidal, doubly oblique, tetarto prismatic, or triclinohedral) system:** Three non-interchangeable axes at oblique angles to each other.

Any general reference to the optical properties of crystals (polarization, etc.) is omitted as metallic crystals are opaque except in extremely thin sections which have no practical importance.

Moses and Parsons (*loc. cit.*, 2 *et seq.*) give the following three fundamental laws of crystals:

1. **Law of constancy of facial angles:** In all crystals of the same substance the angles between corresponding faces are constant.

2. **Law of symmetry:** All crystals of any one substance are of the same grade of symmetry.

3. **Law of simple mathematical ratio:** In all crystals of the same chemical substance, if the intercepts of any face upon the crystallographic axes are divided, term by term, by the corresponding intercepts of any other face, the quotients will always be simple rational numbers or infinity or zero.

Formation of Crystals.—According to the researches of Bragg, in which he employed a **Röntgen ray spectrometer** to study the constitution of crystals, they are made up of atoms and not of molecules. There are different theories or hypotheses as to their origin and growth. According to one, they start from a globular or **utricular mass (globulite)**. These are sometimes referred to as **embryonic crystals**. In heterogeneous crystal mixtures, **absorbens** is the name which has been given to one crystal form when it expands with decreasing temperature and absorbs the other form (Guertler). The points of origin in building up crystals which may be invisibly small and grow by accretion or coalescence (**merging**) are called by Tammann **crystal centers**.

The **space-lattice theory** of crystallization is that the atoms (or molecules) are not in actual contact but separated in accordance with a well defined and regular pattern or structure. The cubical space (this refers to volume and not to form) included within intersecting planes passing through a set of neighboring atoms is called the **space-lattice**. **Quincke's hypothesis** holds that crystallization commences when in the liquid state, the liquid first separating into two immiscible phases, one of which is in relatively large quantity and is composed of the pure substance, the other or smaller containing any impurities or eutectic. This acts somewhat like an emulsion of oil and water, the smaller or **oily liquid** forming the **walls (foam walls or cell walls)** of **foam cells** filled with the pure substance, each spheroid of which being isolated can develop its own orientation, either while still liquid or after complete solidification. Such a structure is known as a **foam**. Depending upon their mode of formation and structure they have been divided into **first, second, and third order**, or **first-class and second-class cells**; also **primary, secondary and tertiary crystals**. Osmond and Werth referred to **simple cells**, bounded by ferrite, and **compound cells** which were larger and composed of dendritic crystals. The formation of grains immediately upon solidification Belaiew calls **granulation**, and where it occurs, the **granulation range or zone**; and this action, **primary crystallization**; the secondary effect when pearlite is formed at A_{r1} , **secondary crystallization**. Arnold suggests **centrifugal extrusion** to express the action when metal crystallizes and any substances are thrown to the edge. According to Desch it is not necessary to assume that crystallization is due to the existence of a separate **crystalline force**, as the ordinary cohesive forces in solids have, in crystals, vector properties and act more strongly in certain directions than in others; this is implied in the idea of a crystal, and the phenomenon of **crystal thrust** is to be explained as the result of the vectorial character of cohesion. The **size of crystals, i.e., their growth**, under normal conditions depends upon the rate of solidification or cooling while they are still at high temperatures where conditions permit of sufficient mobility for the rearrangement of the particles so certain crystals grow at the expense of the others. Howe refers to **parallel growth** where crystals extending in the same direction are connected or grow together.

Properties and Structure of Crystals.—**Morphology** (particularly in biology) is the science of form and structure; **morphometry** is the method of measuring external forms. **Isomorphism** or **homoeomorphism** is where different substances crystallize in identical or closely related forms. **Mitscherlich's law** states that elements in compounds may be replaced by other similar elements without changing the crystalline form (*e.g.*, manganese partly replacing iron in cementite). **Monomorphic** refers to a crystal of the same or similar form. **Polymorphism** or **multiple isomorphism** is the property of crystallizing in more than one form; where there are two forms, the term **dimorphism** is sometimes used, and for three forms, **trimorphism**; **isodimorphism** is

where two substances, in addition to independent forms, can crystallize in another common form; if the presence of both is necessary it is a case of **cryptodimorphism** or **cryptomorphism**. **Metamorphism** is the change or reformation (recrystallization) due to some agent such as heat (**thermal metamorphism** or **pyrometamorphism**); a rock, for example, which owes its (crystalline) form to heat is said to be **pyromorphous**; **pyrocristalline** refers to a body crystallized from the molten state. **Static metamorphism** is a change brought about by gradual or steady forces; **dynamic metamorphism**, by suddenly applied forces; if such a change is incomplete it is a case of **hemimetamorphosis**. A **pseudomorphic crystal** or **pseudomorph** is one which results (a) from the substitution or chemical alteration of, and has the same form as, a crystal previously existing, or (b) from deposition in the space which a crystal previously occupied. An **allomorph** is a pseudomorph where there is no change in chemical composition. A **paramorph** is a crystalline form of one substance assumed by another of similar chemical composition but of different properties. **Heteromorphic** indicates a substance differs in form or properties from the normal. The prefix **holo-** is used to denote completeness, as **holocrystalline**, entirely crystalline (containing no amorphous matter); **holosymmetric**, entirely symmetric; **holoisometric**, completely crystalline according to the isometric system; **holoaxial**, having all the axes but none of the faces; **holohedral** or **homohedral**, having the complete set of crystal faces for the given form. An **anhedron** or **faceless crystal** is a crystal without definite bounding planes; a **hemihedron** is one having only half the regular number of faces. A crystal is said to be **orthobasic** when the axes are at right angles to each other. **Complete crystals**, *i.e.*, those which have been formed when the conditions were favorable for their complete development, are called **idiomorphic**, **automorphic** or **euhedral crystals**; a large crystal of this nature is sometimes termed a **metacryst**. If their bounding surfaces are determined by adjacent (interfering) crystals or bodies, they are called **incomplete**, **hemicrystalline** or **alotriomorphic crystals**. In the case of metals these last are termed **crystalline grains**, **crystal grains** or, more usually, simply **grains** or **granules**, and a structure made up of them is said to be **granular** or **granulitic**.

In the primary crystallization referred to above the growth is by a process of repeated branching in the directions where there is the least interference. These formations are termed **crystallites**, **star-like crystallites**, **skeletal crystals**, **skeleton crystals**, **crystal skeletons**, and particularly because of this branching form and their supposed resemblance, **dendrites**, or **dendritic**, **arborescent**, **tree-like**, **fir-tree**, **pine-tree** and **fern-leaf crystals** or **crystallites**. A **microlite** is a more or less completely defined microscopic crystal. **Cuboid** is a term tentatively applied to crystals which appear to be of cubical form before this has been determined definitely. Crystallites which are wedge shaped are sometimes said to be **cuneiform** or **cuneate**.

A **unit crystal** is the smallest piece of matter which can possess

all the properties of a crystal. The components or grains of a crystallite form are sometimes referred to collectively as **colonies** (of grains). The term **spicule** is used to describe something which is thread-like in form with pointed ends. If before solidification is complete the still molten portion is removed, the crystal so exposed is called an **isolated crystal**. In the case of solutions of certain organic substances Lehmann found globules which acted on polarized light in the same way as ordinary (transparent) crystals and which he termed **liquid crystals**; the same term is also applied to cases which have been found with metallic (solid) crystals which are extremely plastic, resembling fluids in this respect, although in general a crystalline structure has a decidedly embrittling effect.

Crystal Planes.—These may be classified as follows:

i. **Planes of symmetry:** A plane which “so divides the crystal that either half is the mirrored reflection of the other, and every line perpendicular to the plane connects corresponding parts of the crystal and is bisected by the plane of symmetry” (Moses and Parsons, 5); sometimes referred to as the **crystallographic plane**.

2. **Motion planes** (Howe): Those where movement of the particles occurs, also termed **planes of weakness**.

(a) **Cleavage planes:** Those along which a crystal breaks or separates, “always parallel to faces of forms in which the substance can crystallize . . . True cleavage is obtained with equal ease at any part of a crystal, and there is only a mechanical limit in the closeness of one cleavage to the next” (Moses and Parsons, 146-7).

(b) **Gliding planes:** Those where “it has been observed that pressure in certain directions will either produce a separation along a definite plane, which is not a true cleavage plane, or else will develop a twin structure (**secondary twinning**) with this gliding plane as the **twin plane**” (Moses and Parsons, 148).

(c) **Parting planes:** “The planes along which a gliding has occurred may thereafter be planes of easy separation or **parting**, differing from true cleavage, however, because in parting the easy separation is limited to the planes of actual gliding, while true cleavage is obtained with equal ease at all other parallel planes” (Moses and Parsons, 149).

(d) **Slip planes:** Those along which slip occurs (see Metallography, page 282).

Crystal Cleavage.—The separation or rupture of a crystal along cleavage planes (see above) which represent directions of minimum cohesion; also called **intra-crystalline** or **trans-crystalline rupture** (**cleavage brittleness**), *i.e.*, across or through the grains or crystals, as distinguished from **intercrystalline rupture** which occurs between them. “Cleavage is, in general, limited to directions parallel to the simpler and more frequently occurring crystal forms. In the isometric system it is parallel to the cube

(**cubical**), octahedron (**octahedral**) or dodecahedron (**dodecahedral**). In the tetragonal system it is **basal** or **prismatic** and only rarely **pyramidal**. In the hexagonal system it is **basal**, **prismatic**, or **rhombohedral**, but rarely **pyramidal**. In the other systems the arbitrary selection of axes prevents a simple classification of cleavages, but the selection usually makes one direction of cleavage **pinacoidal** and two of equal ease **prismatic** . . . Cleavage is said to be **perfect** or **eminent** when obtained with great ease, affording smooth lustrous surfaces. Inferior degrees of ease of cleavage are called **distinct**, **indistinct**, or **imperfect**, **interrupted**, **in traces**, **difficult**" (Moses and Parsons, 147). **Lateral** and **diagonal cleavages** are those respectively parallel to the lateral face and the diagonal plane. Certain metamorphic rocks have their minerals or constituents segregated or deposited (**interpenetration**) between the strata or grains, called **joint foliation** where cleavage has occurred, or **cleavage foliation** where rupture has been caused by bending (**faulting foliation**), and when deposited as a layer (**stratification foliation**), such surfaces of deformation are called **foldings**.

To indicate the property of cleavage special terms are used such as: **Lamination**, to indicate that a substance is composed of sheets which can be separated as such; **fissile**, of a crystal which can be split; **sectile**, of a crystal which can be sliced, the slices being friable or crumble readily. Different types of cleavage are indicated by the terms **heterotomous**, unusual; **orthotomous**, at right angles to each other; **orthotyous**, perpendicular.

Twinning.—Twins or twin crystals, **hemitropes** or **compound crystals**, are formed by the symmetrical intergrowth of two like crystals; when the two individuals penetrate each other they constitute a **penetration twin**, and when they do not, a **contact twin** or **juxtaposition twin** (Moses and Parson, 65). **Macle** is given (I.A.T.M.) as a synonym for twin crystal, but in mineralogy it is the name of a mineral (chiastolite) having an internal tessellated or cruciform structure (Dana). The twinning plane (see above) is symmetrical to the two portions of the twin, but is not a plane of symmetry for either alone. It may be considered that twinning has occurred by rotation of one portion 180 degrees about a line normal to the twinning plane, termed the **twin** or **twinning axis**. In the case of contact twins the twinning plane is also the contact plane, called the **composition face**, but it is not the same with penetration twins. The crystalline arrangement which produces a definite kind of twinning is called the **twinning law**. There are a number of different types of twin each of which has its own law. If there are only two individuals, it is called **simple twinning**; if more than two, **repeated twinning**. **Multiple** or **polysynthetic twinning** is repeated twinning after the same law; **crossed** or **grid-iron twinning** (**cyclic** or **stellate twins**), repeated twinning after two laws. If the individuals are connected in different ways, it is called a **compound twin**. Twinning may occur (*a*) during crystallization (**congenital twins**), (*b*) as a result of straining alone of crystals already formed (**mechanical twins**), or (*c*) especially for iron, straining

followed by annealing (**annealing twins**). The structure on the surface produced by twinning is a series of bands; from their relative size annealing twins are also termed **broad twins**, while mechanical twins are called **narrow twins** or **Neumann lamellæ** or **Neumann bands**. **Pseudosymmetry** is where the symmetry is apparently of a higher form than normal, often due to twinning.

Crystalline Structure.—The term **structure** (**texture** is used in the same sense but should properly be restricted to woven fabrics) refers to the arrangement and appearance, or organization, of the different constituents of a substance. Rosenhain designates as **simple metals** those composed of only one kind of crystals. A body (and its structure) is said to be **massive** when it does not show crystalline faces, whether it is crystalline or not (Moses and Parsons). A **crystalline aggregate** is a body composed of coherent crystals or grains which cannot be broken apart, *i.e.*, are not elastic. It is **pseudocrystalline** when apparently of a uniform crystalline formation, but really a composite of small grains or pieces densely compacted. A **porphyritic structure** consists of a **semi-crystalline** (partially crystalline) or finely crystalline or glassy portion, appearing compact to the naked eye, called the **ground mass**, **matrix**, **magma**, or **base**, in which are embedded well defined crystals called **phenocrysts**. In metallography these terms refer to the constituent which is predominant. If the phenocrysts are absent, it is termed **felsitic**; **granitoid** or **granulitic**, composed of grains or crystals of about the same size. An **oölitic** (egg-shaped) structure is one made up of spherical individuals each of which has grown around a nucleus, usually of some other material. A **cored structure** has the interior or core of different structure or material from the exterior. A **poikilitic structure** is composed of relatively large crystals or grains which contain, without definite arrangement, numbers of smaller individuals of various substances. A **hemipelic structure** is one resembling fine clay; a **fragmental structure**, one composed of pieces of a preëxistent substance, or **crystal debris**. A **conglomerate** is a structure composed of rounded fragments; **breccia structure** is similar except the component fragments are sharp. **Columnar granulation**, **columnar structure**, or **columnar crystals**, is where the grains or the crystals are arranged in columns; in this sense the term **prismatic** is sometimes applied to alloys; if the columns are very long and slender, as in wrought iron, they are termed **filaments** or **fibers**, and the structure **fibrous**, **fibriform**, **nerve**, **capillary** (hair-like), or **bacillar** (rod-shaped). A **radiating structure** is one consisting of lines radiating from a common center; it is **stellate** when the radiations are of equal length. **Margarite structure** (Vogelsang) is where crystallites are arranged like strings of pearls. A **spherulitic structure**, peculiar to vitreous rocks, and in eutectics of alloys rapidly cooled, is so called because of the small spherulitic bodies, or **spherulites**, they contain (I.A.T.M.). A structure is sometimes referred to as **mushy** when it has no distinct grains. **Druse** (**drusy cavity**) is a term (corresponding to **geode** in geology) used for a cavity formed during freezing, into which the ends of

crystals or crystallites project; **needle-shaped crystals** found in druses are also termed **acicular**. Certain terms referring to minute forms simply add to the ordinary term (already given) the prefix **micro**, and for which no further definitions are necessary: **microcrystallography**, **microcrystalline**, **microcrystallitic**, **microgranular**, **microgranulitic**, **microgranitoid**, **micromeritic** (microcrystalline), **microporphyritic**, **microspherulitic**. **Cryptocrystalline** or **microcryptocrystalline**, a structure of crystalline particles too small to be detected by the naked eye. **Cryptoclastic**, composed of fine grains broken apart from a preëxistent form. When it is composed of cells the following designating terms are used: **Monocellular** or **unicellular**, one cell only; **polycellular** or **multicellular**, many cells; **homocellular**, cells of the same kind; **heterocellular**, cells of different kinds; **microcellular**, minute cells; **cryptocellular**, cells so minute as to be invisible. A **polycentric** body or structure is one built up from many nuclei or centers. A structure consisting of intersecting lines having the appearance of a mesh or net is accordingly termed **mesh**, **net**, **network**, **lattice**, **reticular**, **reticulated**, **cancellated**, or **plaited structure**. If the meshes are of identical size and shape they may be termed **isodictyal**. Howe refers to network as an assemblage of walled cells (with a **kernel** contained within the **envelope**, **shell**, or **cell walls**), and to **network size** as the average size of the walled cells which make up the network (*A.S.T.M.*, 1911-275); he considers the term **phenocellular** for this structure as too pedantic. A structure presenting the appearance of overlapping plates is sometimes called **imbricated**. A thin plate, such as graphite, is termed a **lamella** or **lamina**, and a structure composed of or containing such plates, **lamellar** or **laminated**.

According to Osmond and Cartaud a body may be considered both as cellular (having a network structure) and amorphous; the former in so far as it is formed of polyhedral (many-sided) grains, and the latter when the deformations are governed only by the direction of the strains and are independent of the crystalline structure. Whence arise three kinds of **deformation**, which they call **crystalline**, **cellular** and **banal**. Every deformation has some sort of general **configuration** (**deformation figure** or **compression figure**) which may be called its **silhouette**, and which is the boundary of elementary deformations. It is the area of a previously polished body that loses its polish where the deformations take place. A silhouette is naturally continuous and closed. Its form on an ordinary metal with cellular structure depends only on the form of the sample and on the nature or direction of the strains; but it ceases to be the same on an isolated crystal, for then its form can be in relation with the crystalline symmetry. An observation of the lines of deformation on rupture shows that under the influence of even sudden loads (impact) such lines appear in nicked specimens inside the crystals; these Osmond calls **specific lines** in contradistinction to the **ordinary lines** produced by static stress.

If a surface composed of crystal faces or cleavages is attacked by any solvent, the action proceeds most rapidly along certain

planes (**solution planes**) forming pits or depressions (**etching pits**) of varying depths whereby characteristic figures (**etching figures**) are produced. The term **vesicle** (or **vesicular**) should not be applied to these as it refers to small approximately spherical cavities commonly occurring in volcanic rocks. J. Czochralski distinguishes three kinds of etching figure resulting from (1) **crystal-boundary etching**, (2) **crystal-field etching**, and (3) **crystal-figure etching**. Where a cavity resulting from etching or from a gas bubble has the form of a crystal it is termed a **negative** or **internal crystal**. Referring to the **tripartite** nature of metals Howe says (*Metallography*, 268-9) that they are "(1) **microscopically crystalline**, in that each microscopic grain is a true crystal; (2) **microscopically cellular**, in that they are aggregations of these grains, each of which may be regarded as a cell, probably with an envelope; and (3) **macroscopically amorphous**, because the orientation changes from grain to grain, and hence the mass as a whole has no **internal orientation** of its own." Where crystals with different orientation are in contact, Howe refers to **contact confusion of orientation** as a reason why rupture ordinarily avoids the joints. Howe refers (*ibid.*, 275) to "what may be called grains of two orders in ferrite, each large grain, or **grain of the first order**, being made up of several fragments, or **grains of the second order**, with the usual grain shape and oriented alike." **Rotation effect** is a term used to describe the lighting up and darkening of the crystalline grains in the etched surfaces of polished metals when rotated before oblique rays (Heycock and Neville); Ewing and Rosenhain refer to this as the **selective effect of oblique light** (I.A.T.M.); more recently Rosenhain suggests as preferable the term **oriented lustre**. **Schillerization** "refers to the peculiar bronze-like lustre, "Schiller," in certain minerals, due to the presence of minute inclusions in parallel positions" (Mellor).

When the surface or a section of certain alloys is polished (and sometimes etched) there can be seen markings consisting of parallel or intersecting **lines** or **bands** which have received different names according to their structure. The structure produced by narrow twinning (see above) has, after its discoverer, been called **Neumann bands**, **lamellæ** or **lines**. The **Widmanstätten** or **W structure** or **lines** is discussed under **Meteorites** (page 291); Sauveur suggests that it might be termed **cleavage structure**. In discussing the deformation lines in manganese steel Howe says (*Metallog.*, 460) "The lines which form when this substance is deformed may be divided into the **surface bands** which form on previously polished surfaces, and the **etching bands** which are developed by polishing and etching after deformation." Howe terms **manganese steel lines** those peculiar to this type of steel and differing from ordinary slip bands. What Howe calls **X bands** "are rough striæ found on polishing and etching iron which has been severely deformed plastically. . . . Their nature is not known" (*Metallog.*, 452). **Eutectiferous bands** or **eutectiform patterns** are those caused by eutectics, usually observed after etching in addition to polishing. **Translation banding** is what

is due to movement but is distinguished from that produced by twinning. "**Thorns and boundary edgings** (also called **spikes** and **bordered boundaries** by Osmond, Fremont, and Cartaud) are unexplained deep-seated markings developed occasionally in low-carbon steel, but only by etching and only after plastic deformation, and therefore clearly representing neither mechanical defects nor local concentration of impurities" (Howe, *Metallog.*, 422).

What has been termed a **metallic fog** has been obtained, *e.g.*, by adding small pieces of metallic lead to fused colorless lead chloride; dark colored crystals are formed on solidification with a structure resembling that of gold ruby glass. A **colloidal metal** is referred to as one which is so finely divided it will remain indefinitely in suspension in water; in this condition colors are developed differing from that of the ordinary form; the precious metals have been those principally studied in this connection.

Cubic System.—Of crystallization: see page 120.

Cubical Cleavage.—See page 124.

Cuboid; Cuboidal.—See page 122.

Cull.—A piece of rejected material.

Culm.—See Coal.

Cumberland Process.—See page 365.

Cumulative Class.—In hardening: see page 279.

Cuneate; Cuneiform.—See page 122.

Cunningham's Formula.—For tensile strength: see page 338.

Cup and Cone.—See page 32.

Cup Fracture.—See page 179.

Cupola.—See page 182.

Cupola Crucible.—See page 182.

Cupola Furnace.—(1) See page 182; (2) a name formerly given to a small blast furnace built of brick and bound with bands.

Cupola Metal.—Molten pig iron, obtained by melting in a cupola.

Cupping.—(1) A defect in wire which causes it to break with a cup fracture; (2) pressing a sheet or plate into cup form, as in the manufacture of one kind of seamless tubing; also called dishing: see page 101.

Cupric Reagents.—For etching; those containing some salt of copper: see page 287.

Cure.—In rolling: see page 412.

Curing Color.—See page 371.

Curve.—Also called **graph**; a diagram to illustrate graphically the relative change or changes between two (or three) conditions affecting a body, when one or more of these conditions varies; further, to obtain, by interpolation, any relation, within a given range, from a number of relations actually determined. The usual method is to lay off a vertical line near the left-hand margin of a sheet of paper, intersecting, usually at right angles, a horizontal line near the bottom; these lines are called the **axes**, and they determine the location and the shape of the curve by means of perpendicular distances from them, called **coordinates**. Where the axes intersect is the **zero point** or **origin**. Divisions on the axes represent units of the related conditions. For ex-

ample, in the case of the effect on tensile strength produced by changes in carbon content, the vertical axis will represent pounds per square inch, and the horizontal axis, percentages of carbon. The tensile strength and the carbon content of a specimen having been actually determined, from the point on the vertical axis corresponding to the tensile strength obtained a line is drawn at right angles until it intersects another line drawn at right angles from the point on the horizontal axis representing the known percentage of carbon, the intersection giving one point of the curve. A number of other points have been similarly plotted, they are connected by a line, called a **curve**, which may be straight, broken, or curved. Any point on this curve is called a **locus** (plural, **loci**), the perpendicular distance of which from the

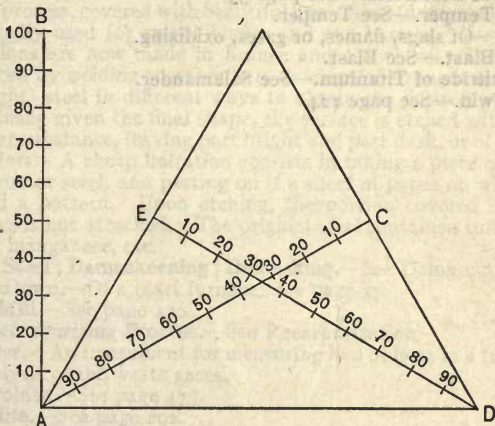


FIG. 14.—Tri-axial diagram.

vertical axis is termed the **abscissa**; that from the horizontal axis, the **ordinate**. A sudden change in the shape of a curve is called a **jog**, **break**, or **perturbation**, and the curve is said to be **discontinuous**: a curve which is smooth or regular is called **continuous** or **jogless**.

Assigning values to a point on a curve is termed **interpolation** if such points lies within limits actually determined; **extrapolation** if it lies outside such points, the assumption being that for a certain distance at least there will be no sudden change in the nature or form of the curve and the corresponding values. The first method is of course much less liable to error than the second.

A **cooling curve** shows the rate of cooling of a body plotted with degrees of temperature and units of time as coordinates. The diagram similarly obtained by heating is known as a **heating curve**. A **solubility curve** shows the percentage of a substance which is dissolved at different temperatures. An **equilibrium**

curve (see page 326) shows the relation between temperature and composition of a heterogeneous system, in which the phases present are in equilibrium with each other (I.A.T.M.). A **freezing-point curve**, **melting-point curve**, or **fusion curve** represents the variation in the temperature of freezing (or melting) of a series of alloys corresponding to changes in composition.

The **triaxial diagram** is designed to show graphically the relation between three variables whose sum is a constant quantity (e.g., percentages). As shown in the sketch, the loci are obtained by the intersection of vertical lines drawn perpendicular to the three axes AB, AC, and DE.

Cut Bar Iron (rare).—(Wrought) iron bars cut for crucible melting.

Cut Out.—Of linings, etc., corroded.

Cutaneous Blowholes.—See page 55.

Cutlery Temper.—See Temper.

Cutting.—Of slags, flames, or gases, oxidizing.

Cutting Blast.—See Blast.

Cyano-nitride of Titanium.—See Salamander.

Cyclic Twin.—See page 124.

D

- Dy.**—Chemical symbol for dysprosium: see page 84.
- Daelen Mill.**—See page 408.
- Daelen Process.**—See page 63.
- Daelen-Pszczolka Process.**—See page 317.
- Dalton's Law.**—See page 85.
- Dam ; Dam Plate ; Dam Stone.**—Of an old-style blast furnace: see page 32.
- Damascus Steel.**—A metal formerly made at Damascus, by some direct process, covered with beautiful figurations (**damaskeening**), principally used for sword blades and gun barrels. Very good imitations are now made in France and elsewhere. These are produced by welding together bars or strips of wrought iron and (wrought) steel in different ways to obtain the desired pattern. After being given the final shape, the surface is etched with acid or other substance, leaving part bright and part dark, or of different colors. A cheap imitation consists in taking a piece of ordinary iron or steel, and pasting on it a sheet of paper on which is printed a pattern. Upon etching, the portion covered by the printing is not attacked. The original steel contained tungsten, nickel, manganese, etc.
- Damask Steel ; Damaskeening ; Damasking.**—See Damascus Steel.
- Damped Down.**—Of a blast furnace: see page 37.
- Daniels Mill.**—See page 420.
- Darby Recarburizing Process.**—See Recarburization.
- Dasymeter.**—An instrument for measuring loss of heat in a furnace by analysis of the waste gases.
- Datum Points.**—See page 473.
- Daubr elite.**—See page 292.
- Davy Portable Converter.**—See page 23.
- Davy Process.**—See page 19.
- Day Gas Pyrometer.**—See page 207.
- De Dion-Bouton Process.**—See page 70.
- De Laval Feeding Head ; Ring.**—See page 60.
- De Laval Process.**—See page 140.
- De Lisle's Scale.**—Of temperatures: see page 205.
- De Marre Formula.**—See page 8.
- De Vathaire Process.**—See page 385.
- De Wees Wood Process.**—See page 369.
- Dead.**—(1) Molten steel which is perfectly quiet, *i. e.*, does not evolve gas: see page 114; (2) steel which has been burnt or contains high sulphur, so that, on rolling or forging, it cracks or breaks up: see page 226.
- Dead Annealing.**—See page 232.
- Deadhead.**—See page 56.
- Dead Load.**—See page 468.
- Dead Melt ; Melted, Molten.**—Of materials in a furnace, etc., fully or completely melted, and from which no gas is being evolved; killed.

- Dead Off the Boil (Eng.).**—When no more carbon is left in a metallic bath.
- Dead Pass.**—See pages 405 and 420.
- Dead Roller.**—See page 407.
- Dead Soft Annealing.**—See pages 232 and 509.
- Dead Soft Steel.**—See page 455.
- Dead Steel.**—Steel, page 144.
- Dead Weight Test.**—See page 477.
- Dean Process.**—See Hardening.
- Decalescent Point.**—See page 265.
- Decarbonization.**—See page 382.
- Decarburization.**—See page 382.
- Decarburizing Process.**—For malleable castings: see page 258.
- Decomposition.**—See page 89.
- Decremental Hardening.**—See pages 9 and 228.
- Decrepitation.**—The action of certain salts or minerals when small fragments fly apart with a cracking sound on being heated.
- Decrystallization.**—See page 281.
- Deep Seam.**—See page 489.
- Deep-seated Blowholes.**—See page 55.
- Defective (noun—Eng.).**—Waste or scrap material.
- Defective Welds.**—See page 502.
- Deficit Substance.**—See page 266.
- Definite Alloy.**—See page 4.
- Definite Proportions, Law of.**—See page 84.
- Deflection.**—Under drop test: see page 481.
- Deflection Tests.**—See page 477.
- Deflocculated.**—Brought to an extremely fine state of division.
- Deformation.**—(1) General: see page 126; (2) energy of: see page 481.
- Deformation Figure.**—See page 126.
- Deformed Bar.**—Bars of irregular section used in reinforced concrete construction.
- Degree of Heat.**—See page 199.
- Degasified.**—See page 55.
- Deighton Converter.**—See page 23.
- Deliquesce ; Deliquescence.**—See Water.
- Delivery.**—Of patterns: see page 296.
- Delta (δ) Iron.**—See page 272.
- Demenge Process.**—See page 8.
- Dempster Process.**—For the recovery of tar and ammonia from the gas of a blast furnace using raw coal.
- Dendrite ; Dendritic Crystal.**—See page 55.
- Dendritic Interlocking.**—See page 282.
- Density.**—Or **specific gravity**; the ratio between the weight of a unit volume of a given substance and that of a unit volume of some other substance taken as a standard under standard conditions of temperature and pressure. The specific gravity of solids and liquids is found by dividing their weight by that of an equal volume of water. For gases, air or hydrogen is taken as the standard.
- Dephosphorization.**—See page 382.

- Deposition Methods of Etching.**—See pages 286 and 288.
- Depuration (rare).**—Purification.
- Desch's Iron-Phosphorus Diagram.**—See page 272.
- Deseaming Process.**—See page 418.
- Deshayes' Formulæ.**—For elongation: see page 338.
- Desiccation.**—See pages 30 and 499.
- Desiliconization.**—See page 382.
- Destructive Distillation.**—Distillation in a closed retort, *i.e.*, without access of air. It is applied to carbonaceous material from which it is desired to drive off the volatile matter without allowing combustion to take place, or only to a very limited extent.
- Destructive Test.**—See page 467.
- Desulphurization.**—See page 382.
- Detail Fracture.**—See page 179.
- Detinned Scrap.**—Tin-plate scrap from which nearly all of the tin has been removed.
- Detmold Process.**—See page 385.
- Detrusion.**—See page 337.
- Devil.**—See page 298.
- Dezincification.**—See page 106.
- Diagonal Cleavage.**—See page 124.
- Diagram.**—See Curve.
- Diameter.**—In measuring magnifications.
- Diamond.**—Form of carbon: See Carbon.
- Diamond Pass.**—See page 405.
- Diamond Rolling.**—See page 412.
- Diamond Theory.**—Of hardening: see page 280.
- Diatomaceous Earth.**—See page 396.
- Diatomic.**—See page 87.
- Dibasic.**—See page 87.
- Dick Process.**—A process for making all kinds of metallic sections, especially those difficult to roll or forge, by forcing hot and plastic metal through a die.
- Die.**—In forging: see page 195.
- Die Plate.**—In wire drawing: see page 507.
- Die Temper.**—See Temper.
- Diehl-Faber Process.**—See page 97.
- Differential Cooling.**—See page 228.
- Differential Freezing.**—See page 266.
- Differential Hardening.**—See page 228.
- Differential Heating.**—See page 228.
- Differential Thermometer.**—See page 205.
- Differential Thermoscope.**—See page 205.
- Differentiation.**—In segregation: see page 56.
- Difficult Cleavage.**—See page 124.
- Diffusion.**—(1) General: see Solution; (2) of carbon in solid solution: see page 213.
- Dilatation.**—Expansion or distension.
- Dilatation Method.**—For determining critical points: see page 256.
- Dilatometer.**—See page 483.
- Dilution.**—In cementation: see page 70.

- Dilution Pyrometers.**—See page 210.
- Dimetric System.**—Of crystallization: see page 120.
- Diminution.**—Lessening or reduction.
- Dimorphism.**—See page 121.
- Dinas Brick.**—See page 395.
- Dip Roof.**—The depressed (concave) roof first adopted for open hearth furnaces, since superseded by the present convex roof.
- Dipping.**—Of tin plates: see page 432.
- Direct.**—Without any intermediate stage or condition, *e.g.*, direct process, where the ore is reduced to malleable iron or steel without first being made into cast iron.
- Direct Bloom.**—Made by some direct process.
- Direct Driven Rolls.**—See page 407.
- Direct Firing Stove.**—See page 34.
- Direct Heating Furnace.**—See page 181.
- Direct Metal.**—See page 36.
- Direct Ore Process.**—See below.
- Direct Process.**—(1) Sometimes applied to the use of direct metal, but undesirably; (2) for by-product recovery: see page 96.
- Direct Processes.**—(1) Those in which wrought iron or spongy iron is made directly from the ore, and either used as such or converted into steel, usually by melting it with cast iron, more rarely by cementing it with carbonaceous matter, or in which weld or even ingot steel (low or high-carbon steel) is made directly from the ore (Howe), sometimes referred to as **direct ore process**; (2) rarely, the use of direct metal in connection with the open hearth or the Bessemer process.

Direct processes may be classified (Howe) according to:

I. Temperature:

- (a) **Sponge making processes:** where the temperature is so low that, while the iron is reduced, it is not thoroughly welded together.
- (b) **Balling heat processes:** where the temperature is sufficient to allow the iron to ball or weld together.
- (c) **Steel melting heat processes:** where the temperature is sufficient to melt the product. If in a shaft furnace, cast iron results. It is applicable only in a reverberatory furnace or a crucible.

II. Action of fuel:

1. Heating fuel also serves for deoxidation:
 - (a) Solid fuel.
 - (b) Gaseous fuel.
2. Separate fuel used for deoxidation.
 - (c) Ore is enclosed in externally heated retorts.
 - (d) Heated by a current of hot gas passing through it.
 - (e) Treated in open reverberatories.

The furnace principally used was of various types and modifications, and was called a **bloomery** (sometimes **bloomery**, **block oven**, **block furnace**) or **forge**. Forge was also the name used for the heating furnace and the hammer, or for the whole plant

consisting of the furnace, a blowing engine, and a hammer. "The sides are iron plates, the **hair plate** at the back, the **cinder plate** at the front, the **tuyere plate** (through which the tuyere passes) at one side (its upper part being called in some bloomaries the **merrit plate**), the **fore-spar plate** opposite the tuyere plate (its upper part being the **skew plate**), and the **bottom plate** at the bottom. The **boot** is the joint connecting the tuyere or nozzle with the blast main, usually made of tin or leather. The tongs with which the blooms are handled were called (U.S.) **grampus**" (Raymond).

A type originally like the *stückofen* (see below), but later used for producing either wrought iron or cast iron, and resembling a crude blast furnace, was termed **blauofen**, **blau furnace**, or **blue furnace**; a **flussofen** was strictly a primitive blast furnace.

The product, extracted as a lump of wrought iron mingled with slag, was called a **loup** (**loop**), **bloom** or **ore bloom**, but sometimes the two latter terms were applied only after it had been worked; **ancony** was the old name for a bloom which had been partly worked under a hammer. **Encrénée** (Fr.) is the first shape given to a bar of iron from the forge. The mass is forged down in the middle to the dimensions of the finished bar, leaving both ends unforged (**ancony**). A **marquette d'encrénée** is an *encrénée* with one of the ends forged. These definitions are given by Grignon (Osmond). In the most carburized bars from direct steel, when the drawing out (under the hammer) has not been pushed very far, there develop under these conditions a great number of small, fine transverse cracks, on the walls of which can be seen, after breaking, concentric zones formed by the temper colors. The name **roses** is given to these colorations, and **rose steel** to the metal. This is forged and then quenched while still hot to classify it by the fracture; the less carburized it is the coarser the grain (Resser).

"No forges for the manufacture of blooms and billets direct from iron ore have been in operation in the United States since 1901, in which year the blooms and billets so made amounted to 2310 gross tons, against 4292 tons in 1900 and 3142 tons in 1899. All the Catalan forges in the South have been abandoned; so have those in the North and West." (Annual Statistical Report of the American Iron & Steel Association, 1908, p. 78).

The production of malleable iron direct from the ore has proved a most attractive field for metallurgists and inventors, and many attempts have been made to devise a process which would accomplish, in one operation, the same result which is obtained by the blast furnace combined with some one of the refining processes. As a matter of logic it does not seem reasonable to produce iron containing a greater proportion of carbon and impurities than is desired, and subsequently remove the excess. The difficulties have been that in the direct process the product cannot be obtained in a fluid state as carbon is then greedily taken up, and this, on account of its cheapness and availability is practically the only substance used for reduction and heating. Materials in a solid, more particularly in a pasty and hot condition,

cannot compare, in ease of handling, with fluids, and this alone would be sufficient to account for the lack of success with which direct processes have met. Furthermore, few ores are sufficiently pure to permit of their use for direct processes without preliminary treatment.

The principal advantages and disadvantages may be summarized as follows:

Advantages:

- (a) An iron nearly free from carbon in one operation.
- (b) Removal of phosphorus, but at a heavy cost of iron.
- (c) Employment of cheap fuel.

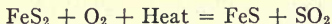
Disadvantages:

- (d) Product not fluid.
- (e) Loss of iron through reoxidation or imperfect deoxidation.
- (f) Heterogeneousness and carburization of product.
- (g) Absorption of sulphur.
- (h) Heavy outlay for labor.
- (i) Rich and cheap ores necessary.

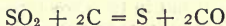
As, in most cases, heating and reduction are performed by the fuel in contact with the ore, there is danger where, as in the case of the old high bloomery, the height of the furnace is considerable, that not only will the ore be reduced, but also carburized to such an extent as to produce cast iron. After the iron has been reduced to the metallic state it will absorb carbon, depending on the length of time it is in contact with the fuel and on the temperature. It is therefore necessary to keep the furnace from getting too hot, and also to hasten the operation as much as possible.

If a considerable amount of the ore is not reduced, the resultant slag is very basic, and consequently possesses the property of holding most of the phosphorus and preventing it from being reduced and taken up by the metallic iron. On the contrary, when reduction is strong, there will be less iron in the slag which will, accordingly, be less basic, and phosphorus is then reduced.

Another advantage, viewed from the standpoint of quality but not of cost, of having the slag very basic, is that less sulphur is absorbed by the metal. While the charge is descending, any pyrites will be partially roasted, and will lose one atom of its sulphur:



The other atom of sulphur will not be much affected on account of the excess of carbon present, which of course tends to make a reducing, and not an oxidizing, atmosphere. The remaining sulphur will be largely taken up by the metal, depending considerably on the nature of the slag. With sulphur dioxide in the products of combustion, the reaction may occur:



The necessary carbon may be obtained either from the fuel or from that in the metal itself.

It should be noted that, in direct processes, the phosphorus is,

to a great extent under control, and that the sulphur is not, while just the reverse is true of the blast furnace. In the latter case, a large amount of lime is charged to remove the sulphur, and as the resultant slag is very infusible, a high temperature is required, and, consequently, all the iron and phosphorus are reduced and the former is highly carburized (after Howe).

In the **Adams process** (sometimes called **Blair-Adams process**) ore in lumps 3" cube and smaller, sometimes mixed with about 5 % of solid fuel, and in vertical chambers above an open hearth furnace, is heated and reduced by a current of hot gas. It passes thence, either continuously or, better, one chamberful at a time, into a chute, and thence into a bath of molten cast iron in the open hearth furnace, diluting and probably also oxidizing the carbon and silicon of the bath, quite as in common open hearth practice (Howe).

The **American bloomary process** (**American forge** or **Champlain forge**), resembling the Catalan process in its general features, differs from it in that the ore is charged wholly in a fine state and mixed with charcoal, instead of chiefly in lumps and in a separate column (Howe). The furnace is somewhat higher, and the bottom plate is of cast iron water-cooled.

In **A. E. L. Belford's process** the ore, pulverized and well mixed with charcoal or other carbonaceous matter, and with or without the addition of fluxes, is heated in a tubular or other suitably shaped vessel. It is then transferred, with as little cooling as possible, to crucibles and melted down. In a modification, where the initial product is evidently obtained in a fused and carburized condition, it is transferred by a closed runner to a decarburizing chamber, heated from without, where it is acted upon by decarburizing gases or steam.

In the **Berner process** a special shaft furnace is employed with tuyeres at different levels, and divided into two parts by a vertical partition. On one side ore is smelted to pig iron with solid fuel, while on the other, ore is reduced to spongy iron with reducing gases. The spongy iron is dissolved in the molten pig iron at the bottom, diluting the impurities to form a sort of steel which is run into a reverberatory furnace, forming a fore-hearth to the shaft furnace, where the treatment is completed.

The **Blair process**, also called **Blair's iron sponge process**, is an improvement over Chenot's process, in which small lumps of ore mixed with charcoal are heated externally in a retort about $4\frac{1}{2}$ feet in diameter and 40 to 50 feet high, the heating taking place at the top, the sponge then descending into a cooling chamber, and being finally taken out at the bottom. Later Blair discovered that the addition of about 5 % of lime to the ore greatly hastened deoxidation. The earlier apparatus consisted of three vertical retorts, but in the later form there was only one, and producer gas was used to heat, first externally, and then near the top, by passing directly through the ore. There was the cooling chamber as before. The sponge when drawn from the reducing furnace was quite cool, so that it did not reoxidize. It was squeezed under a pressure of 30,000 pounds to the square inch into

cylindrical blooms. Later only the fine sponge was compressed, the lumps being shoveled into the open hearth furnace, for which all the material was designed to replace scrap. He also combined the sponge with charcoal or tar to lessen the proportion of cast iron needed in the open hearth process (Howe).

Bull's process: This so-called direct process was hardly one at all, but rather an ill-advised attempt to replace the whole of the solid fuel of the blast furnace with superheated water gas (Howe).

The **Cadinho furnace** is cylindrical and of circular or slightly oval section, about 3 feet high and 1 foot in diameter (inside), and has one tuyere with air supplied by a trompe. The furnace is filled with charcoal, and after it is ignited and the furnace hot, alternate layers of charcoal and moistened powdered ore are introduced. After blowing for about $1\frac{1}{2}$ to $1\frac{3}{4}$ hours the fire is allowed to go down and the bloom is extracted through a hole at the bottom. The reduction is very imperfect, the yield being about 22% of the ore.

The **Carbon Iron Company's process (Iron Company's process):** Iron ore is deoxidized on the carbonaceous hearth of an open reverberatory furnace by means of graphitic anthracite or retarded coke (see Coke) with which it is mixed. These reducing agents, in that they themselves become oxidized only very slowly, indeed reduce the iron less rapidly than charcoal or common coke; but after reduction is effected they resist oxidation, and so persist and remain to protect the reduced iron from oxidation. The reduced iron is then balled and put in an open hearth furnace, or squeezed for rolling into wrought iron (Howe). Blooms made by this process were called **carbon blooms** or **sponge blooms**. The original process (**Eames process**) employed Rhode Island graphitic carbon, and in its later form had a number of modifications, including moistening the carbonaceous reducing material with lime or some similar inert substance to retard its oxidation.

Catalan process or Catalan forge process: The furnace usually consists of an open hearth of about 28" depth to the rear wall, and 30" width, and provided (usually) with one tuyere inserted 2 feet below the level of the top of the fuel. The casing is of cast iron, double and water-cooled. Above the hearth is a stack to carry away the products of combustion. The hearth is open at the front like an ordinary open fireplace. The blast is supplied under a pressure of from $1\frac{1}{2}$ to 2 pounds per square inch, and heated to a temperature rarely if ever measured but generally supposed to be 600° to 800° F. (315° to 430° C.). The heating pipes are bent U-shaped tubes placed in the stack. The tuyere is either pointed horizontally or slightly inclined downward. The furnace is first filled with charcoal, which is lighted, and the blast turned on. When the whole is well ignited, the ore, calcined and coarsely pulverized, is sprinkled with a shovel over the surface of the fuel in small quantities, and at short intervals basketfuls of charcoal are added as the fire burns down. The ore is deoxidized by the fuel as it works downward, and the metal finally collects in an unfused pasty mass at the bottom of the hearth, like a great sponge. The cinder fills its pores as a liquid bath, and is tapped

off occasionally at the front. A mass of iron weighing about 300 pounds is formed in about 3 hours. This is lifted out from under the fuel and is worked under a hammer into a bloom or loup which is reheated when necessary at the charcoal fire. One furnace or fire is expected to yield from 1 ton to 2500 pounds per day. About 3500 to 5000 pounds of charcoal, and $1\frac{1}{2}$ to $1\frac{3}{4}$ tons of selected ore (equivalent to from $2\frac{1}{2}$ to 4 tons of ore as mined) are used per ton of blooms (Thurston).

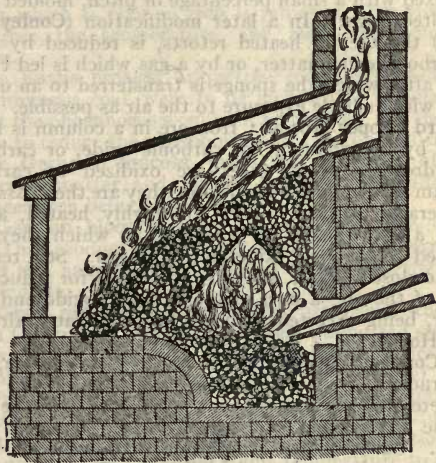


FIG. 15.—Catalan forge (Thurston, "Iron and Steel").

In Chenot's process washed or pure ore, agglutinated with some pasty substance (*e.g.*, 3% of resin) and mixed with a slight excess of charcoal, was charged in vertical rectangular retorts about $28\frac{1}{2}$ feet high, $6\frac{1}{2}$ feet long, and $1\frac{1}{2}$ feet wide, the width increasing slightly at the bottom. The upper part was of fire-brick surrounded and heated by a series of vertical flues, connecting at the bottom with fireplaces, and open at the top. The bottom was of sheet iron, water-jacketed to receive and keep the sponge out of contact with the air until cold. The operation was continuous. In a later method he reduced and heated the ore by passing through it a current of hot carbonic oxide (producer gas) in the same style of apparatus.

In Clay's process red hematite ore, crushed to lumps not larger than a walnut, was mixed with one-fifth its weight of charcoal or other carbonaceous matter and subjected to a bright red heat in clay retorts, etc., until the iron was reduced to the metallic state. The sponge so produced was then transferred to a puddling furnace, with or without the addition of 5% of coke, where it was balled. The process was slow and costly, and the iron produced

was frequently red short. He also mixed ore with half its weight of coal, etc., and heated it in a puddling furnace with four times its weight of pig iron (Percy).

In the **Conley process** crushed and magnetically concentrated ore is mixed with carbon and heated in closed retorts (heated externally), the ore and the reducing agent being stirred continually. The partially reduced ore is transferred to iron cases where it is allowed to cool out of contact with the air and is then mixed with a small percentage of pitch, molded into bricks and melted down. In a later modification (**Conley-Lancaster process**) the ore, in heated retorts, is reduced by intermixed solid carbonaceous matter, or by a gas which is led through the retorts, after which the sponge is transferred to an open hearth furnace with as little exposure to the air as possible.

Edward Cooper process: Iron ore in a column is heated and reduced by a current of hot carbonic oxide, or carbonic oxide and hydrogen. These gases are oxidized to carbonic acid and steam by the oxygen of the ore: they are then passed through a regenerator, in which they are highly heated, and thence through a bed of coal or other fuel in which they are again deoxidized to carbonic oxide and hydrogen. Still remaining in the same closed circuit, they are then used for reducing a fresh portion of the ore, a part of the carbonic oxide and hydrogen, however, being diverted to heat the regenerator already mentioned (Howe).

The **Corsican process** is similar to the Catalan, but very much cruder. The furnace is really a blacksmith's forge with one tuyere. About 10 cwts. of ore are placed on the side away from the tuyere and moistened crushed charcoal is packed between. Care is taken at first not to melt the ore. Charcoal is thrown on at intervals, and finally the reduced sponge is melted down, and the bloom extracted, hammered, etc. The process takes about 24 hours and uses about 9 parts by weight of charcoal to 1 of iron produced, and the loss of iron is about 30%.

The **De Laval process** consists in heating a mixture of pulverized ore and carbonaceous matter in a rotating cylinder, and then bringing it in contact with a powerful electric arc to reduce the iron to the metallic state. The melted iron is transferred into a large and highly heated furnace where it can be directly made into steel, or from which it can be cast into molds for further treatment.

In the **Du Puy process** about 116 pounds of ground iron ore, mixed with carbonaceous matter for reduction and with suitable fluxes to scorify the gangue, is enclosed in annular sheet-iron canisters about 13" high, 15" in diameter, and weighing 6 pounds. The charged canisters are heated to bright whiteness (a welding heat) for from 5½ to 10 hours on the coke-covered hearth of a common open reverberatory furnace. The reduced metal, still in its canister, may, according to Du Puy, be converted into muck bar by hammering or squeezing and rolling and then cut up and treated by the crucible process: it may be charged at once in the open hearth process with or without (?) cast iron;

or it may be melted down with cast iron in the furnace in which it has been reduced (Howe).

In **J. G. von Ehrenwerth's process** high carbon iron (pig iron) is melted at a high temperature in an open hearth furnace; ore is added, the iron in which is reduced by the carbon of the bath and dissolved by the bath, which is recarburized with solid carbon in the furnace itself, or in a pan, or in a small blast furnace. Ore is again allowed to act on the carburized material, and the process is repeated until the requisite amount of iron is produced. The slag which is poor in iron is removed from time to time. The higher the temperature, the more satisfactory is the operation.

In the **Eustis process** briquettes, made by coking fine ore with bituminous coal, were to be melted in a cupola, with the idea that the phosphorus would not be reduced, but the tendency would be to reduce the phosphorus and also to produce cast iron.

In the **Gerhardt process**, briquettes composed of ore, flux, carbonaceous matter, and tar were heated in a puddling furnace, the reduced iron being balled, etc.

The **German bloomery** was like an early form of Catalan forge. The product was sometimes termed **German steel**, although this name was also applied to wrought iron produced by refining pig.

The **Graff process** appears to be practically the same as the Iron Company's process. Coarsely pulverized coke, treated with a wash of lime or clay, is mixed with ore and heated, on the hearth of a reverberatory furnace lined with coke, at a temperature sufficient to slag off the gangue. The iron may be balled or transferred direct to the bath of an open hearth furnace.

G. Gunther's process consists in (1) the reduction of finely divided ore by solid carbon at a low temperature to avoid slagging off any unreduced ore; (2) the transfer to a receptacle filled with reducing gases to complete the reduction; and (3) fusion of the reduced iron with coke and fluxes in a shaft furnace.

The **Gurlt process** consisted in deoxidizing iron ore and carburizing (?) the resulting sponge in the central shaft of a special type of furnace by passing through it a stream of hot producer gas from producers forming part of the furnace. Here the producer gas both heats and deoxidizes the ore which is unmixed with solid fuel. The hot spongy iron was drawn through a doorway at the bottom of the shaft, to be balled, or, if highly carbureted, to be melted, in an open hearth furnace or in a charcoal hearth (Howe).

The **Harvey process**, similar to Renton's, consisted in heating coarsely powdered ore with charcoal on inclined steatite shelves connected with a balling furnace, and heated by a passing flame. The deoxidized ore was transferred to the hearth of the balling furnace and balled (Howe).

Hawkins process was to cement (heat) iron ore in lumps surrounded with charcoal.

Gustave Hofer's process employs a special type of furnace having the shape of a truncated cone with the smaller end

downward, and mounted on trunnions so it can be tipped. It is lined with refractory material, and inside is a separate refractory chamber between which and the lining are a number of gas passages. This inner or reducing chamber is provided with two pipes, an upper for tapping the slag, or the iron by tipping the furnace, and a lower one for introducing gases, and for tapping the iron. The main or outer vessel is provided with inlets for gas and air which burn and go up through the gas passages. Ore and coal are charged in the reducing chamber, and are heated by the burning gases on the outside. When the reduction and smelting are complete, the slag is tapped off, the valve in the bottom of the furnace opened, and gases blown into the bath of metal to purify it. The furnace may also be fired from the outside.

Husgafvel's high bloomary or continuous stückofen was a tall shaft furnace about 26 feet high, with double air-cooled walls between which the blast was preheated. It had a movable hearth with four water-cooled tuyere holes on each of the two opposite sides on two levels. The blast was introduced in the lower holes first and, as the hearth filled up, these were plugged up and the upper ones used. When the hearth was filled up to these, the blast was stopped and the hearth removed. A fresh hearth was put in place and the process continued.

The **Imperatori process** consists essentially in adding briquettes of iron ore and coal to the bath of metal in an open hearth furnace.

The **Ireland process** has to do with melting sponge in a cupola furnace.

The **Irving process** is conducted in an electric furnace. A continuous shower of ore (fine magnetite) and limestone is passed from an upper stack through a reduction chamber, in which the ore is partly reduced by ascending carbon monoxide, to a crucible at the bottom in which the reduction is completed by means of finely powdered coke introduced at the top of the crucible arch. The steel produced in eight experimental heats contained from 0.12 to 0.35% carbon.

The **Italian process** is similar to, but less perfect than, the Catalan process. The hearth is smaller and shallower. The tuyere is less inclined and enters the fire nearly in a line with the opposite wall. The yield was only up to 40 or 45%.

The **Jones step process**, as applied to iron ores provides for **metallizing** (reducing) the oxides by subjecting them in a heated condition, without fusion, to a reducing atmosphere. It is claimed that a product consisting of 97% pure iron can be secured which is suitable preferably for briquetting and charging in an open hearth furnace, or by melting in a cupola carbon can be added for the manufacture of castings. In preparing the ore for treatment, it is first crushed and passed over a $\frac{3}{4}$ inch screen. It is mixed with coal and placed in the first of a pair of cylindrical sheet iron furnaces arranged tandem. The charge may be preheated to about 700° F. (370° C.) by an oil flame at which temperature the reducing action begins and the preheating flame is then shut off. The first stage consists largely of heating to about

1500° F. (815° C.), with attendant volatilization of the hydrocarbons in the coal and the partial reduction of the ore and the formation of carbon monoxide. The pressure of gas causes circulation and forces the gas into the second furnace where a reducing atmosphere is established for another fresh charge. When the action in the first tube is complete, as determined by a time limit, this furnace is cut off, the charge dumped and quenched, the same as coke, and jigged to separate the coke from the metallic particles. The metallized ore is then crushed in rolls, magnetically separated, and formed into briquettes, either by pressure or with a tar binder. The two furnaces are thus alternately dumped and charged (*Iron Age*, 12/14/11).

In **Francis Knowle's** process clean ore in lumps was heated in retorts through which various reducing gases were passed.

H. Larkin's process employed magnetite which was crushed and passed through a magnetic separator. The concentrates were molded into bricks with carbonaceous matter, which were then placed in retorts of D-section, externally heated with gas. After exposure to a red heat for 24 hours, the iron was obtained as a powder.

In the **Lash-Johnson** process ore and carbonaceous matter are ground together to a fine powder, and mixed with a binding material such as sodium silicate or tar. The resultant material, after drying and coking, is spread on the hearth of a reverberatory furnace. The surface is protected with a mixture of two-thirds glass and one-third carbon, and the slag, fairly rich in oxide, which is tapped off, is claimed to carry much of the phosphorus with it.

The **Laureau** process aims to deoxidize iron ore with natural gas, and to prevent the deposition of carbon which occurs when fuel is passed directly through hot ore. To prevent this, before admitting the gas to the ore column, it is mixed with enough air to convert its carbon into carbonic oxide, and the mixture is heated to the temperature at which carbon tends to deposit. But when the carbon is now set free, instead of depositing as such, it unites with the oxygen present, and we have a mixture of hydrogen and carbon monoxide (Howe).

In the **Leckie** process briquettes composed of coal or peat were heated and deoxidized in chambers connecting with an open hearth furnace containing a bath of pig iron into which they were then transferred.

Liebermeister proposed to produce steel directly in a blast furnace by interrupting the carburization at the proper moment.

In **Samuel Lucas' earliest** process ore was deoxidized with carbonaceous matter in a furnace similar to that used for cementation. The sponge obtained was melted in crucibles. A later method was to heat bars of wrought iron in alternate layers with ore, charcoal, and oxide of manganese in the same type of furnace.

Matthiessen's process was not a commercial proposition but simply designed to obtain chemically pure iron. It consisted in fusing together pure ferrous sulphate and sodium sulphate, washing the oxide obtained, and reducing it by heating in a

stream of hydrogen, the resulting sponge being compressed in the cold, or melted in lime crucibles.

David Mushet's process was about the same as the first one of Lucas.

In the **native forge** or **bloomary process** (used in India and the East) ore and charcoal are heated in a small clay furnace with either natural or forced draft. From 20 to 120 lbs. of iron are produced from a charge. With natural draft about 20 tuyeres are used, and with forced draft there are 3 tuyeres. The bloom is reheated and hammered to free it from slag. Both soft and steely iron can be produced according to the charge.

In the **Neville process** ore and carbonaceous matter are charged into the upper of two sets of chambers through which the gases from the furnace pass and effect a partial reduction. The charge is then dropped into the lower set of chambers, and thence into the hearth of the furnace where it is balled.

W. E. Newton's process consisted in piling together layers of ore, charcoal, etc., and flux which were heated in a suitable vessel at a white heat for about 48 hours. The reduced iron was melted in a crucible or treated in a puddling furnace.

The **Nyhammer continuous high bloomary** consists of a shaft 16 feet high and 18" wide, from the bottom of which covered flues lead to closed charcoal hearths. Ore and charcoal are charged in the hearth continuously, and through this the gases from the charcoal hearths pass to heat the charge. The proportion of ore to charcoal charged in the shaft is regulated so that the temperature and reducing conditions in the shaft may be such as to deoxidize the ore and heat the resulting sponge strongly, but not to carburize or to soften it. The hot but not sticky spongy iron, together with the residual charcoal, is raked from the bottom of the shaft into one of the charcoal hearths, through one of the flues already described. In this hearth the spongy iron is heated to the welding point and balled, fresh lots of sponge apparently being raked in as fast as the iron, balling, sinks, till enough for a bloom has reached the hearth, when raking ceases or is diverted to another hearth. The melted slag is tapped from the hearth, the iron worked into a bloom, drawn and hammered (Howe).

The **Osmund process** employed a rectangular furnace (**Osmund furnace**) about 8 feet high, and provided with one tuyere, and a tapping hole for running off the slag. It was built of masonry, which was packed around with earth held in place by a timber casing. Calcined phosphoric bog or lake ores were smelted with charcoal much as in the Catalan process, and the bloom (**osmund**) was extracted by removing the front of the furnace. The loss was about 33 to 50%.

The **Otto process** consists in reducing ore by gas under high pressure in an externally heated horizontal retort, the gas for reduction being subsequently used for heating the retort.

In **Ponsard's process**, which resembled Siemen's earlier process, several fireclay retorts, 8" in diameter and 40" high, were placed in a reverberatory furnace, their mouths being fitted to openings in the roof, their lower parts open or perforated

and resting upon the hearth which had gutters leading to a central sump. In the retorts is charged ore with flux and about 12% of carbon for deoxidation and carburization. The reduced ore, melting, runs through the holes in the bottoms of the retorts and collects in the sump (Howe).

Ramdohr's process consisted essentially in dropping fine ore through a furnace of special construction, reduction being effected by carbonic oxide.

In **Jacob Reese's process** ores were melted in a cupola, and petroleum was blown through them. He expected the phosphorus to be given off as phosphoreted hydrogen.

In the **Rinton process** a furnace was employed resembling an ordinary puddling furnace, with a vertical fire-brick retort or chamber at one end, surrounded externally by the flues from the furnace by which it was heated. Broken ore and coal, in the proportion of 1 to 3, are charged in the retort, and when the ore is sufficiently reduced the spongy iron is discharged upon the hearth of the furnace and balled.

In **G. Roger's process** the iron ore mixed with coal is heated and reduced in a rotating cylinder, externally heated, and situated above a puddling furnace into which the resulting sponge is dropped and balled.

The **Rudolphs-Landin process** consists in making briquettes of fine ore, carbonaceous material, and flux as required, which are dried, and the iron reduced while being passed through a long furnace. The reduced briquettes are dropped into a bath of molten metal covered with slag contained in a reverberatory furnace, and portions of the bath are transferred from time to time to an open hearth furnace and finished.

In the **Särnström process**, a modification of the Osmund or the Catalan process, the furnace consists of a vertical reduction shaft connected with a number of hearths by small passages which can be closed by dampers which are provided with small holes so the gases from the hearths may pass through the shaft. Ore and charcoal are charged at the top of the shaft, and during its descent the ore is reduced and the iron sponge produced is worked and balled in the hearths.

In **A. Sattman and A. Homatsch's process** ore is heated (calcined if necessary) by the combustion of gas in a special type of shaft furnace; reduction is effected by passing reducing gas alone through the charge, the resulting sponge being melted in a chamber at the bottom of the shaft, and connecting with a closed chamber in which solid fuel is burned. The fluid iron, somewhat carburized, may be run directly into an open hearth furnace and finished, or partial removal of the carbon may be effected by hot oxidizing gases acting on the metal as it runs from the melting chamber to a receiving chamber. The process is intended to be worked either intermittently or continuously.

In the **Schmidhammer process**, apparently following out the idea of the Nyhammer furnace, a special form of continuous stückofen was proposed. The shaft is charged continuously with ore and enough charcoal for deoxidation; the ore is deoxidized

during the descent; the temperature is raised to the welding point by hot blast and hot water gas blown through the tuyeres; the spongy iron is balled through working openings; and the balls are drawn from a fore-hearth on lifting the door. The distinctive features are substitution of hot gas and air for part of the more costly charcoal; the fore-hearth and the door which permit of forming and drawing the balls without allowing the superincumbent charge to slide down as in Husgafvel's furnace (Howe).

C. W. Siemens' process: In one of his early direct processes two cast-iron retorts or hoppers, with fire-clay ends, were suspended above the hearth of an open hearth furnace. Around each hopper is a space heated by a regulated supply of flame from the open hearth furnace: within is a wrought-iron pipe supplying producer gas for deoxidizing the ore. About 28 pounds of charcoal is charged through each hopper, and on this sufficient ore to fill the hopper completely. Producer gas is then injected through the pipes in the center of the hoppers, and deoxidizes the ore which has meanwhile been raised to redness by the heat conducted through the walls of the hoppers. About half a ton of pig iron is charged on the open hearth; melting, it dissolves the lower end of the columns of more or less completely deoxidized iron, with a rapidity which is only limited by the time needed to deoxidize the ore in the hopper. Sufficient sponge having been thus melted off in three or four hours, charging ceases, the remaining ore in the hopper sinks, a clay-coated cast-iron cover suspended by strong wire descending with the ore column, so that the flame may not enter the empty hoppers. On this cover is placed the charcoal and ore of the subsequent charge, eventually lowered by cutting the wire. The charge already melted is brought to the right degree of carburization, and, after an addition of spiegel-eisen, is tapped (Howe).

In the later process (**Siemens' precipitation process**) fine ore was reduced by coal, with which it was mixed and heated in a rotating furnace, the coal precipitating metallic iron from the molten ore. The resulting metal was balled as in puddling, squeezed to expel slag, and either used as material for the open hearth process, or worked into merchantable wrought iron. The furnace was regenerative and gas fired (Howe).

The **cascade furnace**, used at one time by Siemens, instead of a rotator, had two hearths at different levels. A lake of fused ore was formed on the upper hearth, and, by piercing the intervening bank of unmelted ore, was run at intervals upon the lower hearth, upon which meanwhile a layer of equal parts of powdered anthracite or coke and ore had been spread. On stirring, the mass foamed and became pasty; in from 40 to 50 minutes the iron, precipitated by the carbon, was balled, to be melted in the open hearth or squeezed (Howe).

In **Frederick Siemens' process** ore, coal, and fluxes are charged continuously through a slit at the end of a regenerative gas furnace, which is rectangular in plan, with the entrance and exit ports at the same end, the opposite end being strongly inclined. The heat is so high that the ore melts immediately on entering

the furnace, and so coats over and protects the coal from the action of the flame of the furnace. The melting ore trickles down the incline, its iron being reduced by the coal, partly during its descent, partly after reaching the bath at the bottom of the incline. Basic additions are made to the molten slag to permit dephosphorization and the reduction of the iron. The slag runs out continuously; the metal is tapped from time to time (Howe).

In Snelus' process the ore, heated in a special form of furnace, was to be reduced by carbonic oxide or hydrogen.

O. Stromborg's process employs an open hearth furnace provided at the top with special reservoirs from which tubes extend down below the surface of the bath on the hearth through which ore and carbon, separately, are forced under air pressure. The furnace being provided with molten steel, carbon is introduced, and, after it has been taken up by the bath, ore is added to be reduced by the carbon. Heating may be effected by producer gas as in ordinary open hearth practice, but principally by blowing air through one of the feed pipes. A limy slag is employed which can be tapped off as necessary.

The *stückofen* or old high bloomery (also called salamander furnace, wolf furnace, wolf oven, wulf's oven, and stuck oven) was a shaft furnace 10 to 16 feet high, either round or rectangular in section, and provided with one tuyere, somewhat over a foot above the hearth, and a drawing hole for the blooms. It may be considered as approaching the present blast furnace, and frequently cast iron was produced. The fuel was charcoal. The wolf oven was somewhat lower, and between it and the *stückofen* German metallurgists (Percy) place a furnace of intermediate height called *blaseofen* and *bauernofen* (osmund furnace, in Sweden). The product of the *stückofen* may contain a certain amount of highly carburized iron, and when the bloom is reheated and most of this cast iron runs out, the remainder, which is more infusible (wrought iron), is called a *blume* (Overman).

Swedish Metallic Sponge.—This appears to be manufactured by a process similar to Chenot's. It is obtained by reducing compressed briquettes of ore by carbon monoxide at a temperature slightly below the melting point of iron. The ore used is a magnetite as pure as possible. The sponge produced is very light, in color varies from blue to black, has no metallic luster, and is not very pleasing in appearance. The analysis of a sample showed metallic iron slightly over 96% (*Rev. Met.*).

The Tourangin process is a modification of Chenot's direct or internal method of heating. The furnace employed was about 20 feet high, and cost less than Chenot's, but the principle was the same. The sponge produced was drawn at the bottom, covered with ashes, or kept in special water-jacketed legs at each side of the furnace until cool, and subsequently worked up in a charcoal hearth, etc. (Percy).

In the Trosca process ore was reduced by contact with carbonaceous matter in externally heated vertical retorts; the resulting sponge was removed in an air-tight buggy (Howe).

In the Twynam process briquettes of ore and carbonaceous

matter were thrown into the bath of metal in a basic open hearth furnace.

Westman's process resembles Cooper's except that common producer gas is used, and that the gas passes through the regenerator while on its way from the gas producer to the deoxidizing furnace (Howe).

In the **Wilson process** coarsely pulverized ore with 20% of charcoal or coke dust is heated to 800° to 1000° F. (427° to 538° C.) for 24 hours in vertical retorts at the end of a puddling furnace by whose waste heat they are heated externally. The partially deoxidized ore is then dropped into a second hearth of the puddling furnace, and after 20 minutes more is pushed into the hearth proper where it is balled (Howe).

The **Yates process** appears to be identical in principle with Chenot's indirect heating process, reduction of the ore being effected by heating in contact with carbonaceous matter in vertical retorts in sections, one above the other, connected by socket joints, and heated externally with producer gas. The sponges produced are balled in a puddling furnace.

Direct Recovery Process.—See page 96.

Direct Stress.—See page 332.

Dirt Inclusion.—See page 57.

Dirt Pocket.—See page 311.

Dirty Gas.—See page 33.

Discard.—In rolling or forging, particularly ingots, the portion cut off and rejected to insure sound material. The discard from the top, whether from the ingot, the bloom or billet, or the finished section, containing the pipe and the segregated portion, is called specifically the **top discard**, and the piece next to it, the **top cut**; the discard at the bottom, the **bottom discard**, and the piece next to it, the **bottom cut**. Both discards are also referred to as **crops** or **crop ends**.

Discontinuous Combustion.—See page 202.

Discontinuous Curve.—See Curve.

Discrystallization.—Amorphizing: see page 282.

Dishing.—See Cold-Working.

Disk Radio-balance.—See page 207.

Dissociation ; Point ; Theory.—See page 89.

Dissolved Carbon.—See page 275.

Distillation.—See page 202.

Distillation Process.—See page 385.

Distinct Cleavage.—See page 124.

Distortion.—See page 334.

Distribution of Carbon.—See page 213.

Distribution, Coefficient of.—See Coefficient of Distribution.

Distributor.—For ore: see page 32.

Divalent.—See page 86.

Divariant System.—See page 327.

Division.—See page 81.

Divorcing ; Divorcing Annealing.—See page 274.

Dode Process.—See page 370.

Dodecahedral Cleavage.—See page 124.

- Dodecahedral Iron Ore.**—See page 244.
- Dog Collar.**—See page 315.
- Dolite.**—See page 399.
- Dolly.**—A heavy iron bar, suspended at about the middle, used to strike a heavy blow by swinging it against the given object in the same manner as with an ancient battering ram; also called **top** or **monkey**.
- Dolomite.**—See pages 175 and 397.
- Dominant Element ; Metal.**—In an alloy: see page 4.
- Donner Mill.**—See page 434.
- Doubles.**—Of sheets: see page 430.
- Double-acting Hammer.**—See page 196.
- Double Annealing.**—See page 232.
- Double-burned Dolomite.**—See page 397.
- Double Furnace ; Double-double Furnace.**—See page 376.
- Double Gross Ton (obs.).**—See **Ton**.
- Double Hardening.**—See page 228.
- Double-level Furnace.**—See page 312.
- Double-melting Process.**—See page 75.
- Double Mill.**—See page 430.
- Double Pouring.**—See page 57.
- Double-refined Iron.**—See page 378.
- Double-rolled Iron.**—See page 378.
- Double Shear.**—See page 337.
- Double Shear Heat.**—See page 71.
- Double Shear Steel.**—See **Shear Steel**.
- Double Shrink.**—See page 296.
- Double Skip.**—See page 33.
- Double Steel ; Doubler ; Doubling Shear.**—Of sheets: see page 430.
- Doubly Converted Bars.**—See page 71.
- Doubly Oblique System.**—Of crystallization: see page 120.
- Doubly Refined Iron.**—See page 378.
- Dowlais Mill.**—See page 417.
- Down Draft Producer.**—See **Producer**.
- Downcomer.**—See page 33.
- Dowson Gas.**—See **Producer**.
- Dozzle.**—See page 59.
- Draft.**—(1) In molding: see page 296; (2) in rolling: see page 407.
- Draft Fluid Compression.**—See page 64.
- Drag.**—See page 297.
- Draper's Law.**—See page 208.
- Draught.**—See **Draft**.
- Draw.**—(1) In the crucible process: see page 115; (2) in heat treatment: see pages 230 and 232; (3) in molding: see page 296; (4) of wire: see page 507.
- Draw Bench.**—See page 508.
- Draw Bottom.**—See page 17.
- Draw Down.**—To reduce the section of a piece of metal by mechanical means, such as hammering, rolling, or drawing.
- Draw Hole.**—(1) In castings: see page 53; (2) for wire: see page 507.
- Draw Plate.**—See page 507.

- Draw Tempering.**—See pages 230 and 232.
- Drawing Back.**—See pages 230 and 232.
- Dressing.**—(1) Of castings: see page 58; (2) of ores, preparing by crushing, washing, etc. (but not roasting); (3) of metallic pieces, machining; (4) of rolls, turning down in a lathe after they have become worn.
- Drier.**—Of a paint: see page 365.
- Drift Test.**—See page 477.
- Drill Temper.**—See Temper.
- Driving-in Method.**—To determine hardness: see page 478.
- Drop (obs.).**—See Slag.
- Drop of the Bath.**—See page 376.
- Drop of the Beam.**—See page 469.
- Drop Bottom.**—See page 182.
- Drop of the Flame.**—See page 20.
- Drop Forging.**—See Forging.
- Drop Hammer.**—See page 197.
- Drop Stamping (Eng.).**—Drop forging.
- Drop Test; Drop Weight Test.**—See page 481.
- Dross.**—The sullage, scurf, oxide, or other impurities which are skinned off the top of molten metals, or which accumulate in the sinkhead or riser of a casting.
- Drummer (Eng.).**—A smith's hammerman (Horner).
- Druse; Drusy Cavity.**—See page 125.
- Dry; Dryness.**—(1) Of pig iron, low in silicon; (2) of slags, infusible; (3) of steel which is red-short or tender: see Brittleness.
- Dry Analysis.**—See page 82.
- Dry Blacking.**—See page 298.
- Dry Blast.**—See page 29.
- Dry Bottom.**—See pages 253 and 377.
- Dry Brush.**—See page 298.
- Dry Cleaning.**—Of gas: see page 33.
- Dry Coal.**—See Coal.
- Dry Drawing.**—Of wire: see page 508.
- Dry Dust Catcher.**—See page 33.
- Dry Finish.**—Of sheets: see page 433.
- Dry Fusion.**—See page 201.
- Dry Galvanizing.**—See page 371.
- Dry House.**—In wire practice: see page 507.
- Dry Iron.**—See page 343.
- Dry Method of Analysis.**—See page 82.
- Dry Ore (Eng.).**—See page 243.
- Dry Process.**—See page 82.
- Dry Puddling.**—See page 374.
- Dry Sand; Dry Sand Molding.**—See page 296.
- Dry Slag.**—See Slag.
- Drying.**—(1) Of molds: see page 298; (2) same as coming to nature: see page 376.
- Drying Oven; Stove.**—See page 298.
- Du Puy Process.**—See page 140.
- Dualistic Theory.**—See page 89.
- Ductilimeter (rare).**—See page 483.

- Ductility.**—(1) General: see page 331; (2) formulæ for: see page 338.
- Ductility Test.**—See pages 481 and 483.
- Düdelingen Process.**—See Recarburization.
- Dull Fracture.**—See page 178.
- Dull Iron ; Metal.**—See page 343.
- Dulong's Law.**—See page 203.
- Dulong & Petit's Law.**—See page 85.
- Dummy Tuyère.**—See page 17.
- Dump.**—To discharge by gravity, as the contents of a cupola.
- Duo Mill.**—See page 408.
- Duplex Constituent.**—Eutectic: see page 266.
- Duplex Process.**—See page 317.
- Durr (Eng.).**—Jar or shock.
- Dust Catcher ; Chamber.**—(1) In connection with a blast furnace: see page 33; (2) this term is rarely used for the cinder pocket of an open hearth furnace.
- Dust Coke.**—See page 97.
- Dust Plate (obs.).**—A vertical iron plate supporting the slag runner of a blast furnace (Raymond).
- Dusting.**—Of sheets: see page 430.
- Dwight and Lloyd Process.**—See page 45.
- Dyad.**—See page 86.
- Dyer Process.**—See page 317.
- Dynamic Deformation.**—See page 333.
- Dynamic Hardness.**—See page 331.
- Dynamic Indentation.**—To determine hardness: see page 478.
- Dynamic Load.**—See page 333.
- Dynamic Metamorphism.**—See page 122.
- Dynamic Methods.**—Of hardening: see page 279.
- Dynamic Resistance ; Strains ; Strength ; Stress.**—See pages 330 and 333.
- Dynamic Test.**—See pages 468 and 481.
- Dynamic Theory of Heat.**—See page 199.
- Dynamometer.**—See page 483.

E

- Er.**—Chemical symbol for erbium: see page 84.
- Eu.**—Chemical symbol for europium: see page 84.
- E.B.B. Wire.**—See page 509.
- E.S.C. (Brit.).**—The Engineering Standards Committee (*q.v.*).
- Eames Process.**—See page 138.
- Ease, State of.**—See page 332.
- East Coast Hematite.**—See page 344.
- Eaton Process.**—(1) In cementation: see page 68; (2) in purification: see page 385.
- Ebullition.**—See page 202.
- Eccentric Converter.**—See page 17.
- Edge Steel.**—In a casting, the metal solidifying first on the outside, and which on etching sometimes presents a different appearance from the central portion which is then called **core steel**.
- Edging Pass.**—See page 408.
- Edison Gage.**—See page 187.
- Edwards and Carpenter's Theory.**—Of hardening: see page 281.
- Edwards Flying Shears.**—See page 413.
- Efficiency of Corrosion.**—See page 108.
- Effloresce; Efflorescence.**—See Water.
- Egg Coke.**—See page 97.
- Ehrenwerth Process.**—See page 141.
- Ehrenwerth and Prochaska Process.**—See page 317.
- Eifel Walloon Process.**—See page 80.
- Eisen-Portland.**—See Slag Cement.
- Elastic After-working.**—See page 333.
- Elastic Break-down.**—See page 333.
- Elastic Compressive Strength.**—See page 336.
- Elastic Deformation.**—See page 330.
- Elastic Limit.**—(1) General: see pages 330 and 469; (2) by dividers: see page 470; (3) by drop of the beam: see page 470; (4) by extensometer: see page 470.
- Elastic Limit Strength.**—See page 330.
- Elastic Ratio.**—See page 335.
- Elastic Resilience; Strain; Strength.**—See pages 330 and 331.
- Elasticity.**—(1) General: see page 330; (2) coefficient of: see page 334; (3) modulus of: see page 334.
- Eldred Process.**—See page 24.
- Electric Arc Furnace.**—See page 153.
- Electric Arc-resistance Furnace.**—See page 153.
- Electric Blast.**—See page 503.
- Electric Casting.**—See page 65.
- Electric Furnace Process.**—See page 153.
- Electric Furnaces, Types of.**—See page 153.
- Electric Hardening.**—See page 230.
- Electric Processes.**—For cementing: see page 70.
- Electric Processes.**—Electricity, in the commercial manufacture of

iron and steel, is used almost exclusively as a source of the heat necessary to cause the various reactions to take place, and not for any direct chemical action, or only to a limited and practically negligible extent; the more correct, and therefore preferable, designation is **electro-thermal** or **electro-thermic process** or, referring to the type of furnace employed, **electric furnace process** (also termed **electro-metallurgical process**, and the product, **electric steel**). Electrolysis of suitable solutions, which depends on a direct chemical reaction, has recently been developed to a point where production of nearly pure iron is on a commercial but comparatively limited scale (see Electrolytic Iron, page 165).

Electro-thermic processes may be classified according to the following **types of furnace**, based on the manner in which the heating is effected.

1. **Induction furnace (induction heating)**: The furnace usually consists of an annular trough (the furnace proper), the contained metal constituting part or all of the secondary circuit of a transformer (an alternating current must be employed), the primary circuit of which is arranged as usual. The type where the bath forms the entire secondary winding is called a **simple induction furnace**; where the bath forms only a part of the secondary circuit, a copper winding being added to assist in the heating, it is a **combination induction furnace**.

2. **Resistance furnace (resistance heating)**: The charge or bath of metal forms part of the regular circuit, and the resistance it offers to the passage of the current yields the required temperature.

3. **Surface resistance furnace**: The electrodes do not suffice for the passage of the current. To heat up the furnace it is necessary to connect them by means of some kind of conducting material, such as a bed composed of pieces of carbon. These conductors are then brought to a state of extreme incandescence, and form a melting hearth upon which the materials to be treated are placed. The materials themselves afterward, being traversed throughout their extent by the current, serve as a conductor between the electrodes (Keller).

Arc furnace, radiation furnace, or arc radiation furnace (arc heating, radiation heating): The requisite temperature is obtained by radiation from an arc (**radiating arc**) formed between two electrodes, or between two or more electrodes and the charge. In the latter case the current may pass from one electrode into the bath, then out again to another electrode in series with the first, or through the bottom of the furnace (which in this case forms an electrode); the direction being constantly reversed if an alternating current is employed. By either method a certain amount of resistance heating occurs (**indirect resistance heating**), and this combination is called an **arc-resistance, resistance-arc, or combined arc and resistance furnace**.

The **advantages** of electric heating as compared with that obtained from the combustion of fuel are, in general:

(a) A higher temperature available.

- (b) The possibility for greater purification, both because the high temperature available permits a slag high in lime which otherwise would be too infusible, and also because reducing conditions can be maintained (particularly at the end of the process) whereby reduction and consequent elimination of oxides and dissolved oxygen can be secured.
- (c) More complete exclusion of air or gases (except in the case of the crucible process).
- (d) Carbon is required only for reduction (also for recarburization, if desired), including what is added to the slag for this purpose, hence a smaller amount of impurities is introduced than with ordinary fuel.

The usual disadvantage is:

- (e) That the cost is generally higher, except where power is extremely cheap and fuel dear (as in Norway), so it is usually available only for the finer grades of steel (*e.g.*, to replace that made by the crucible process), or when used simply for final purification.

The furnaces are nearly always basic lined, so that purification with lime can be effected, but they can also be acid lined if desired.

Allevard process: Very little has been published about this process. It is stated that an electrode furnace is employed in which various grades of steel are made from either pig and ore or pig and scrap.

The **Anderson furnace** for refining or making steel appears to be very similar to a Héroult furnace, with the addition of electro-magnets placed underneath the furnace in line with the electrodes, from which arrangement benefits are claimed. A type for smelting ores is similar to the Keller furnace designed for that purpose.

The **Bailey resistance furnace** is used simply as a heating furnace for forging or heat treating purposes. The resistance material is essentially crushed coke connected with graphite electrodes and protected by a lining of magnesite.

The **Borchers furnace**, which is somewhat similar to the above, being used only for heating purposes, employs a carbon rod of relatively small cross-section, called a **resistor**, which is heated by the passage of the current, and about which the charge is placed.

The **Burke furnace** is of the arc type, operates at preferably two phase, each circuit entirely distinct from the other (Vom Baur).

In the **Chapelet furnace**, of the arc type, the current flows into the bath from a hanging carbon electrode, much as in the Girod furnace. From the bath it goes through a horizontal channel to a hanging cast iron electrode that touches the channel. This constitutes the peculiarity of the furnace. It is not apparent that this offers any advantage over the Girod arrangement (Vom Baur).

The **Colby furnace** is very similar to the Kjellin, differing principally in the use of a copper tube, through which water

circulates, for the primary coil. It was patented by E. A. Colby, and the rights for these two furnaces in this country have been consolidated under one management; it is then called a **Kjellin-Colby furnace**.

M. R. Conley's process is somewhat similar to Stassano's, as reduction and purification are effected in the same chamber. The furnace employed has somewhat the shape of a blast furnace: the walls converge at about the middle, below which is the hearth where the final reduction and melting take place; the charge is introduced at the top, and the molten products are tapped out through a hole at the bottom. The furnace is of the resistance type: the current is brought into contact with the charge by means of two graphite electrode rings built into the wall, one of which is at the narrowest point of the furnace and the other a short distance above. It was designed to produce either cast iron or steel.

The **Crafts furnace** is a steel furnace of the induction type in which the transformer cores are horizontal instead of vertical. These cores are around heating channels leading up to the bath above, much like the flues in an open hearth furnace. The channels are always full of molten metal. The bath can be worked as in an open hearth furnace (*Iron Age*, Sept. 18, 1913).

In the **Ferranti process**, patented in 1885, the first induction furnace was employed, which, however, did not prove a commercial success. It consisted of a laminated iron core wound with fine wire, constituting the primary circuit, and around this an annular refractory trough in which the molten metal formed the secondary circuit.

The **Frick furnace** is of the induction type, and is very similar to the Kjellin, the principal difference being that in the former the primary windings are placed above and below the annular hearth instead of within it. Heating is produced in exactly the same way. Another difference is that the Frick furnace has a single cover which can be rotated, so that, by having one opening, the whole of the ring-shaped hearth can be inspected. Also a skimmer introduced through the hole during rotation would serve to bring the slag to the spout very easily.

The **Galbraith furnace** was designed to extract iron from fine ores without previous briquetting. The iron sand is mixed with fine carbon and is led downward in a zigzag manner in a furnace constructed entirely of graphite over twelve roasting bars also made of graphite. The entire furnace is closed. On their way through the furnace, the ores mixed with fine carbon are reduced and, to assist in this, carbureted hydrogen is also introduced into the lower portion of the furnace. The iron collects at the bottom in a liquid state.

Gin furnace: One form is of the resistance type. In this the metal is contained in a long, narrow, shallow trough to obtain sufficient resistance and which, for convenience, is doubled upon itself. Connection with the current is made at the ends of the trough by two water-cooled metal electrodes plunged in the molten metal. A later form is of the induction type: the metal

circulates in a number of troughs connected together by channels; the bottoms of the troughs are inclined. The furnace is tilting, and has a rectangular shape.

The **Girod furnace** resembles a small tilting open hearth furnace. The hearth consists of a circular or oblong cavity in which the metal when molten reaches a height of from 10 to 11 inches. One or more electrodes (depending upon the size of the furnace) in parallel are maintained above the bath, and soft steel pieces, embedded in the hearth of the furnace, and in direct contact with the molten metal, form the negative

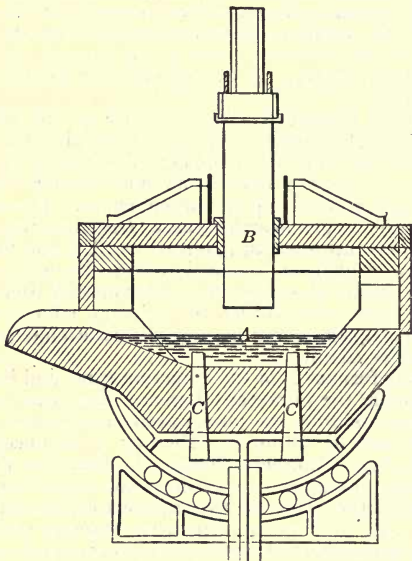


FIG. 16.—Girod furnace.—A, molten metal. B, upper electrode. C, lower electrode (*Eng. and Min. Jour.*).

electrode. The current, entering by the way of the upper electrode, forms an arc between itself and the bath, traverses the bath, and passes out through the lower pole pieces, the upper parts of the lower pole pieces, which are in direct contact with the metallic bath become molten at their extreme ends; the lower ends are water-cooled. This furnace is of the arc type. Girod also manufactured ferro-alloys in a resistance furnace in which the resistance consisted of a layer of graphite in the walls; this type was also used for a crucible furnace.

The **Gronal-Kjellin furnace**, or **Gronal furnace**, is a modification of the original Kjellin furnace, differing principally

in the method of forming the primary circuit, and in means provided for tilting.

The **Grönwall furnace** of the induction type was devised with the object of increasing the resistance of the bath and so improve the power factor by greatly elongating the ordinary channel of

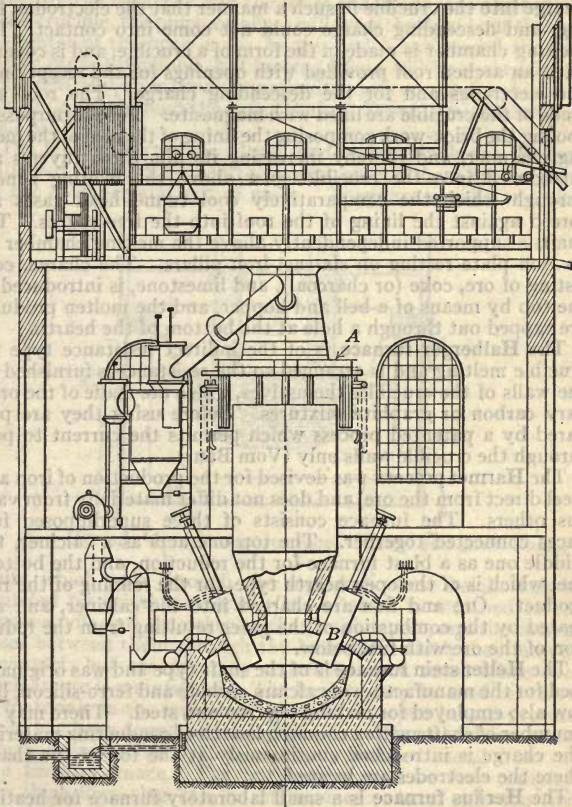


FIG. 17.—Grönwall furnace; vertical section.

the induction furnace. This result is largely secured, but with considerable losses of heat by radiation (Vom Baur).

The **Grönwall** or **Grönwall, Lindblad and Staalhane electric shaft furnace** is devised for the reduction of iron from its ore, and is unlike any hitherto constructed, resembling most nearly an ordinary blast furnace in which the tuyeres are replaced by electrodes,

three in number. The height of the furnace above ground level is about 25 feet. The melting chamber or crucible containing the electrodes is about 7 feet high, and is of greater diameter than any other part. The shaft is about 18 feet high, the lower end of which—for about 4 feet—has the form of an inverted truncated cone; the angle of this cone is for the purpose of directing the charge into the crucible in such a manner that the electrodes, lining, and descending charge could not come into contact. The melting chamber is made in the form of a crucible, and is covered with an arched roof provided with openings for the reception of the electrodes and for the descending charge. The roof and walls of the crucible are lined with magnesite. For the purpose of cooling the brick-work composing the lining of the roof of the melting chamber, and thereby increasing its life, three tuyeres are introduced into the crucible—just above the melting zone—through which the comparatively cool tunnel-head gases are forced against the lining of the roof into the free spaces. The shaft is supported independently above the melting chamber by an iron plate resting on six cast-iron pillars. The charge, consisting of ore, coke (or charcoal), and limestone, is introduced at the top by means of a bell and hopper, and the molten products are tapped out through a hole at the bottom of the hearth.

The **Halberger furnace** is of the indirect resistance type for crucible melting and is arranged so the resistance is furnished by the walls of the crucibles themselves, which are made of the ordinary carbon or graphite mixtures. Before using they are prepared by a patented process which permits the current to pass through the crucible walls only (Vom Baur).

The **Harmet process** was devised for the production of iron and steel direct from the ore, and does not differ materially from various others. The furnace consists of three superimposed furnaces connected together. The top one acts as a calciner, the middle one as a blast furnace for the reduction, and the bottom one, which is of the open hearth type, for the refining of the raw product. Ore and flux are charged into the calciner, and are heated by the combustion of the gases resulting from the reduction of the ore with fuel below.

The **Helfenstein furnace** is of the shaft type and was originally used for the manufacture of calcium carbide and ferro-silicon, but now also employed for making pig iron and steel. There may be a number of shafts with a common hearth of conducting material. The charge is introduced continuously at the top of the shafts where the electrodes are located.

The **Heräus furnace** is a small laboratory furnace for heating crucibles, combustion tubes, etc., consisting of a tube of porcelain or other refractory material which is heated by a resistance coil of platinum wire or strip wound about it, and protected from radiation on the outside by a layer of heat insulating material.

The **Hering furnace** is based on the **pinch phenomenon**: When a current passes through a conductor, the magnetism produced in and about it has a crushing effect, as the surrounding magnetic flux acts like stretched rubber bands. This crushing force is not

strong enough to be noticeable in solid conductors, but when they are liquid, and the current is sufficiently large, it is clearly evident. This is sometimes powerful enough to sever the conductor, and generally occurs locally at the weak spot. If the conductor consists of a column of molten metal confined in a hole in a refractory material near the bottom of a crucible, and if the outer end is sealed by the electrode and the inner end opens into the bath or in the crucible, the pinching effect will force the liquid out through the center of the open end. As this end is submerged the conductor cannot pinch off, but instead liquid will be sucked in circumferentially, thus producing simultaneous outward and inward flow of liquid through the hole (Hering, *Trans. Am. Electrochem. Soc.*, XXXV).

The Héroult furnace is tilting, and is very similar to the type employed in the open hearth process except there are no ports for the entrance and exit of gases. There are usually two elec-

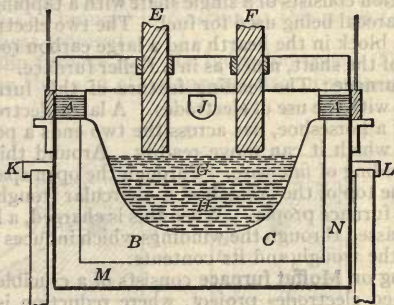


FIG. 18.—Héroult double arc furnace. (*Eng. and Min. Jour.*)

trodes which pass through the roof and whose height can be regulated by suitable means. One of these is attached to the negative pole and the other to the positive pole, and the current passes between them through the bath with which they may be in contact, but are generally separated by a small space over which an arc is maintained. The furnace may be used for treating materials in the same manner as in the open hearth process, but it has been found advantageous to work with blown metal from a Bessemer converter, or nearly finished metal from an open hearth furnace. The purification may be very complete as a high-lime slag can be maintained. As a rule the first slag, containing most of the phosphorus, is removed, and a second slag, consisting of lime and fluorspar, is then formed. Crushed coke is added to complete the removal of the oxygen in the bath. A process devised by Ernest Humbert (Dr. Héroult's metallurgist) consists in removing the phosphorus, not as usual as phosphate but as phosphide. Use is made of an oxidizing basic slag to combine with the phosphorus and form a phosphate, after which a reducing material, usually crushed coke, is added, and

floats on the slag, reducing the calcium phosphate to phosphide, which cannot be taken up by the iron as phosphorus without first being converted back to phosphate. In this way it is intended to purify with a single slag, but so far, on tapping, a considerable amount of phosphorus seems to pass back into the metal.

Héroult ore smelting furnace: The furnace consists of an approximately vertical shaft at the top of which the coke for the reduction is charged. On one side there is an inclined shaft by which the ore is introduced into the main shaft and comes into contact with the column of coke. The heat is supplied by the resistance of the charge to the passage of the current. There are two electrodes, both consisting of solid blocks of carbon, one of which is situated near the top of the coke column, and the other at the bottom of the hearth. The action is somewhat similar to what takes place in a blast furnace, the molten pig and slag which collect in the hearth being tapped out through suitable openings. A modification consists of a single shaft with a tapping hole at the bottom, charcoal being used for fuel. The two electrodes consist of a carbon block in the hearth and a large carbon rod suspended at the top of the shaft, much as in a Keller furnace.

Hiorth furnace: The leading feature of this furnace is that it dispenses with the use of electrodes. A large electro-magnet, in the form of a horseshoe, has across the two ends a perpendicular rod, about which it can move readily. Around this rod is the primary winding of fine wire. Through the open space, and surrounding the top of the horseshoe, is a circular trough which constitutes the furnace proper. When this is charged, a high tension current is passed through the windings which induces a secondary current in the trough and its contents.

The **Irving or Moffat furnace** consists of a crucible into which three inclined electrodes project, where reduction is completed with coke, surmounted by a stack, through which the charge passes to the crucible, being there preheated and partially reduced by carbon monoxide.

Keller furnace (Keller-Leleux process): The furnace formerly employed was very similar to the Héroult type, the current passing from one electrode into the bath, and then out of it into another electrode, both electrodes being above the bath. In one form it consisted of two furnaces at different levels, one fixed and one tilting. When working with pig and scrap, the materials were melted and partially refined in the upper stationary furnace, and then run into the lower tilting furnace where the process was completed; with scrap alone the whole operation was conducted in the tilting furnace. In the latest type adopted, which resembles Girod's furnace, there is only one electrode at the top or, if several electrodes are employed, they are all connected in parallel; the other terminal is the bottom or hearth of the furnace. The current, therefore, passes from the electrode at the top into the bath and leaves the furnace at the bottom. In a recent patent, which provides for a durable bottom, Keller places a bundle of iron bars vertically in the furnace bottom, connecting them to a conducting plate arranged below their bottom ends. Between

these bars and around the bundle which they form, a refractory material, preferably magnesia, is strongly rammed. The furnace bottom consists, therefore, partly of vertical iron rods and partly of magnesia, the latter also becoming a conductor at high temperatures.

The **Keller ore smelting furnace** is practically the same in principle and construction as the form originally employed for making steel, and is of the resistance type. There are two vertical shafts connected at the bottom by a horizontal canal. The charge, consisting of the proper proportion of ore, coke, and flux, is charged at the top of both shafts, and reduction takes place during its descent. One large carbon electrode is suspended in each shaft, connected respectively to the negative and the positive terminals. The bottoms of the shafts are connected by a copper rod on the outside and underneath, fastened to blocks of carbon. A small well between the two shafts serves to collect the molten materials. If there is any danger of chilling up, a third electrode can be brought into action at this point to supply the additional heat required.

The **Kjellin furnace** is of the induction type. The hearth or crucible is in the form of an annular ring provided with covers,

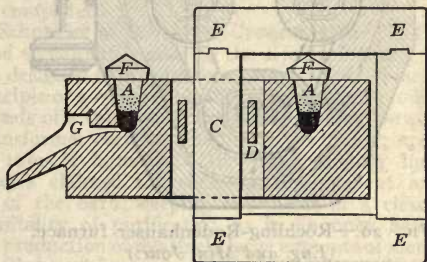


FIG. 19.—Kjellin induction furnace.—AA, circular trough in which steel is melted and treated. C, magnetic core. D, primary coil. E, frame connecting ends of C. F, cover for melting chamber. G, spout. (*Eng. and Min. Jour.*)

and the contained metal forms the secondary circuit of a transformer, the primary circuit of which consists of a coil of fine, insulated copper wire with a laminated iron core. The winding is placed on one leg only, the primary being next the core, and the secondary outside of this. It is protected from radiated heat by air spaces and a water jacket. The process has generally been used for obtaining steel of any grade from dead soft to hard by a suitable mixture of pure pig and scrap, with the proper additions of ferro-silicon, etc.; little purification has been attempted. The initial charge has been cold pig and scrap, but after it has been operating, only a portion is tapped out each time.

The **Lavol furnace** was one of the earlier forms of resistance furnace designed for refining spongy iron. The furnace, of cylindrical

cal shape, consisted of two compartments to be filled with molten iron oxide to above the top of the separating wall. The current passed through this between electrodes placed in the bottom of the compartments. The spongy iron was to be refined while sinking through this molten oxide.

The **Ludlum furnace**, used for producing cast steel, cast iron, low phosphorus pig, and washed metal from steel scrap, is of the arc type. It has an elliptical hearth in which are three electrodes in line, which arrangement is claimed to give great uniformity.

The **Nathusius furnace** is of the arc type with additional resistance, and represents a combination of the Hérault and the Girod furnace, the current traveling between combinations of electrodes above and below the bath, so that it also passes through the bath (Vom Baur).

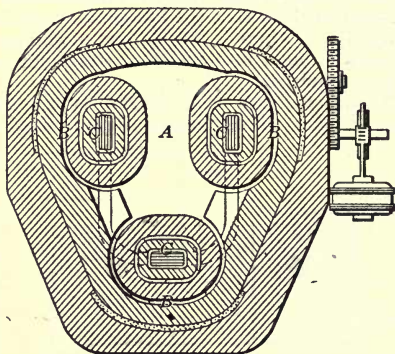


FIG. 20.—Röchling-Rodenhauser furnace.
(*Eng. and Min. Jour.*)

The **Noble furnace** is very similar to the Grönwall, Lindblad and Staalhane shaft furnace, differing from it principally in regard to the arrangement between the electrodes and the charge, no space being left between them. It is sometimes referred to as the **Californian type** of furnace from the installation at Hérault, California.

The **Rennerfelt furnace** is of the arc type and employs essentially a two-phase current. There are three electrodes; the middle one is connected to the neutral point and each of the two outside ones to a phase of the two-phase system. By this arrangement of current distribution the arc flame is forced down on the bath, producing a powerful effect.

The **Röchling-Rodenhauser furnace**, sometimes called **Schönawa-Rodenhauser furnace**, is a modification of the Kjellin furnace devised by Schönawa and Rodenhauser to obtain higher temperatures, and so be better able to effect purification than with the original. It is of the induction type but in addition to

this method of heating employs resistance, for which purpose currents are introduced into the bath through metal electrodes, so that a double effect is obtained. It has a hearth of a very different shape from other induction furnaces. The furnace is constructed for single-phase or for three-phase alternating current; in the former case the hearth (composed of grooves) is like two Kjellin rings intersecting (forming a figure 8), in the latter case, like three. In both cases these two or three grooves or heating channels open into a distinct open hearth, the working chamber, where all the metallurgical operations take place, while the grooves, which have a comparatively small cross-section, form the secondary circuits in which the currents which heat the metal are induced.

The **Ruthenburg process** is a link between magnetic separation and the fusion process. It is used for the purpose of agglomerating fine particles of magnetically concentrated ores, as briquetting presents certain difficulties or objections. The fine concentrates are passed through this furnace, the fusion zone of which is a strong magnetic field, and the ore particles are agglomerated. If, in addition, carbon is added to the ore before entering the apparatus, a partial reduction takes place which is subsequently further completed.

The **Schneider** or **Schneider-Creusot** furnace of the induction type and somewhat similar to the Kjellin furnace, is employed, but it is designed to give better circulation of the metal. It is on the principle of a water-tube boiler: a large reservoir is connected to the ends of a tube at an angle, and passing between the arms of a transformer carrying the primary winding; one of the legs of the tube is horizontal, the other slightly inclined. The advantages claimed for such an arrangement are: energetic mixing of the bath; keeping the metal in a closed chamber; the possibility of purification as in an open hearth furnace; and the production of relatively large amounts of metal.

Wm. Siemens' furnace, which was used only for experimental purposes, was on the arc principle and consisted of a graphite crucible provided with two electrodes: in one form one electrode entered through the bottom and the other through a hole in the cover; in a modification the electrodes were introduced at the sides; a water-cooled metallic electrode was subsequently used instead of the carbon one.

The **Snyder furnace** is of the arc type, being an adaptation of Siemens' original furnace with single phase bottom electrode (Vom Baur).

Stassano furnace: This is an arc furnace, nearly cylindrical in cross-section, and rotating about a vertical axis inclined about 7° to the vertical (the furnace may also be stationary). It is provided with three or more large cylindrical electrodes inserted through the sides, and nearly meeting at the center, supplied with a three-phase alternating current. The furnace is usually lined with magnesite, and the charge is introduced at the top, and the molten products are tapped out at the bottom. This furnace has generally been used to produce steel direct from ore,

but pig and scrap may also be employed as in other steel-making processes. In the former method, pure, finely ground ore, with just the right proportion of carbon and flux, is molded into bri-

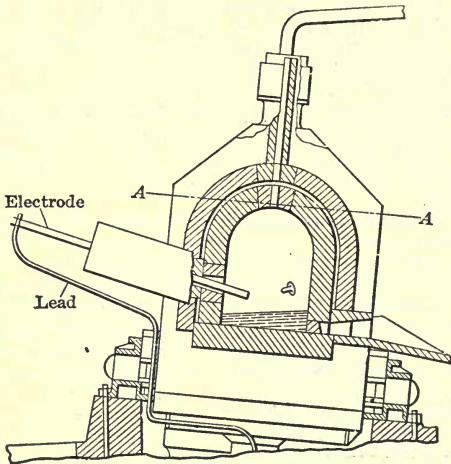


FIG. 21.—Stassano furnace: vertical section.

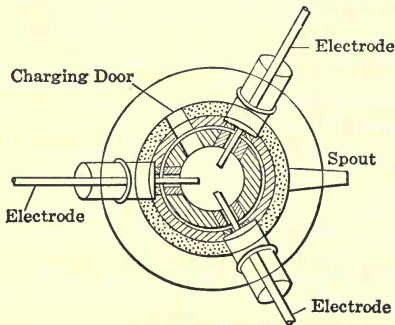


FIG. 22.—Stassano furnace: transverse section.—AA, of Fig. 21.
(*Eng. and Min. Jour.*)

quettes and subjected to heat from the arc. The rotation of the furnace helps to keep the ore and carbonaceous matter in contact.

The **Taussig furnace** is of the direct resistance type, the charge being contained in a long narrow channel.

The **Vom Baur furnace** is of the arc type, and involves the combination of a two-phase, three-wire circuit, three upright electrodes connected to this circuit, a solid bottom for the furnace and an oval-shaped side wall of refractory material.

The **Wile furnace**, of the arc type, employs a three-phase current and two top and one bottom electrode; it has been used for melting ferro-manganese, etc.

The number of furnaces bearing some distinctive or modifying name is steadily increasing. While some of them may possess essential differences, the great majority vary only slightly from those now in use or which are known

Electric Pyrometer; Resistance Pyrometer.—See page 208.

Electric Resistance Furnace.—See page 153.

Electric Shears.—See page 412.

Electric Steel.—See page 153.

Electric Surface Resistance Furnace.—See page 153.

Electric Tempering.—See page 230.

Electric Welding.—See page 503.

Electrically Driven Rolling Mill.—See page 407.

Electro-affinity.—See page 108.

Electro-cementizing.—See page 70.

Electro-chemical Cleaning.—Removing the scale, etc., from iron objects by attaching them to the negative pole in an electrolytic bath.

Electro-chemical Equivalent.—See page 89.

Electrode Volume.—See page 364.

Electro-galvanizing.—See page 371.

Electro-iron.—Iron produced electrolytically.

Electrolysis.—(1) General: see page 89; (2) for iron: see Electrolytic Iron; (3) in corrosion: see page 365.

Electrolyte.—See page 89.

Electrolytic Corrosion.—See page 108.

Electrolytic Dissociation.—See page 89.

Electrolytic Iron.—That produced by an electrolytic process, the anode consisting of metallic iron (**electrolytic refining**). It was first carried out successfully by Prof. C. F. Burgess in 1904 by a double operation. Typical analyses are given as follows (*Trans. Am. Electrochem. Soc.*, XXV, 489).

	Single refined	Double refined
Sulphur, %.....	0.001	None
Silicon, %.....	0.003	0.0013
Phosphorus, %.....	0.020	0.004
Manganese, %.....	None	None
Carbon, %.....	0.013	0.012
Iron, %.....	99.963	99.971
Hydrogen, %.....	0.083	0.072

O. W. Storey (*ibid.*, XXIX, 357) states that "at least one of the large electrical concerns is turning out (1916) 1000 pounds of electrolytically refined iron per week, with a probable increase to

several times this output in the near future. The method used is that developed by **Burgess** and later modified by **Watts**. The electrolyte consists of 150 grams of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, 75 grams $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$, and 120 grams $(\text{NH}_4)_2\text{SO}_4$ per liter with a specific gravity of 1.125 at 20°C . Ammonium oxalate is used as an addition agent. The anodes consist of bars of basic open hearth steel. The deposit reaches a thickness of $\frac{3}{8}$ to $\frac{1}{2}$ inch before it is necessary to remove the cathode . . . Until recently the only use to which electrolytic iron had been put was in the so-called **steel facing** of dies and electrotypes. Its hardness, which makes it suitable for such purposes, is due to hydrogen, either occluded or combined." In the **Cowper-Coles process** "the electrolyte is a concentrated solution of ferrous chloride with additional organic compounds, such as the cresol-sulphonic acids, and enough iron oxide to make a sort of gruel. The additional iron oxide is used for reducing the acidity and polishing the iron which is deposited as a sheet on a rapidly revolving cathode at a temperature near the boiling point of water. The current density used is about 63 amperes per square foot. The resulting product is brittle due to the presence of several tenths of 1% of hydrogen. It also contains about 0.50% of impurities, exclusive of hydrogen, while the pig iron used for anodes contains about 7%. The chlorine content . . . is high" (*ibid.*, 358-9). "In 1913 Cowper-Coles obtained a British patent in which he proposes to avoid exfoliation and brittleness . . . by suspending an iron sponge in an electrolyte used for refining iron" (*ibid.*, 361). "In 1911 **Fisher** took out patents . . . in which he claims that ductile iron may be deposited from a hot solution of ferrous chloride if hygroscopic salts, such as the chlorides of calcium, magnesium, or aluminum are added to the electrolyte. He claims that the ductility of the product increases with the electrolyzing temperatures and that perfectly ductile iron is obtained at temperatures varying between 100 and 120°C . The preferred solution consists of a highly concentrated mixture of ferrous and calcium chlorides, 450 parts of ferrous chloride and 500 parts of calcium chloride being dissolved in 700 parts of water. Under these conditions a current density of 180 amperes per square foot may be used" (*ibid.*, 359). **Ramage** took out two patents, one in 1911 for the use of ferric iron ore, dissolved in sulphuric acid and reduced to the ferrous state by sulphur dioxide, and a later one in which he "dissolves iron in a ferric liquor and electrolyzes the resulting ferrous liquor" (*ibid.*, 359-60). In **Boucher's process** "the electrolyte is a solution of one or more ferrous salts, such as the sulphate or chloride" (*ibid.*, 360). In **Reed's process** which also covers "the making of sulphuric acid as a by-product. The electrolyte is a solution of iron sulphate. The anode is made of spongy lead which becomes sulphated as the electrolysis proceeds" (*ibid.*, 361). The **Le Fer process** employs pig iron as the raw material. "A cathode revolving in a neutral solution of iron salts is used, the solution being maintained neutral by the circulation of the electrolyte over the surface of the iron" (*ibid.*,

361). In regard to its properties Storey says (in part—*ibid.*, 362): "Electrolytic iron when deposited by the usual methods is brittle, due to the hydrogen present. In this form it can be easily broken into smaller pieces and even ground into powder. By heating the iron to a red heat the hydrogen is driven off and the iron becomes ductile, the ductility increasing with the temperature of annealing. Brittle electrolytic iron as deposited is highly soluble in acids, being much more readily soluble than zinc. Annealing the iron makes it become more resistant to acid attack than ordinary irons and steels."

Electrolytic Methods of Etching.—See page 288.

Electrolytic Process.—(1) For producing iron: see Electrolytic Iron;

(2) for coating: see Protection, page 371.

Electrolytic Refining.—See page 165.

Electrolytic Theory.—Of corrosion: see page 108.

Electro-metallurgical Process.—See page 153.

Electron ; Electron Theory ; Electronic Theory.—See page 81.

Electronegative Ion.—See page 89.

Electro-percussive Welding.—See page 503.

Electropositive Ion.—See page 89.

Electro-thermal (-ic) Process.—See page 153.

Element.—See page 83.

Eliquation.—Separating an alloy by heating it so as to melt the more fusible of its ingredients but not the less fusible (Raymond); usually called **liquation**: see Segregation.

Ellershausen Process.—See page 385.

Ellis Process.—See page 9.

Elongation.—(1) General: see page 336; formulæ for: see page 338.

Elsner Process.—See page 30.

Embrittling (Howe).—Causing brittleness.

Embryonic Crystals.—See page 120.

Emery.—Impure corundum (alumina) used for grinding and abrasive purposes.

Emulsified Carbide.—Troostite: see page 276.

Eminent Cleavage.—See page 124.

Emissive Power.—See page 207.

Emissivity.—See page 200.

Empirical Formula.—See page 86.

Emulsified Pearlite.—See page 276.

Emulsion Martensite.—See page 276.

Enamel ; Enameling.—See page 370.

Encrénée (Fr.).—See page 135.

End Shears.—See page 413.

Endosmose.—See Solution.

Endothermic Reaction.—See page 82.

Endurance Limit.—See page 333.

Endurance Tests.—See pages 481 and 482.

Engineering Standards Committee, The (Brit.).—Organized for the purpose of drawing up "British Standard Specifications," definitions, and methods of testing for various classes of material and objects. Supported by the following British societies:

The Institution of Civil Engineers.

The Institution of Mechanical Engineers.

The Institution of Naval Architects.

The Iron and Steel Institute.

The Institution of Electrical Engineers.

English Brick ; Dinas Brick.—See page 395.

English Formula.—For quality: see page 340.

English Foundry Iron ; Pig Irons.—See page 349.

English Scale.—Of temperatures: see page 204

English Standard Wire Gage.—See page 187.

English Yield Point.—See page 471.

Engorgement.—See page 35.

Entering Angle.—In rolling: see page 407.

Envelope.—See page 126.

Eolotropic ; Eolotropy.—A name given by T. Gray to the phenomenon when a flat bar shows greater elasticity when bent in one direction than in the other. This effect was produced by heating it in a smithy fire, whereby one side was probably converted into cast iron which had higher elasticity in compression than in tension: see page 330.

Equalization of Carbon.—See page 213.

Equalizer.—(1) Of blast: see page 34; (2) in cementing: see page 68.

Equalizing.—In heat treatment: see page 232.

Equiaxed Crystal ; Grain.—See page 217.

Equilibrium.—(1) General: see page 326; (2) equation of: see page 327.

Equilibrium Diagram.—See pages 271 and 327.

Equilibrium Temperature.—See page 327.

Equivalent.—See page 87.

Equivalent Proportions, Law of.—See page 85.

Erhardt Process.—See page 491.

Erosion.—See page 106.

Etch-polishing.—See page 288.

Etching.—See page 286.

Etching Band ; Figure ; Line ; Pit.—See page 127.

Etching Reagents.—See page 287.

Eudiometer.—An instrument for measuring the proportions of various gases which are necessary to form a given compound. It consists of a graduated tube of heavy glass, sealed at one end, into which the gases are introduced and are caused to explode by an electric spark, the open end of the tube being held down on a pad during the explosion. The residual gases are then measured.

Euhedral Crystal.—See page 122.

European Process.—For malleable castings: see page 258.

Eurythronium.—See Vanadium.

Eustis Process.—See page 141.

Eutectic.—See page 266.

Eutectic Alloy.—See page 270.

Eutectic Austenite.—See page 275.

Eutectic Austenoid.—See page 275.

Eutectic Cast Iron.—See page 271.

Eutectic Cementite.—See page 273.

- Eutectic Line.**—See page 266.
- Eutectic Mixture ; Point ; Ratio ; Solution.**—See page 266.
- Eutectic Steel.**—See page 273.
- Eutectic Temperature.**—Eutectic point: see page 266.
- Eutectic Time.**—See page 266.
- Eutecticum.**—See page 266.
- Eutectiferous Band.**—See page 127.
- Eutectiform Pattern.**—See page 127.
- Eutectoid.**—See page 270.
- Eutectoid Cementite.**—See page 273.
- Eutectoid Ferrite.**—See page 272.
- Eutectoid Steel.**—See page 273.
- Eutectoid Transformation.**—Of hypoeutectoid Steel: see page 275.
- Eutectomeric Alloy.**—See page 4.
- Eutexia.**—See page 267.
- Eutropic Mixture ; Point.**—See page 270.
- Evans and Spencer Process.**—See page 64.
- Evaporation.**—See page 202.
- Evaporative Power.**—See page 203.
- Even Fracture.**—See page 178.
- Ewing and Rosenhain's Theory.**—Of slip bands: see page 282.
- Excess Cementite.**—See page 273.
- Excess Ferrite.**—See page 272.
- Excess Substance.**—See page 266.
- Exchanges, Law of.**—See page 200.
- Exfoliation.**—See page 68.
- Exhaust Tuyere.**—See page 32.
- Exhaustion.**—Of cement: see page 67.
- Exhaustion Method.**—For the removal of gases from liquid steel by creating a vacuum; tried but not practical.
- Exosmose.**—See Solution.
- Exothermic Reaction.**—See page 82.
- Expanded Metal.**—Sheets in which a series of short, disconnected, transverse cuts have been made, and the sheets then extended longitudinally, producing the effect of a framework or grille.
- Expanding Cupola.**—See page 182.
- Expansion.**—(1) General: see page 204; (2) coefficient or factor of: see page 204.
- Expansion Crack.**—See Crack.
- Expansion Pyrometer.**—See page 205.
- Explosion Door.**—See page 33.
- Extension.**—See page 336.
- Extensometer.**—See page 471.
- Exterior Shrinkage.**—See page 54.
- External Conductivity.**—See page 200.
- External Forces.**—See page 331.
- Extra Lattens.**—Of sheets: see page 433.
- Extraction Process.**—One where a metal is smelted or reduced from its ore.
- Extrapolation.**—See Curve.
- Extrusion.**—The forcing of a substance through a die or aperture.
- Extrusion, Centrifugal.**—See page 121.

Exude.—To ooze out, either under heat or pressure, *e.g.*, for a more fusible or a softer substance to exude from one which is less fusible or harder.

Eye.—(1) The peep hole, covered with glass, in the tuyere of a blast furnace; (2) the hole for the pin in the end of an eye bar.

Eye Piece.—See page 285.

Eyermann Process.—See page 318.

F

- F.**—(1) Fahrenheit scale: see page 204; (2) chemical symbol for fluorine: see page 84.
- Fe.**—Chemical symbol for iron (Latin, *ferrum*), *q. v.*
- Fl** (rare).—Chemical symbol for fluorine: see page 84.
- F. P.**—Freezing point.
- Face.**—Of a crystal: see page 119.
- Face-hardened Armor Plate.**—See page 8.
- Faceless Crystal.**—See page 122.
- Facing Sand.**—See page 298.
- Faggot** (Eng.); **Fagot**; **Fagoted Iron.**—See page 378.
- Fahrenheit Scale.**—Of temperatures: see page 204.
- Falk Method.**—See page 65.
- Fall.**—(1) Of meteorites: see page 290; (2) of malleable castings: see page 257.
- Fall of the Beam.**—See page 469.
- Falling Seam.**—See page 489.
- Falling Weight Test.**—Drop test: see page 481.
- False Block.**—See page 195.
- False Pass.**—See page 405.
- Fament Process.**—See page 385.
- Faraday's Laws.**—See page 83.
- Faraday's Theory.**—Of passivity: see page 364.
- Farrar Process.**—See page 385.
- Fat Coal.**—See Coal.
- Fat Lime.**—See Flux.
- Fat Sand.**—Sand for molding which contains a large amount of clay or alumina.
- Fatigue.**—See page 333.
- Fatigue Limit**; **Stress.**—See page 333.
- Fatigue Test.**—See page 482.
- Fault** (obs.).—The tymp arch or working arch of a furnace (Raymond).
- Faulting Foliation.**—See page 124.
- Feather.**—See page 58.
- Feed Roll.**—See page 415.
- Feeder**; **Feeding Gate**; **Feeding Head.**—See pages 56 and 299.
- Felsitic Structure.**—See page 125.
- Fermentation** (obs.).—The boiling stage in the puddling process.
- Fern Leaf Crystal.**—See page 122.
- Ferranti Process.**—See page 155.
- Ferrate.**—A chemical compound: see Iron.
- Ferrated Carbides.**—See page 278.
- Ferric Acid.**—See Iron.
- Ferric Oxide Theory.**—Of puddling: see page 378.
- Ferrite.**—(1) A chemical compound: see Iron; (2) pure iron: see page 272.
- Ferrite Ghost.**—See page 289.

- Ferrite Point.**—See page 273.
- Ferrite-refinement Principle.**—See page 341.
- Ferrite Steels.**—Those consisting principally of ferrite; hypo-eutectic steels.
- Ferro-Alloys.**—See page 351.
- Ferro-Aluminum.**—See page 351.
- Ferro-Brass.**—See page 372.
- Ferro-Carbon.**—See page 351.
- Ferro-Carbonyl.**—See Carbon.
- Ferro-Chrome ; Ferro-Chromium.**—See page 352.
- Ferro-Ferrite.**—See page 272.
- Ferro-Manganese.**—See page 352.
- Ferro-Molybdenum.**—See page 353.
- Ferro-Molybdenum Hardenite.**—See page 275.
- Ferro-Nickel.**—See page 353.
- Ferronite.**—See page 277.
- Ferro-Phosphorus.**—See page 353.
- Ferro-Products.**—See page 351.
- Ferro-Silicon.**—See page 354.
- Ferro-Sodium.**—See page 355.
- Ferrostic Pressure.**—See page 56.
- Ferro-Steel.**—A trade name for semi-steel (*q.v.*).
- Ferro-Titanium.**—See page 355.
- Ferro-Tungsten.**—See page 355.
- Ferro-Vanadium.**—See page 356.
- Ferrous Acid.**—See Iron.
- Ferrous Alloy.**—See Alloy.
- Ferrous Structure.**—That of ordinary or carbon steels or cast irons.
- Ferruginous.**—Carrying or containing iron.
- Ferruginous Manganese Ore.**—See page 245.
- Ferro-Concrete.**—Reinforced concrete.
- Féry Pyrometers.**—See page 207.
- Fetch Up.**—Of carbon: see Recarburization.
- Fettling.**—(1) Of castings: see page 58; (2) of a furnace: see pages 315 and 376.
- Fiat Gage.**—See page 187.
- Fiber ; Fibre.**—See pages 125 and 337.
- Fiber Stress.**—See page 337.
- Fibriform Structure.**—See page 125.
- Fibrous Fracture.**—See page 178.
- Fibrous Iron (obs.).**—Wrought iron which is tough, comparatively soft, and neither cold nor red-short in a sensible degree (Percy).
- Fibrous Silica.**—See Salamander.
- Fibrous Structure.**—See page 125.
- Fibrox.**—See page 398.
- Field.**—See page 291.
- Field Coat.**—See page 365.
- Fiery Fracture.**—See page 178.
- Figure of Merit.**—See pages 8 and 340.
- Filament.**—See page 125.
- Fill Out.**—In rolling: see page 414.
- Fillet.**—The curved junction of two surfaces which would otherwise

meet at an angle. Its object is to lessen the danger of cracking, and it is used particularly in connection with castings, machined material, and rolled sections.

- Fin.**—See Forging.
- Final Additions.**—See Recarburization.
- Final Slag.**—See Slag.
- Find.**—See page 290.
- Fine-grained Fracture.**—See page 178.
- Fine-grained Iron; Metal; Pig.**—Pig iron having a fine fracture.
- Fine Metal.**—See page 383.
- Finer.**—See page 316.
- Finer's Bar.**—See page 75.
- Finer's Metal.**—See page 383.
- Finery; Finery Fire.**—See page 382.
- Finger.**—See page 411.
- Fining.**—See page 383.
- Finished.**—Material which is ready for the market without any further treatment. Blooms and similar material are termed **semi-finished**, except only when they are sold as such, when they may be called finished.
- Finished Black Plate.**—See page 431.
- Finished Charcoal Bar.**—See page 75.
- Finished Iron.**—A name sometimes applied to merchant (wrought iron); muck bar piled and rerolled.
- Finished Material Analysis.**—See page 82.
- Finished Products.**—(1) General: see page 411; (2) mills for: see page 413.
- Finisher.**—See page 316.
- Finishing Block.**—See page 508.
- Finishing Metal.**—See Recarburization.
- Finishing Rolls; Stand.**—See page 414.
- Finishing Temperature.**—See page 218.
- Finkelstein's Theory.**—Of passivity: see page 364.
- Fir-tree Crystal.**—See page 122.
- Fire Assaying.**—See page 82.
- Fire Bar; Bed.**—See page 183.
- Firebrick.**—See page 396.
- Fire Bridge.**—See page 183.
- Fireclay; Fireclay Brick.**—See page 396.
- Fireclays, Grades.**—See page 396.
- Fire Crack.**—(1) In rolling: see page 405; (2) of refractories: see page 395.
- Fire Gases.**—See page 202.
- Fire Hole.**—See page 114.
- Fireplace.**—See page 183.
- Firestone.**—See page 395.
- Firing Test.**—See page 482.
- First Annealing.**—Of sheets: see page 431.
- First Class Foam Cells.**—See page 121.
- First Order Cells.**—See page 121.
- First Pickling.**—Of sheets: see page 431.
- First Strand.**—See page 415.

- Fisher Process.**—See page 166.
Fissile.—See page 124.
Fissure.—See Crack.
Fix (Eng.).—See page 376.
Fixed Carbon.—See Fuel.
Fixed Converter.—See page 17.
Fixed Elements.—See page 70.
Fixed Furnace.—See page 312.
Fixed Points.—Of a temperature scale: see page 204.
Flake.—See pages 71 and 178.
Flame.—See page 203.
Flame Contact Furnace.—See page 181.
Flame Cut.—Of material cut by means of an oxyacetylene or oxyhydrogen flame.
Flame Furnace.—See page 181.
Flameless Combustion.—See page 203.
Flanch (obs.).—Flange.
Flange Steel.—Steel of suitable quality to be bent (flanged) cold.
Flanging.—See Cold Working.
Flash.—See Forging.
Flash Annealing.—See page 232.
Flash Heating.—See page 228.
Flash Point.—See page 202.
Flask.—See page 297.
Flask Annealing.—See page 58.
Flat ; Flat Iron ; Flat Bar Iron.—A long narrow strip or plate, usually produced on a bar or merchant mill.
Flat Roll.—See page 404.
Flatter.—In forging, a swage used to flatten.
Flattening Mill.—A machine for flattening wire.
Flavite.—See pages 69 and 279.
Flaw.—Defect.
Flexure ; Flexural Rigidity ; Resilience ; Strength ; Stress.—See pages 330 and 337.
Flicker Photometer.—See page 208.
Flint Hardness.—See Hardness.
Floating.—Of cores: see page 298.
Flohr Process.—See page 21.
Floor Sand.—See page 301.
Floss ; Floss Hole.—See page 375.
Flow.—See page 209.
Flow Gate.—See page 299.
Flow Lines.—See pages 283 and 289.
Flue.—A passage for air or other gases.
Flue Bridge.—See page 183.
Flue Cinder.—See page 375.
Flue Dust.—See pages 33 and 44.
Fluid Bottom.—See Lining.
Fluid Compressed Steel.—Steel which has been subjected to compression before it has entirely solidified: see page 63.
Fluid Compression.—See page 63.

Fluid Metal.—Suggested by Von Ehrenwerth for slagless iron products.

Fluid Movement.—See page 281.

Fluid Pig Iron.—Suggested by Von Ehrenwerth to replace *hot metal*.

Fluid Rolling Process, Norton.—See page 65.

Fluid Stress.—See page 332.

Fluorspar.—Also called **spar** or **calcium**; fluoride of calcium, CaF_2 ; used as a flux: see below.

Flush.—See pages 36 and 438.

Flushed Bars.—See page 71.

Flushing Hole.—See page 32.

Flussofen.—See page 135.

Flute ; Fluting.—In a plate which has been rolled out longer on one side than on the other; when it is straightened the long side shows **flutes**, or **waves**; where the center has been rolled out longer than the outside, producing the same effect in the middle, the plate is said to be **buckled**.

Flux.—(1) In the crucible process: see page 115; (2) in welding: see page 501.

Flux.—A material used in smelting metals for the purpose of combining with the gangue of the ore and producing a suitable slag (*a*) by making it sufficiently fusible, and (*b*) by combining with certain impurities and preventing them from entering or remaining in the metal. The term is also used for a substance added in a refining (oxidizing) process to make the slag more fusible. A flux may be either **acid** or **basic** depending upon its chemical properties. The principal **basic flux** is **limestone**, CaCO_3 , also called **lime**, or **raw limestone** occurring naturally, and containing small amounts of silica, magnesia, alumina, iron, etc. In color it is ordinarily gray, white, or slightly yellow, and is massive (non-crystalline) in structure. If crystallized, it is known as **calcite**. For blast furnace work the silica should generally be less than 5%, and for basic Bessemer and basic open hearth practice not over 1 or 2%. The magnesia, as well as the iron and alumina, is not especially objectionable for its use as flux, but as a rule they are less than 4%. The material is sometimes calcined to expel the carbonic acid, but the action is usually not perfectly complete; it is then termed **burnt lime** or **quick lime**. If, owing to imperfect calcination or the presence of other substances it slacks with difficulty (better, however, with hot water) it is designated as **poor lime**; if it slacks easily, as **fat lime**. **Magnesia** and **dolomite** do not find much application as fluxes (see Refractories). **Fluorspar** or **calcium fluoride**, CaF_2 , sometimes called **spar**, occurs in translucent or transparent crystals, which may be colorless, light yellow, or purple in color. It should contain less than 10% of impurities, but calcite, which is frequently present, is not particularly objectionable; the silica should be less than 2%. A by-product, sometimes employed, contains about 50% of calcium fluoride mixed principally with lime; this, as well as fluorspar, is occasionally called **calcium**. This flux is used principally in

open hearth practice for thinning basic slags which are too viscous. **Calcium chloride**, alkaline salts, etc., are sometimes used in purification processes (*q.v.*). The only **acid flux** is **sand**, which is practically never used as an addition to a slag which is too viscous from high lime: it, as well as **borax**, is used in welding (*q.v.*) to obtain a fusible cinder.

McClenahan's process for smelting certain southern red iron ores was to use common salt (NaCl) instead of limestone, claiming that "limestone has no affinity for the aluminous components of the red ore."

Flux Line ; Stick.—See page 115.

Fly.—See Ladle.

Fly Hammer.—See page 196.

Flyer.—See Cold Working.

Flying Shears.—See page 413.

Foam ; Foam Cell ; Wall.—See page 121.

Foaming.—See Frothing.

Foepl's Method.—Of determining hardness: see page 478.

Foerster and Schmidt Theory.—Of passivity: see page 364.

Folding.—See page 124.

Foliation.—See page 124.

Forbes Process.—See page 369.

Forced Solution.—See page 279.

Fore Blow.—See page 21.

Fore Hearth.—(1) Of a blast furnace: see page 32; (2) of an open hearth furnace: see page 315.

Fore Plate.—See page 415.

Fore-Spar Plate.—See page 135.

Foreign Pig Iron.—See page 344.

Forge.—(1) To work a piece of metal with a hammer or a press; (2) a power hammer; (3) a plant for the manufacture of (wrought) iron blooms direct from the ore: see page 134; it consists of a furnace or forge fire, a blowing apparatus and a hammer; (4) later, this term was applied to that part of a (wrought) iron works where the balls were hammered or squeezed, and then rolled into muck bar; that part of the works where the muck bar was reheated and rerolled into finished iron was called the mill.

Forge Cinder.—See Slag.

Forge Coal.—See Coal.

Forge Effect.—In electro-percussive welding: see page 504.

Forge Fire.—Forge, *q.v.*

Forge Iron ; Pig.—See page 344.

Forge Process.—See page 74.

Forge Rolls ; Train.—See page 413.

Forging.—The operation of working metal or of changing its shape by striking it a sharp blow (usually while hot) with a hammer or other suitable instrument; also the object so produced. The action of a hydraulic press is frequently termed forging (**hydraulic forging**), but as the action is more of a steady squeeze the designation **pressing** would appear to be preferable. To indicate the use of a hammer, the term **hammer forging** is employed. The

operation of hammering puddle balls was formerly called **shingling** or **nobbing**. The term **smithing** (Eng.) is sometimes used for working a piece, especially by hammering, for the purpose of straightening or flattening it. Removing or correcting the irregularities of a piece by hammering (sometimes cold) may be referred to as **dressing** or **hammer dressing**. Where a forging, for example a projectile, is made by **hot punching** a portion of its length, the billet may be placed in a die and forced down until it completely fills it, an operation known as **setting down**. **Drop forging** (and the object) is a process designed for making a large number of objects exactly the same. It consists in forging a suitable piece of steel between dies under a hammer, the lower die being attached to the anvil block, while the upper is fastened to the hammer itself, and moves up and down with it. When the object is simple, one set of dies may suffice, but with more complicated pieces, two or more are necessary for roughing and finishing. The **fin** or **flash**, formed at the sides of the piece where a small portion of the metal is forced out between the edges of the dies, is dressed off, and any other required machining is done. **Hollow forging** is where a piece, usually a heavy shaft or column, is bored and then forged out on a mandrel. Its object is to secure better working of the metal than would be the case with a solid piece of large cross-section. See also Hammer and Press.

Forging Crack.—See Crack.

Forging Strain.—A strain set up in forging at too low a temperature, or where a part receives more work than another.

Forging Test.—See page 476.

Form.—Mold.

Formation of Crystals.—See page 120.

Former.—See page 405.

Formula.—Chemical Formula: see page 86.

Fornoconvertisseur.—See page 318.

Forsyth Process.—See page 62.

Forty-eight-hour Coke.—See page 95.

Fosberg's Swedish Hearth.—See page 76.

Fossil Ore ; Fossiliferous Red Hematite.—See page 244.

Foster Pyrometer.—See page 207.

Foul Gas Main.—See page 96.

Founding ; Foundry.—See page 53.

Foundry Coke.—See page 96.

Foundry Iron ; Pig.—See page 344.

Foundry Pit.—See page 57.

Four-high Mill, Bleckley's.—See page 417.

Four-sided Charcoal Wire.—See page 509.

Fournier Pyrometer.—See page 209.

Fox Tail.—See page 79.

Fracture.—The irregular surface, and its appearance, produced when a piece of metal is **ruptured** or broken. The terms fracture and rupture are frequently used interchangeably; it is, however, desirable to restrict them as just indicated.

Howe (*Metallog.*, 527-8) classifies fractures as follows:

1. **Granular or intergranular**, caused by rupture passing along grain boundaries instead of across the crystalline grains themselves.

2. **Crystalline, trans-crystalline, or intra-crystalline**, caused by rupture passing across the crystalline grains themselves.

3. **Silky**, caused by the thread-like drawing out of the fragments of the crystals in the act of rupture.

4. **Hackly or hooked**, sharp or jagged and irregular, which may be referred to the drawing out of the ferrite in the act of rupture.

5. **Fibrous and slaty**, caused by rupture occurring consecutively through distinct layers.

6. **Columnar**, as in the case of the outer parts of ingots and other castings of quiet or piping steel.

Granular fractures better reflect the light than those which are trans-crystalline; they are also more frequent with overheated or highly heated steel and are called **coarse-grained, rough, bright crystalline, bright, or granular-crystalline**; if especially coarse and bright, **brilliant, splendid, sappy, or fiery** and, in the case of crucible steel held too long in the pot, **scorched** or, if pieces of fuel have fallen in, **staring**. Where tool steel or other steel high in carbon has been heated in such a way as to convert some of the carbon into graphite, it is said, from the appearance, to have a **black fracture** (or **black center**). **Flaking** is the scaly fracture in high-speed steels due to being soaked at high temperatures and afterwards not forged sufficiently to break up the coarse grain; this condition disappears on annealing, but reappears on rehardening (Brearily). The **trans-crystalline fractures** are also referred to as **fine grained, smooth, even, or amorphous**, but preferably for the last should be used the terms **porcelanic or aphanitic**; due to the absence of pronounced luster they are also called **dull** or, more rarely, **gray-granular**.

If wrought iron is nicked all around and broken short off with a sharp blow, the fracture may be granular; but if nicked on only one side, and bent slowly away from the nick, the intermingled slag causes the iron to break in layers, and the fracture is **barked, fibrous, laminated, or splintery**. Such an appearance is not often found in the case of plain carbon steel, but is obtained with screw stock grade (high in manganese sulphide), also with certain alloy steels, especially those containing nickel. Material which has been broken at one time, as by a single blow, so quickly that the piece snaps off without any appreciable bending, gives rise to a **brittle fracture or sudden fracture**, in contradistinction to the **tough fracture** resulting from considerable bending and tearing.

If the fracture shows very sharp points it is sometimes called a **needle fracture**; if, as in the case of certain zinc-copper or tin-copper alloys, it has the appearance of a number of little shells, it is termed **conchoidal**.

A **star fracture** is the term applied to the fracture of certain broken tensile test specimens, which are generally found only when the elastic limit is about 90,000 lbs. per square inch or over. It has the appearance of a star with raised ribs (or rays) radiating outwards from a common center. A fracture is referred to as

composite when it consists of more than one form or type. An irregular fracture is sometimes spoken of as **uneven**. Fractures (usually of slags, etc., which are non-metallic) having a glassy appearance or shape, are termed **vitreous** or **vitriform**.

Where a piece has broken under alternate bending stresses, the material usually gives way gradually, *i.e.*, one part at a time, and the first part to give way gives rise to rubbing and blackening of the opposed surfaces, while the last part is usually more or less granular; this is known as a **progressive fracture** or a **detail fracture**. Before rupture was complete there would be found a **partial fracture**. A detail fracture may be started either on the outside or the inside, in the latter case giving rise to an **internal fracture** whose appearance may throw valuable light on the condition of strains which brought it about. Detail fractures are sometimes attributed to what is erroneously termed **cold crystallization**, it being claimed that actual growth of the grain occurred while the given piece was in service. This has been thoroughly disproved as regards ordinary temperatures for iron and steel, and was probably due to the fact that the fracture of a tensile test specimen, or where there has been considerable deformation, always has a much finer appearance than where the rupture was abrupt.

Frémonville investigated fractures occurring in metals, by means of observations on ruptured glass and bitumen. He enunciated the following laws in regard to his **bursting theory**: 1. The origin of all breakages is a burst taking place in the interior of the body, and only develops itself by a succession of bursts, which are general in the case of sudden fractures and localized in the case of progressive fractures. 2. The first burst—the origin of all rupture—takes place in a region where the principal stress is positive, but not necessarily at a point where that stress reaches its maximum value. Other things being equal, the stress normal to the principal stress determines the **danger of rupture** (*Inst. Met.*, 1915, I, 318).

In tensile testing, if the metal is relatively soft and ductile, the entire exterior portion may be extended more than the interior which, accordingly, is depressed, and this effect gives rise to a **cup fracture**; if only a portion of the exterior has been so extended, a **half-cup**, etc. If the piece breaks at an angle, it is called an **angular, oblique, or slip fracture**. If the fracture is partly angular and partly a cup, it is known as an **irregular fracture**.

Fracture Test.—See page 483.

Fragility.—Brittleness, *q.v.*

Fragmental Structure.—See page 125.

Fragmentation Test.—See page 483.

Franche-Comté Process.—See page 76.

Franklinite.—See page 244.

Fredenhagen Theory.—Of passivity: see page 364.

Free Carbon Dioxide.—See page 107.

Free Cementite.—See page 273.

Free Ferrite.—See page 272.

Free Iron (Sorby).—See page 272.

- Free Phosphide.**—See page 289.
- Freedom, Degree of.**—See page 327.
- Freezing ; Freezing Point ; Freezing Point Curve.**—See page 201.
- Freezing Range.**—See page 267.
- Frémont Machine.**—For impact testing: see page 482.
- Frémont's Method.**—To determine hardness: see page 478.
- French Calorie.**—See page 199.
- French Metal.**—See Antimony.
- Fresh Iron.**—See page 364.
- Freshen.**—Sometimes used in the sense of to purify, *e.g.*, when air is blown through molten pig iron.
- Friable.**—Easily crumbled; reducible to powder.
- Frick Furnace.**—See page 155.
- Friction Drive.**—See page 418.
- Frigo-Tension.**—See Cold Working.
- Frischen Process.**—See page 383.
- Fritting.**—Becoming pasty and melting down on heating; the action of some soft coals.
- Fritz Mill.**—See page 408.
- Frondescent Hematite.**—See page 244.
- Frontal Hammer ; Helve.**—See page 197.
- Frothing.**—Also called **foaming** ; the condition of a slag in a refining process which is viscous and becomes puffed up by the carbonic oxide gas evolved from the oxidation of the carbon in the metal underneath.
- Frothy.**—(1) Of slags, the same as frothing; (2) of steel, unsound from foaming or rising in the mold.
- Frozen Continent.**—See page 54.
- Fryer Process.**—See page 30.
- Fuel.**—From a commercial standpoint a substance which can be burned economically for the generation of heat to be applied to some useful purpose. Fuels may be either solid, liquid, or gaseous. They consist of **combustible matter** (matter which will burn) and **ash** or matter which will not burn. The combustible matter consists of carbon and hydrogen, combined or uncombined. If the fuel is solid, the combustible matter is divided into **volatile matter** which is driven off upon the application of heat, and **fixed carbon** which is left behind. The residue, containing both the fixed carbon and the ash, is sometimes referred to as the **coke**.
- Fuel Gas.**—Any gas suitable for use as a fuel; sometimes used more particularly for producer gas or water gas.
- Fuliginous (rare).**—Smoky or dirty.
- Full Radiator.**—See page 207.
- Full-size Test.**—See page 468.
- Fuller.**—A tool with a face of sharp curvature, fitting in the socket of an anvil, on which bars are hammered down.
- Furgen (obs.).**—A round rod used for sounding a bloomy fire (Raymond).
- Furnace.**—A structure in which heat is generated by the combustion of fuel, more particularly for the smelting of ore or the treatment of metal. They may be classified according to:

- I. The nature of the fuel:
 1. Solid fuel: **coal, coke or charcoal furnace.**
 2. Liquid fuel: **oil furnace.**
 3. Gaseous fuel: **gas furnace.**
- II. Method of applying the heat:
 4. **Direct heating furnaces**, where the fuel or flame comes in contact with the charge:
 - (a) **Contact heating furnaces**, where solid fuel is in contact or mixed with the material to be heated, as in the blast furnace.
 - (b) **Flame contact furnace or flame furnace**, where only the flame strikes the charge, as in a reverberatory furnace.
 5. **Indirect heating furnaces**, where the charge does not come in contact with either the fuel or the flame, but is heated by conduction and radiation through a wall, as in a muffle furnace.
- III. The form or construction of the furnace. This classification will be more particularly followed below.
- IV. The purpose for which the furnace is intended, *e.g.*, an annealing furnace. Except where a special type is introduced, such furnaces will be found discussed in connection with the special process involved.

Heap, pile, or mound: This is the oldest form of heating arrangement and is employed only for roasting or calcining. The material, mixed with solid fuel, is piled up, usually without any covering (**open**), sometimes, as in the case of the old method for the preparation of charcoal, covered with earth or turf, small openings being left for draft.

Stall: This is somewhat similar to the heap, but usually has brick walls on three sides, the top and the front being left open. This insures a more even heating than the heap. It is used for roasting and calcining, formerly also for coking coal.

Oven: This name is sometimes used synonymously with furnace (the German word for furnace is *Ofen*), *e.g.*, a furnace of the reverberatory type for drying molds is called a drying oven. It is principally restricted to furnaces for making coke (*q.v.*); an oven for annealing was called a **calcar**.

Shaft furnace: This consists of vertical brick walls, and is usually circular in cross-section, with the height several times the inside diameter. The material is charged at the top and removed at the bottom. The top may be provided with a bell and hopper (see page 32) or simply left open. The fuel is usually solid and is charged in lumps at the top mixed with the other materials, and the air for combustion may be supplied by natural draft, or more generally under pressure through pipes or tuyeres near the bottom. Oil or gas is sometimes employed for fuel, in which case it is injected with the air through similar pipes at the bottom.

Kilns are shaft furnaces for roasting or calcining ore, limestone, etc., where a very high temperature is not required, and may be fired in any of the ways described above, but generally with coke,

and the employment of a gentle blast. They are relatively short, up to about 30 feet, and as a rule are of uniform diameter throughout. A furnace of this type, somewhat resembling a beehive coke oven, is generally used for firing bricks (**brick kiln** or **brick oven**).

Cupolas are similar to kilns and are used for melting pig iron. They are usually of the same diameter throughout, but may have the walls slightly divergent at about the middle, rarely called an **expanding cupola**. They are practically always fired with coke and a gentle blast, generally cold, but occasionally slightly preheated, in which case it is termed a **hot-blast cupola**, and, in contradistinction, the former would be referred to as a **cold-blast cupola**. The blast may be supplied to each tuyere separately from a fan, but usually through a casing surrounding the furnace, similar to the bustle pipe of a blast furnace, called an **air chamber** or **air belt**. An arrangement is sometimes made by which the tuyeres can be placed at different levels (**adjustable tuyere**). The bottom of the cupola is called the hearth or well. There are holes provided at the bottom for tapping the molten cinder and the iron. The **tapping hole** is closed with a plug of clay (**bod, bot, or bott**) thrust in on the end of an iron rod (**bot stick**); the operation of closing the hole is sometimes called **stopping in** or **botting up**. If the bottom is built on a solid foundation of masonry, it is called a **stationary bottom**, but, according to modern practice, it is generally closed with a hinged plate of cast iron which can be opened to dump the material remaining in the cupola after a run, and called a **drop bottom**. Foundry cupolas may have an arched hole (**breast hole**) above the bottom which can be opened for cleaning out the cupola, and is closed with an iron door (**breast plate**). A **reservoir cupola**, **tank cupola**, or **compound cupola** is one with a greater diameter at the bottom, or provided with a connecting chamber, so a greater amount of iron may be kept molten. A very small furnace for melting purposes, which can be picked up by a crane for pouring the molten iron into a ladle, has been styled a **cupola crucible**. Cupolas used in connection with the Bessemer process are charged at the top; foundry cupolas through a hole on the side near the top (**charging door**). A cupola is said to be ready to **run** when the pig iron has melted. The man in charge is called the **melter**.

Shaft furnaces for smelting iron ore are termed blast furnaces (*q.v.*).

Hearth: This is a rectangular chamber of only moderate depth, in which the charge is heated in contact with solid fuel, the walls and bottom of which are usually of cast iron, frequently water-cooled. If the top is enclosed with a hood, it constitutes a **closed hearth**, otherwise, an **open hearth**. The air for combustion is blown in through one or more tuyeres. The action may be reducing when used for some direct process (*q.v.*), or oxidizing when used for refining (see Purification Processes and Charcoal Hearth Processes).

Reverberatory furnace (air furnace): In this furnace the charge is heated, not by direct contact with the fuel, but by the gaseous

products of combustion (the flame) and, as a rule, no blast is employed. Where a very strong draft is maintained it may be termed a **wind furnace**. It consists of the heating chamber, called the **hearth** or **laboratory**, on the bottom or sole (also called the **hearth** or rarely the **firebed**) of which the charge rests. At one end is a small chamber (**fireplace**) in which the fuel is burned; at the other end the chimney or stack. At each end of the hearth is a low wall (**bridge** or **bridge wall**); that next the fireplace is called the **fire bridge**; that next the chimney, the **flue bridge** or **altar**. The roof usually has a very flat arch, springing from the side walls, and covers both the fireplace and the hearth; it is highest over the fireplace, and thence slopes downward to the chimney flue, so that the flame, after striking the roof, will be deflected down (reverberated) upon the charge. If the roof is high enough, so that the flame does not actually touch the charge, which is then heated by radiation from the roof, the furnace is termed a **radiation furnace**. The fuel is usually solid, and is supported on grate bars (**fire bars**) which may be easily removed to permit of cleaning and replacement. The furnace may be used for heating purposes, or for melting operations as in the puddling process. In the former case it may be built entirely of brick (with iron tie rods, etc.), but in the latter, the hearth generally has cast-iron sides and bottom, either air-cooled or water-cooled. The charge is usually introduced through one or more doors (**charging doors**) in the side: for roasting purposes, sometimes through hoppers in the roof.

Recuperative furnaces are similar to ordinary reverberatory furnaces, but the air for combustion (under a slight pressure) is preheated by entering through pipes in the chimney flue, around which the products of combustion pass.

Regenerative furnaces are special reverberatory furnaces using either gaseous or liquid (practically never powdered) fuel, in which the air alone, or both the air and the fuel, are preheated in special chambers (**regenerators**) situated at each end of the furnace, between the furnace and the stack (see Heat). In this arrangement the air and fuel are burned alternately at each end, one set of regenerators being heated by the products of combustion while on their way to the stack, while the other set is heating the air and fuel before entering the furnace proper. In this country, when this type is used for making steel it is called an **open hearth furnace** or a **Siemens furnace** (see Open Hearth Process).

Crucible furnaces are properly furnaces in which crucibles (*q.v.*) are heated and may be of various types. The crucibles may be set directly on the solid fuel, supported on grate bars in a small, short, shaft furnace; heated in similar chambers with gas preheated in regenerators (**regenerative crucible furnace**); or on the hearth of a regenerative reverberatory (open hearth) furnace.

Muffle furnaces consist of a closed chamber in which the charge is heated out of contact with the fuel or the products of combustion. Converting furnaces (used for cementation) are of this type, but are frequently termed retort furnaces. In

England this name is sometimes applied to a fire used for heating crucible steel ingots, etc., similar to a smith's forge, consisting of a hollow fire made with large lumps of coal and blown with a fan blast, bricks and a few plates being used to confine the fire (Harbord and Hall).

Retort furnaces are properly those used (in non-ferrous metallurgy) for distilling (volatilizing) metals, etc., as in the purification of zinc. They contain a chamber in which the material is heated out of contact with the fuel or gases, and a flue leading to a condensing (cooling) chamber; they may be similar to a muffle or a crucible furnace.

Heating furnaces or **reheating furnaces** are those used for heating solid pieces of iron or steel to a temperature suitable for rolling, forging, etc. They are usually of the ordinary or regenerative reverberatory type, and the names given above are used more generally for those which are built above the floor level, and in which the material is charged horizontally through doors in the side (**horizontal heating furnace**), as in reheating billets, slabs, etc. A special type, built below the floor level, and charged through the top (**vertical heating furnace**), is employed for heating ingots which are usually charged before they have completely solidified, and hence must be kept in a vertical position to have the pipe in the top. Such furnaces are called **soaking pits**, **soaking furnaces**, or **pit heating furnaces**. They are generally provided with regenerators, but the original type (**Gjers pit**; **soaking pit process**) did not employ any fuel, the heat of the still molten interior of the ingot being depended upon to bring the exterior portion to the proper temperature; the action whereby the heat diffuses is termed **soaking**.

A **continuous furnace**, strictly speaking, is one which is charged at one end and drawn (or tapped) at the other. This, of course, includes such types as the blast furnace, but is generally considered to mean a **continuous heating furnace** which is of the reverberatory type, but longer than ordinary, frequently recuperative, and used for heating billets, etc.; these are charged cold at the flue end and are moved forward over water-cooled pipes (with rounds, they may simply roll down by gravity) by hydraulic pushers, and are drawn at the fire-place end.

Furnace Additions.—See Recarburization.

Furnace Amianthus.—See Salamander.

Furnace Annealing.—See page 232.

Furnace Coal.—See Coal.

Furnace Coke.—See page 96.

Furnace Cooling.—See page 232.

Furnace Slag.—See Slag.

Furnace Test.—Sometimes simply **test**. A portion of metal taken from an open hearth furnace and cooled and broken to determine by the fracture the approximate amount of carbon, etc., in the bath. If this is sent to the chemical laboratory, it is frequently called the **preliminary test**. In England it is usually forged down under a hammer before quenching and breaking to determine its freedom from red-shortness.

Fuse.—To melt; to liquefy by the application of heat.

Fused Silica.—See page 395.

Fusible Alloy.—See page 4.

Fusible Cement.—See page 69.

Fusible Cones.—See page 209.

Fusing-point Pyrometry.—See page 209.

Fusion.—(1) General: see page 201; (2) zone in meteorites: see page 292; (3) zone of complete fusion in blast furnace practice: see page 36; (4) zone of incipient fusion in blast furnace practice: see page 36.

Fusion Curve.—See Curve.

Fusion Point.—See page 201.

G

G.—(1) Gravity, *q. v.*; (2) gram or gramme.

Ga.—Chemical symbol for gallium: see page 84.

Gd.—Chemical symbol for gadolinium: see page 84.

Ge.—Chemical symbol for germanium: see page 84.

Gl.—Chemical symbol for glucinum (at one time called beryllium): see page 84.

G. M. V.—Gram-molecular volume: see page 83.

G. M. B.—Good merchantable brand (of pig iron).

G. M. W.—Gram-molecular weight: see page 83.

Gag.—See Hammer.

Gag Press.—See Straightening Press.

Gage.—(1) The thickness of a sheet or plate; (2) an instrument for measuring the dimensions, etc., of an object or substance; (3) a table showing the equivalents of the arbitrary markings on a fixed gage. Among those of more particular interest in this connection are the following: **Limit, plus and minus**, or **high and low gages** are those provided with two measuring devices corresponding respectively to the maximum and minimum dimensions to which the object must conform; for example, in measuring a hole, the minimum gage must enter, while the maximum gage must not. **Inside and outside gages** are to measure respectively the internal and external dimensions of a hollow object. A **stud gage** is used to determine the proper spacing of two or more holes as in splice bars. For shrinkage gage, see Molding, page 296.

In the following table are given the various gages used for wire and sheets or thin plates (heavier plates are recorded in fractions of an inch or other unit).

"The wire gage for which sizes are shown under the title of American Steel & Wire Co.'s gage, was the same as the Washburn & Moen gage, and also the same as that used by practically all of the steel wire manufacturers of the United States, under various names. It results from this fact that there is really a standard steel wire gage in the United States, although this has not been formally recognized.

"Upon the recommendation of the Bureau of Standards at Washington, a number of the principal wire manufacturers and important consumers have agreed that it would be well to designate this gage as the **Steel Wire Gage**; in cases where it becomes necessary to distinguish it from the British Standard Wire Gage, it may be called the **United States Steel Wire Gage**. The name thus adopted has official sanction, although without legal effect.

"The only wire gage which has been recognized in Acts of Congress is the Birmingham gage. The Treasury Department has for many years used this gage in connection with importations of wire, and the adoption of succeeding tariff acts with provisions for the assessment of duty according to gage numbers gives legislative sanction to the gage.

"Until certain provisions of the tariff act are amended, the Treasury Department probably cannot discontinue the use of the Birmingham gage. It should, however, be abandoned by all other users, since the gage itself is radically defective, and it is nearly obsolete, both in the United States and in Great Britain, where it originated.

"For copper wires and wires of other metals the gage universally recognized in the United States is the American Wire Gage, also known as the Brown & Sharpe. No confusion need arise between the Steel Wire Gage and the American Wire Gage, because the fields covered by the two gages are distinct and definite." (From pamphlet of the American Steel & Wire Co.)

The **Roebling gage** is practically the same as the American Steel & Wire Company's gage. The Birmingham gage is sometimes referred to as the **English standard wire gage**. The **Edison or circular mil gage** was devised by the Edison Company to simplify calculations and the ordering of round wires for electrical purposes. The **mil (m)** is 0.001"; the **circular mil (c.m.)** is the area of a circle with a diameter of 1 mil. The comparative area of a wire (or circle) in circular mils is considered simply as the square of its diameter in mils. As the areas of circles are to each other as the squares of their diameters, comparative results are thus secured without the trouble of working out $\frac{\pi D^2}{4}$. On the scale employed the number multiplied by 1000

gives the number of circular mils; thus, No. 100 is 100,000 c.m., and No. 50 is 50,000 c.m., etc. The square root of the number of c.m. gives the diameter in mils; multiplying by 0.7854 will give the actual area in square mils. There are also in use in this country a number of screw gages, nominally the same but which vary with different makers; and the **piano wire gage**, in which the numbers increase with the diameter. To test the accuracy of the openings or notches of a wire gage an instrument known as a **flat gage** is provided. A **micrometer gage** or **micrometer caliper** has an opening regulated by a screw arrangement usually reading in thousandths of an inch (or millimeter). This is the type, in different sizes, most commonly used for measuring thickness, particularly of plates and similar material. A special form of **plate gage**, to measure them during rolling (while hot), is provided with a handle and is operated by a spring and trigger to obviate a too near approach to the hot pieces. **Calipers**, consisting of two curved arms pivoted at one end are frequently used for large objects, the dimensions being determined by measuring on a scale the opening between points. A **transfer caliper**, used where there is an enlargement, which would prevent withdrawing the caliper without opening it, has a small arm which can be adjusted to show the point at which the caliper is set when on the object, so that, after opening the arms for withdrawal, they may again be closed to the same point as before and the opening measured. There are various other forms specially devised and named according to the purpose for which they are used, such as screw thread gages, track gages, wheel gages, etc.

Standard Wire Gages Thickness in Decimals of an Inch

Number of Gage	American Steel & Wire Co., or Washburn & Moen	Birmingham, or Stubs' Iron Wire	British Imperial, or Imperial Wire	American, or Brown & Sharpe	Stubs' Steel Wire	Paris or J. deP.	Westphalia	U. S. Standard Sheet & Plate Iron & Steel
000000	.4900		.500					.46875
000000	.4615		.464	.5800				.4375
00000	.4305		.432	.5156				.40625
0000	.3938	.454	.400	.4600				.375
000	.3625	.425	.372	.40964				.34375
00	.3310	.380	.348	.3648		(PP) .0157		.3125
0	.3065	.340	.324	.32486		(P) .0196		
1	.2830	.300	.300	.2893	.227	.0236	.0236	.28125
2	.2625	.284	.276	.25763	.219	.0275	.0279	.265625
3	.2437	.259	.252	.22942	.212	.0314	.0300	.25
4	.2253	.238	.232	.20431	.207	.0354	.0314	.234375
5	.2070	.220	.212	.18194	.204	.0393	.0350	.21875
6	.1920	.203	.192	.16202	.201	.0433	.0393	.203125
7	.1770	.180	.176	.14428	.199	.0472	.0441	.1875
8	.1620	.165	.160	.12849	.197	.0512	.0472	.171875
9	.1483	.148	.144	.11443	.194	.0551	.0512	.15625
10	.1350	.134	.128	.10189	.191	.0590	.0551	.140625
11	.1205	.120	.116	.090742	.188	.0630	.0614	.125
12	.1055	.109	.104	.080808	.185	.0708	.0653	.109375
13	.0915	.095	.092	.071961	.182	.0787	.0724	.09375

14	.0800	.083	.080	.064084	.180	.0866	.0803	.078125
15	.0720	.072	.072	.057068	.178	.0944	.0866	.0703125
16	.0625	.065	.064	.05082	.175	.1062	.0944	.0625
17	.0540	.058	.056	.045257	.172	.1181	.1023	.05625
18	.0475	.049	.048	.040303	.168	.1338	.1150	.05
19	.0410	.042	.040	.03589	.164	.1535	.1338	.04375
20	.0348	.035	.036	.031961	.161	.1732	.1512	.0375
21	.03175	.032	.032	.028462	.157	.1929	.1653	.034375
22	.0286	.028	.028	.025347	.155	.2126	.1830	.03125
23	.0258	.025	.024	.022571	.153	.2322	.2145	.028125
24	.0230	.022	.022	.0201	.151	.2520	.2346	.025
25	.0204	.020	.020	.0179	.148	.2756	.2756	.021875
26	.0181	.018	.018	.01594	.146	.2914	.2992	.01875
27	.0173	.016	.0164	.014195	.143	.3228	.3464	.0171875
28	.0162	.014	.0148	.012641	.139	.3464	.3700	.015625
29	.0150	.013	.0136	.011257	.134	.3700	.3937	.0140625
30	.0140	.012	.0124	.010025	.127	.3937	.0125	.0125
31	.0132	.010	.0116	.008928	.120	.0109375	.0109375	.0109375
32	.0128	.009	.0108	.00795	.115	.01015625	.01015625	.01015625
33	.0118	.008	.0100	.00708	.112	.009375	.009375	.009375
34	.0104	.007	.0092	.006304	.110	.00859375	.00859375	.00859375
35	.0095	.005	.0084	.005614	.108	.0078125	.0078125	.0078125
36	.0090	.004	.0076	.005	.106	.00703125	.00703125	.00703125
37	.0085		.0068	.004453	.103	.006640625	.006640625	.006640625
38	.0080		.0060	.003965	.101			
39	.0075		.0052	.003531	.099			
40	.0070		.0048	.003144	.097			

Gage Hole.—See page 507.

Gage Length ; Gaged Length.—Of a test piece: see page 473.

Galbraith Furnace.—See page 155.

Gallet Process.—See page 118.

Galvanic Action.—Same as voltaic action.

Galvanic Process (rare).—Of galvanizing: see page 370.

Galvanized Wire.—See page 508.

Galvanizing.—See pages 370 and 431.

Galvanizing Pan.—See page 509.

Galvanizing Pot.—See page 431.

Galvanometric Method.—For temperature measurements: see page 208.

Galy-Cazalet Process.—(1) For fluid compression: see page 63;
(2) for steel: see page 318.

Gamma Cementite.—See page 273.

Gamma (γ) Iron.—See pages 264 and 272.

Gamma Iron Theory.—Of hardening: see page 280.

Gamma Martensite.—See page 276.

Gamma Theory.—Of hardening: see page 280.

Gangue.—(1) General: see Ore; (2) nature of, in iron ore: see page 243.

Ganister.—See page 395.

Gantry Crane.—See page 32.

Garnaut and Siegfied Process.—See page 233.

Garnier Process.—See page 385.

Garrett Mill.—See page 417.

Gartsherrie Process.—Same as Alexander and M'Cosh process; for the recovery of tar and ammonia from the gas of a blast furnace using raw coal.

Garut Process.—See page 503.

Gas.—Matter in a state where the molecules are free to move except for any external restraint. A **perfect** or **ideal gas** is one which conforms to the **characteristic equation** of a gas:

$$pv = RT$$

p and v are respectively the pressure and the volume at the given temperature; T is the absolute temperature; R is $\frac{p_0v_0}{273}$

(for centigrade degrees) or $\frac{p_0v_0}{469}$ (for Fahrenheit degrees) where

p_0 and v_0 are values at absolute zero for pressure and volume respectively. **Boyle's law** (also called **Mariotte's law**), which is not entirely true, is that the volume of a gas varies inversely as the pressure, the temperature remaining constant. The **law of Charles** (also called after **Dalton** and **Gay-Lussac**) is that the volume of a gas varies directly with the absolute temperature, the pressure remaining constant. **Van der Waal's formula** expresses Boyle's law with the additional factor of molecular attraction. **Graham's law** states that the rate of flow of a gas is inversely proportional to the square root of its density.

Gas Cleaning.—See page 33.

Gas Coal.—See Coal.

- Gas Coke.—See page 97.
- Gas Collector.—See page 61.
- Gas Furnace.—See page 181.
- Gas Generating Furnace ; Generator.—See page 362.
- Gas Hammer.—See Hammer.
- Gas Hole.—See page 55.
- Gas-house Coke.—See page 97.
- Gas Producer.—See Producer.
- Gas Pyrometer.—See page 207.
- Gas Thermometer.—See page 205.
- Gas Washer.—See page 33.
- Gas Waste Acid.—Sulphurous acid, SO_2 ; made from spent oxide (oxide of manganese containing sulphur) from the purifiers in gas works; it contains no arsenic.
- Gaseous Cements.—See pages 67 and 69.
- Gaseous State.—See page 81.
- Gaseous Volumes.—Law of: see page 85.
- Gasogène (French).—Gas producer.
- Gasometer.—A vessel or tank for holding or measuring gases.
- Gasparin's Pyrometer.—See page 207.
- Gassed.—Of a person overcome by gas at a blast furnace.
- Gate.—See page 299.
- Gathmann Process.—See page 60.
- Gauge.—See Gage.
- Gay-Lussac's Law.—See page 85.
- Gayley Dry-blast Process.—See page 30.
- Gear Driven.—See page 407.
- General Purposes Temper.—See Temper.
- General Selective Corrosion.—See page 106.
- Generator ; Generator Gas.—See page 362.
- Gentle Aeration.—See page 107.
- Geode.—See page 125.
- Gerhardt Process.—See page 141
- German Bloomary.—See page 141.
- German Clay.—See page 302.
- German Dinas Brick.—See page 395.
- German Forge.—See page 383.
- German Forge Hammer.—See Hammer.
- German Mill.—See page 417.
- German Process.—See page 75.
- German Steel (obs.).—(1) Steel (wrought iron) made either direct from the ore (see page 141) or first into pig (see page 75); (2) cemented iron: see page 71; (3) an old name for shear steel, *q.v.*
- Gerstner's Law.—See page 334.
- Gesner Process.—See page 369.
- Ghost ; Ghost Line ; Ghost Structure.—See page 289.
- Gilchrist (P.C.) Process.—See page 318.
- Gill (Chas.) Method.—Of quenching: see page 229.
- Gillon and Dujardin Mill.—See page 417.
- Gin Furnace.—See page 155.
- Girod Furnace.—See page 156.
- Git ; Git Mold.—See pages 61 and 299.

Gjers Method.—For mixing steel: by pouring it from one ladle into another.

Gjers Pit.—See page 184.

Glance Coal.—See Coal.

Glanced Sheet.—See page 431.

Glass Hardness.—See Hardness.

Glaze.—See page 370.

Glazed Bars.—See page 71.

Glazed Pig ; Glazy Iron.—See page 343.

Glide Plane ; Gliding Plane.—See pages 123 and 282.

Globular Pearlite.—See page 274.

Globulite.—See page 120.

Glut Weld.—See page 502.

Gnathoid.—See page 290.

Gobbed Heat.—See page 377.

Gobbing Up.—See page 35.

Goethite.—See page 244.

Goldschmidt Process.—A method for producing metals by reduction with aluminum. The ore or oxide of the metal and metallic aluminum, both in a finely granular condition, are mixed together (this mixture is called **thermit**), and the reaction started by igniting a small quantity of magnesium powder or ribbon, etc., called the **starter**, placed on top of the charge. The reaction then proceeds with considerable violence and the resulting metal is at a high temperature. The process is used for obtaining carbonless metals and alloys; the metal, on account of its high temperature is also employed for repairing broken pieces of machinery, and the hot slag produced is also used for heating the ends of tubes, etc., which are to be welded together.

Goniometer.—See page 119.

Gore's Phenomenon.—See page 265.

Gossan.—See page 245.

Gothic Pass ; Groove.—See page 405.

Gozzan.—See page 245.

Grade.—Of steel: see page 455.

Gradual Cement.—See page 67.

Graduated.—Of a measuring tube or vessel which is marked off with fine lines to show proportional volumes; such a vessel is called a **graduate**.

Graff Process.—See page 141.

Graham's Law.—See Gas.

Grain.—See page 122.

Grain of First Order.—See page 127.

Grain Growth.—(1) General: see page 213; (2) as affected by strain: see page 216.

Grain Refining.—See pages 212 and 232.

Grain Roll.—See page 403.

Grain of Second Order.—See page 127.

Grain Size.—See page 213.

Gram Calorie.—See page 199.

Gram-centigrade Heat Unit.—See page 199.

Gram-molecular Volume.—See page 83.

- Gram-molecular Weight.**—See page 83.
- Grampus.**—See page 135.
- Granitoid Structure.**—See page 125.
- Granular.**—See page 122.
- Granular-crystalline Fracture.**—See page 178.
- Granular Eutectic.**—See page 269.
- Granular Fracture.**—See page 178.
- Granular Iron.**—Bar (wrought) iron which shows a granular fracture due to the absence of cinder, and is therefore a guarantee of its strength and purity (Horner).
- Granular Pearlite.**—See page 274.
- Granulated Iron.**—Pig iron reduced to the size of shot by pouring the molten metal into water.
- Granulation.**—See page 121.
- Granulation Range ; Zone.**—See page 121.
- Granule ; Granulitic.**—See page 122.
- Granulitic Structure.**—See page 125.
- Graph.**—See Curve.
- Graphic Formula.**—See page 86.
- Graphite.**—(1) Form of carbon: see page 50; (2) constituent of iron: see page 277; (3) a refractory: see page 398.
- Graphite Blacking.**—See page 298.
- Graphite Crucible.**—See page 111.
- Graphitic Carbon.**—See Graphite.
- Graphitic Corrosion.**—See page 106.
- Graphitic Pig.**—See page 342.
- Graphitic Silicon.**—See Silicon.
- Graphitiferous.**—Containing graphite.
- Graphitite.**—See Carbon.
- Graphitization.**—See pages 106 and 278.
- Graphitization of Cementite.**—See page 278.
- Graphitoid ; Graphitoidal.**—See Carbon.
- Graphitoidal Pig Iron.**—Graphitic pig iron; in which practically all the carbon is in the graphitic form.
- Graphitoidal Silicon.**—See Silicon.
- Grate Bars.**—The bars across a fireplace which support the fuel.
- Gray Body.**—See page 207.
- Gray Cast Iron ; Forge Iron.**—See page 342.
- Gray-granular Fracture.**—See page 178.
- Gray Iron ; Pig.**—See page 342.
- Grease Pan ; Pot.**—See page 432.
- Greater Calorie.**—See page 199.
- Greatest Principal Stress.**—See page 332.
- Green.**—Unused or raw; untreated or incompletely treated.
- Green Brick.**—See page 395.
- Green Coal.**—See Coal.
- Green Fire.**—See page 203.
- Green Ingot.**—See page 57.
- Green Sand ; Green Sand Molding.**—See page 296.
- Green Vitriol.**—Commercial sulphate of iron.
- Greenawalt Process.**—See page 45.
- Gregory and Green Process.**—See page 386.

- Grenet's Series of Salts.—To determine temperatures: see page 209.
- Grey Mill.—See page 417.
- Gridiron Twinning.—See page 124.
- Grinding.—(1) Preparing smooth surfaces by abrasion; (2) reducing a substance to a fine state of division.
- Grips.—Of a testing machine: see page 469.
- Gripper.—In wire drawing: see page 508.
- Grog (Eng.).—See page 396.
- Gröndal Furnace.—See page 156.
- Gröndal-Kjellin Furnace.—See page 156.
- Gröndal Process.—See page 44.
- Grönwall Furnace.—See page 157.
- Grönwall, Lindblad and Stalhane Furnace.—See page 157.
- Groove; Grooved Roll.—See page 404.
- Gross Ton.—See Ton.
- Ground Mass.—See page 125.
- Group Casting.—See pages 61 and 299.
- Growth of Crystals.—See pages 120 and 213.
- Grundy.—Granulated pig iron (Raymond).
- Gruson's Chilled Cast Iron Armor.—See page 9.
- Guard.—See page 415.
- Guard Plate.—See page 32.
- Gubbin.—A kind of ironstone (Raymond).
- Guenyveau Process.—See page 380.
- Guest Process.—See page 380.
- Guide; Guide Mill; Guide Roll.—See page 415.
- Guillaume's Invar.—See page 451.
- Guillery's Method.—For determining hardness: see page 478.
- Guillet's Theory.—(1) Of hardening: see page 280; (2) of ternary steels: see page 443.
- Guillotine Shears.—See page 412.
- Guit.—See page 299.
- Gun.—For a blast furnace: see page 37.
- Gun Iron; Metal.—See page 343.
- Gun Screw Wire.—See page 509.
- Gunther Process.—See page 141.
- Gurlt Process.—See page 141.
- Gusy (Eng.).—Of steel, wild.
- Guthrie's Cryohydrate.—See page 266.
- Gutowsky's Diagram.—See page 272.
- Gutter.—(1) Spout; (2) the name sometimes given to the runner of a blast furnace.

H

- H.**—Chemical symbol for hydrogen, *q.v.*
- He.**—Chemical symbol for helium: see page 84.
- Hg.**—Chemical symbol for mercury (Latin, *hydrargyrum*): see page 84.
- Ho.**—Chemical symbol for holmium: see page 84.
- H. J.**—Hot junction (of a couple): see page 209.
- H. R. P. & L.**—Hot rolled, pickled and limed (of strips, bars, etc.).
- Hackly Fracture.**—See page 178.
- Hadfield's Manganese Steel.**—See page 451.
- Hadfield Process.**—(1) For reduction: heating the oxide of a metal with granulated aluminum and a little fluorspar in a crucible; (2) for sound ingots: see page 60.
- Hæmatite (Eng.).**—Hematite, *q.v.*
- Hainsworth Process.**—See page 60.
- Hair Crack.**—See Seam.
- Hair Plate.**—See page 135.
- Hair Seam.**—See Seam.
- Halberger Furnace.**—See page 158.
- Half-chamotte Brick.**—See page 396.
- Half-cup Fracture.**—See page 179.
- Half Roll.**—See page 404.
- Half-silica Brick.**—See page 396.
- Hammer.**—Of a drop test machine: see page 481.
- Hammer.**—A device for forging or reducing the section of a piece of metal, or changing the shape, consisting essentially of a mass of metal, the hammer proper (**hammer head** or **tup**), which falls or is driven violently against the piece to be acted upon. The face of the hammer is usually removable and is called the **hammer block** or **die** (particularly the latter if of a special section; this also applies to the anvil block). The piece is supported on a heavy mass of metal, the **anvil**, generally of cast iron or steel, to render the blow effective. If the face is removable it is called the **anvil block**. A **working anvil block** (Eng.) is a block of steel or cast iron fitting on the top of the anvil block. A **false-block** is usually a casting inserted between the anvil block and the bottom die of a steam hammer to raise the die to the proper height. A projecting dovetail on the lower face of the false-block is keyed into a recess in the anvil block, while a recess on its top face receives the dovetail projecting from the bottom surface of the bottom die. Its only purpose is to save weight in the bottom die. When this is to be changed often, as in **shape** or **swage work**, it is undesirable to have it as heavy and cumbersome as would be necessary were the die keyed directly into the anvil block (G. Aertsen). Hammers light enough are worked by hand (**hand hammer**, **sledge**), but those of any considerable weight are operated by power, usually steam, rarely water. They may be classified according to the source of power, into:

- I. Water:
 - 1. Indirect: Helve.
- II. Steam:
 - 1. Indirect: Helve:
 - 2. Direct: Ordinary steam hammer:
 - (a) Single-acting.
 - (b) Double-acting.
- III. Gas: Direct.

Steam hammers consist of an anvil, and the hammer proper fastened to one end of a rod, the other end being connected to a piston which travels in a steam cylinder. If steam is admitted to only one side of the piston, simply to raise the hammer which falls by gravity, it is **single-acting**; if steam is also used to drive the hammer down and so increase the force of the blow, **double-acting**. In either case the hammer is always rated according to

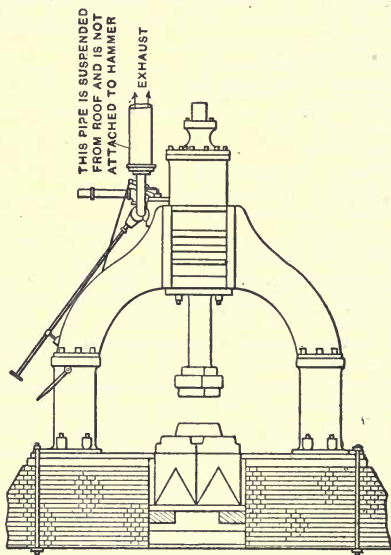


FIG. 23.—Steam hammer.
(Thurston, "Iron and Steel.")

the weight of the tup. A helve (crocodile hammer, lift hammer, tilt hammer, trip hammer, fly hammer, German forge hammer) is a hammer operated on the principle of a lever, the tup falling by gravity. The tup is attached to a bar or handle of wood or iron, working on a pivot or fulcrum. The actuating mechanism consists of a wheel or shaft driven by water (water helve, battery) or by steam (steam helve), provided with cams or teeth. De-

pending upon the general arrangement, various names are assigned: If the power is applied at one end, the pivot being at the other, and the tup intermediate, it is called a **nose helve**, **frontal helve**, or **T hammer**; if the force acts in the middle, a **belly helve**; while if the pivot is in the middle, a **tail helve**. When not in use the helve is supported by a wooden prop or **gag**. A **drop hammer** is one which is allowed to fall by gravity, being attached to a belt which passes over a pulley supplying the necessary power for raising it. A **cogging hammer** is one used for reducing ingots to blooms. A **plating hammer** (obs.) was formerly used in the manufacture of plates or sheets. A **gas hammer** is operated on the same principle as a gas engine. A **raising hammer** (Eng.) is a term sometimes employed for a hammer used for forming or cupping sheets, having a long rounded head. See also Forging.

Hammer Block.—See Hammer.

Hammer Dressing.—See Forging.

Hammer Forging.—See Forging.

Hammer Hardness.—See Hardness.

Hammer Head.—See Hammer.

Hammer Refining.—See Mechanical Refining.

Hammer Scale.—See Scale.

Hammer Slag.—See Slag.

Hammer Test.—See page 476.

Hammered Weld.—See page 501.

Hamoir Process.—See page 386.

Hampton Process.—See page 9.

Hand Guide Mill.—See page 416.

Hand Hammer.—See Hammer.

Hand Mill.—See page 416.

Hanging.—Of a blast furnace: see page 35.

Hanging Guard.—See page 415.

Hanging Test.—See page 469.

Hank.—See Coil.

Hannover Process.—See Alloy.

Harbord Process.—See page 30.

Hards.—See Slag.

Hard Blow.—See page 21.

Hard Castings.—Malleable castings: see page 257.

Hard Center.—The effect produced usually by too rapid heating, so that the inside of a piece of metal is insufficiently heated, and consequently is worked at too low a temperature; rarely caused by segregation.

Hard-centered Steel.—See page 64.

Hard Coal.—See Coal.

Hard Solder.—See page 505.

Hard Spots.—Spots or streaks in steel which are harder than the body of the metal. This is generally observed when material is machined. They are of infrequent occurrence and may be due to segregation (**segregated spot**) or to imperfect mixing of the manganese addition (**manganese spot**). **Soft spots** are just the

opposite, due to absence of carbon and manganese, probably on account of some local oxidizing action.

Hard Steel.—See page 455.

Hard Tap.—In tapping a furnace, when the tapping hole is opened up only with difficulty.

Hardened Castings (rare).—See page 58.

Hardener.—The name sometimes used for foundry iron high in manganese, or for the manganese itself.

Hardening.—Bringing material to the condition in which it is best able to resist indentation, abrasion or scratching. There are two general methods for accomplishing this: (a) heating to a sufficiently high temperature and then cooling rapidly (this applies only to steel or iron alloys: see Heat Treatment), and (b) by cold mechanical working. The **Dean process** was designed to harden and strengthen the bore of guns, etc. It consisted in forcing through them a succession of tapered steel cylinders, each slightly larger than the preceding. It was stated to have been used successfully for bronze guns, but that it did not diminish the erosion of steel guns.

Hardening Carbide.—See page 276.

Hardening Carbon.—See pages 276 and 278.

Hardening Carbon Theory.—Of hardening: see page 280.

Hardening Effect.—Of permanent set: see page 334.

Hardening on a Falling Heat.—See page 229.

Hardening Phosphorus.—See Phosphorus.

Hardening Quenching.—See page 228.

Hardening by Reheating.—See page 279.

Hardening on a Rising Heat.—See page 228.

Hardening, Special Methods of.—See page 229.

Hardening by Subcooling.—See page 279.

Hardening Theories.—See pages 279 and 280.

Hardening by Overstraining.—See page 279.

Hardenite.—(1) Constituent of steel: see page 275; (2) Caron's cement: see page 68.

Hardite.—See page 278.

Hardness.—The resistance offered by a body to abrasion or penetration. (For methods for determining relative hardness, see Testing.) The hardness of steel is sometimes called its **temper**, and to **draw the temper** means to anneal. **Natural hardness** is the hardness of material as ordinarily made, without any special additional treatment. **Glass hardness** is the highest degree of hardness attainable by steel, in which condition it can scratch glass; but as the hardness of glass may vary, it has been suggested that **flint hardness** be substituted. **Hammer hardness** (or **rolling hardness**) is the effect produced when heated metal is worked below its critical temperature; if this reaches a temperature corresponding to a blue temper color (blue working), the metal may be rendered brittle, in this case called **blue-shortness**: see also page 331.

Hardness Number.—See page 477.

Hardness Tests.—See page 477.

Harmet Process.—(1) Fluid compression: see page 64; (2) electric furnace: see page 158; (3) basic Bessemer: see page 21.

Harvey Process.—(1) Carburizing: see page 9; (2) direct: see page 141.

Hatton Converter.—See page 24.

Hawkins Process.—See page 141.

Hay Band ; Rope.—See page 299.

Haythorne Process.—See page 385.

Head ; Head Metal.—See page 56.

Head Squeezer.—See page 377.

Header.—See page 56.

Healing.—Where cracks are formed in an ingot during the first few passes in rolling it down, which are later welded up if the temperature is high enough and the metal is sufficiently soft (low in carbon).

Heap.—See page 181.

Heart.—Core: see page 67.

Hearth.—(1) Of a blast furnace: see page 27; (2) charcoal hearth: see page 75; (3) furnace: see page 182; (4) of an open hearth furnace: see page 310.

Hearth Fining ; Refining.—See page 382.

Heat.—A form of energy (heat energy) due to molecular motion (dynamic theory of heat.) It was at one time believed that heat was an actual substance called caloric. Two kinds of heat are recognized: sensible and latent. Sensible heat or thermometric heat is the degree of heat which a body possesses, commonly known as its temperature. The measurement of ordinary or relatively low temperatures is performed by instruments called thermometers, and of high temperatures by pyrometers (see below).

Latent heat is the amount liberated or absorbed due to an internal or molecular change occurring in a body at constant temperature. There are three causes for this spontaneous liberation (evolution) or absorption of heat: (a) formation or dissociation of chemical compounds; (b) changes of state; (c) allotropic or polymorphic transformations. The amount of heat is measured in heat units or thermal units which are based on either the metric or the English system. In the metric system the calorie (sometimes spelled calory; also called kilogram-centigrade heat unit, large calorie, kilogram calorie, greater calorie, major calorie, French calorie, or true calorie) is the amount of heat required to raise 1 kg. of water through 1° C.; the zero calorie is where the water is raised from 0° to 1° C.; the common calorie where the water is raised from 15 to 16° C.; and the mean calorie the one-hundredth part of the amount of heat necessary to raise the kilogram of water from 0° to 100° C. The small calorie (gram-centigrade heat unit, gram calorie, minor calorie or lesser calorie) is the heat required to raise 1 gram of water through 1° C., hence is the one-thousandth part of the calorie. The British thermal unit (B.T.U.) is the amount of heat required to raise the temperature of 1 lb. (avr.) of water through 1° F., usually at ordinary temperatures from say 65 to 66° F., sometimes from 32°

to 33° F. A hybrid unit rarely employed is the **pound calorie** (**pound-centigrade heat unit**) which is the amount of heat required to raise the temperature of 1 lb. of water through 1° C. For purposes of conversion: 1 cal. = 3.968 B.T.U.; 1 B.T.U. = 0.252 cal.; 1 lb. cal. = $\frac{9}{5}$ B.T.U. = 0.4536 cal.

Heat may be transmitted in one or more of three ways, by

1. **Conduction**: the heat traveling through a solid body one end of which is connected directly with the source of heat; molecular transference.

2. **Convection**: by currents (transference) of the actual particles of a gas or liquid.

3. **Radiation**: by heat waves emanating from the source of heat and not affected by the medium through which they pass; also termed **radiant energy** or **radiant heat**. **Thermal conductivity** is used to distinguish it from electrical conductivity, etc., also for the relative property of a given body or the amount of heat passing through a unit plate when the opposite sides have a difference of 1° of temperature; **thermometric conductivity** is the thermal conductivity with a unit of "heat sufficient to raise a unit volume one degree" (Std. Dict.). **Newton's law of radiation** (or of cooling) is that "the amount of heat radiated from one body to another in a unit time is a direct function of the difference in temperature of the two bodies." **Emissivity** or **external conductivity** is the rate at which a body radiates heat. Dulong and Petit found that the rate of radiation depended only on the nature of the surface and on the temperature of a body and of its surroundings and not on its shape; that convection depended on the temperature of a body and of its surroundings and upon its shape and position, but not on the nature of its surface (Langmuir). **Langmuir's film theory** is that around each surface there is a small volume of gas through which heat passes mainly by conduction. The term **surface resistance** refers to resistance, offered by the surface itself irrespective of the material, to loss of heat from furnaces, etc., while **thermal resistance** refers to the material itself irrespective of the surface. A **radiation curve**, showing the rate of cooling of a body, is the same as a cooling curve. **Prevost's law**, also known as the **law of exchanges**, is that all bodies above absolute zero radiate heat, the amount being dependent only upon the absolute temperature; of two adjacent bodies at different temperatures, the one at the lower temperature receives more than it emits; if at the same temperature, the exchange is equal but does not cease.

A process in which heat is liberated is known as an **exothermic reaction**; one in which it is absorbed, an **endothermic reaction**. A body responsible for an exothermic reaction is sometimes termed a **refrigerating agent** or **refrigerant**; in the case of an endothermic reaction, a **calorific agent**. The amount of heat liberated or absorbed when a chemical compound is formed is called the **heat of formation**. **Hess's law**, forming the foundation of thermo-chemistry, is that in any chemical action the amount of

heat liberated is independent of whether the action is continuous or interrupted. The law of constant heat sums is that in any chemical change the amount of heat is not dependent on the order or nature of changes, but only on the final result. The law of thermoneutrality is that if dilute solutions of neutral salts are mixed and no precipitation occurs, no thermal change is involved.

Calorimetry is the determination of the total heat units in a body or involved in a given reaction or transformation. The measurement of heat liberated or absorbed is determined by means of an instrument called a calorimeter, in which the given determination is made, *e.g.*, when fuel is burned (heat of combustion), the value being usually obtained from the increase or decrease in the temperature of a definite weight of water. Calorimeters on this principle have been devised by Berthelot, Siemens, and White. Specific heat (thermal capacity) is the ratio between the amounts of heat required to raise the temperature of a unit weight of a substance and of water 1 degree (either Centigrade or Fahrenheit). This may be determined for a given substance by mixing a known weight at a certain temperature with a known weight of water at a different temperature and calculating from the temperature of the mixture; this is called the method of mixtures. If the mixture evolves heat (as when sulphuric acid and water are mixed) this method cannot be used, but the result may be secured by the method of cooling which consists in comparing the time required for cooling of the same weights of water and of the substance through the same range of temperature under identical conditions. The water equivalent of a substance is its weight multiplied by its specific heat. The molecular heat of a substance is its specific heat multiplied by its molecular weight. The heat weight is the amount of heat in a body divided by its absolute temperature. The heat of solution is the amount of heat, either positive or negative respectively, when heat is liberated or absorbed when a body goes into solution. When an acid is neutralized by an equivalent weight of a base, or *vice versa*, the heat liberated is called the heat of neutralization. The heat of ionization is the difference in the amount of heat when the body is undissociated (neutral) and when ionized.

Fusion or melting is the conversion of a solid into a liquid. The water of crystallization of certain salts may be sufficient to dissolve them when heated; this is really a case of solution, but is sometimes termed aqueous, aqueo-igneous, hydrothermal, or watery fusion; true fusion, where heat alone is responsible for the change of state, is then termed igneous or dry fusion. The heat absorbed in the conversion is called the heat of fusion or more specifically the latent heat of fusion. The temperature at which this change occurs is the fusion point or melting point (on cooling, the freezing or solidification point). If there is no well-defined temperature, the change extending over a range, it is sometimes known as vitreous fusion. A fused substance above (usually considerably above) its melting point is sometimes

referred to as **supermolten**. If under given conditions of temperature and pressure a body may exist simultaneously as a liquid and a gas, the latter is termed a **vapor** and its formation from the exposed surface of the liquid is called **evaporation** or **vaporization**; the heat absorbed in the process is the **heat of vaporization** or **latent heat of vaporization**; if under the given conditions no more vapor can be formed it is said to be **saturated**. If the evolution of the vapor occurs throughout the liquid, thereby stirring it up and disturbing the surface, the process is called **ebullition** or **boiling**, and the minimum temperature at which this can occur, the **boiling point**. The heat consumed in changing a liquid into a vapor is converted into two kinds of energy; that which causes a separation of the particles (**heat of disgregation**, and that which overcomes the external pressure in increasing the volume (**heat of expansion**). The **total heat** (sensible plus latent) is that required to bring a liquid from the melting point and change it into saturated vapor. **Superheating**, as a general term, signifies heating above a critical point, *e.g.*, superheated steam is steam heated above the point of vaporization (the boiling point). Where a liquid is converted by heat into vapor which is led into another cold vessel and there condensed, the process is termed **distillation**; where a solid changes into a vapor (and back again into a solid) without passing through an intermediate liquid state, the process is termed **sublimation**.

Combustion is oxidation accompanied by the evolution of light and heat. In its commonly accepted sense, it is the oxidation or **burning** of carbon and hydrogen, either free or combined; it is also applied at times to the oxidation of impurities or constituents in some refining process. **Ignition** is frequently used in the same sense as combustion; it is also employed to indicate heating to incandescence, resulting also in the burning and driving off of any combustible and volatile matter, as in the case of chemical precipitates. Before combustion can take place, each fuel must be heated to a certain definite temperature known as its **ignition point**, and, depending upon whether the temperature of combustion does or does not exceed this, it is **continuous**, or **non-continuous** (**discontinuous**) **combustion**. In the case of liquid fuels (oils), a combustible vapor is given off at a temperature below the ignition point, and this temperature is called the **flash point**. If the action is very feeble, the combustion is said to be **slow** or **incipient**; while if energetic, it is called **rapid** or **active**. **Spontaneous combustion** is the result of oxidation of a substance by the air at ordinary temperatures, where the heat is not removed as rapidly as formed, so that finally the temperature of the substance reaches the ignition point. The **products of combustion** (**waste gases** or **fire gases**) are the gases resulting when a fuel is burned, and do not include any solid residue or ashes. When the waste gases and the ashes contain no combustible substance, the combustion is **complete**; otherwise **incomplete**. **Retarded combustion**, as in the manufacture of producer gas, is a case of incomplete combustion. **Smoke** is produced when the waste gases contain fine particles of unconsumed carbonaceous

matter as a result of incomplete combustion; a **green fire** is one which is smoky hence has a tendency to be reducing. **Flame** is the phenomenon occurring when combustible gases are formed during combustion, and the luminosity depends upon the temperature of the flame, the density of the gases, and the presence of solid incandescent particles, principally the last. **Dulong's law** for carbonaceous and hydro-carbonaceous fuels, which is only approximately correct, is that the heat generated in their combustion is equal to the sums of the heat of the carbon and hydrogen separately, less an amount of the latter element in the proportion necessary to form water with any oxygen present.

$$\text{C. P.} = 8080\text{C} + 34,462\left(\text{H} - \frac{\text{O}}{8}\right)$$

C. P. = calorific power in calories; C, H, and O the weights in kilograms respectively of carbon, hydrogen, and oxygen.

"If an explosive gaseous mixture is either ignited on or forced through the interstices of a porous, refractory, incandescent solid under certain conditions, a greatly accelerated combustion takes place within the interstices or pores, or in other words, within the boundary layers between the gaseous and solid phases whenever these may be in contact—and the heat developed by this intensified combustion maintains the surface in a state of incandescence without any development of flame. Such conditions realize my conception of **flameless, incandescent, surface combustion** as a means of greatly increasing the general efficiency of industrial heating operations whenever it can be conveniently applied." (W. A. Bone, abs. in *Iron Age*, Dec. 7, 1911, 1248+.)

The amount of heat (number of heat units) produced when a unit weight of a substance burns is called the **calorific power (C. P.)** or **heat of combustion** and always has the same value irrespective of the **rate of combustion** (*i.e.*, the time occupied). The resulting temperature is called the **calorific intensity (C. I.)** or **pyrometer effect** (rare), or **temperature of combustion**, which varies according to the rate of combustion and other conditions, such as the presence or absence of diluting substances (*e.g.*, nitrogen), and the initial temperature. The calorific power of fuels is sometimes measured by the weight of water at a given temperature evaporated by a unit weight of the fuel; this is called the **evaporative power**.

Regeneration is a method for preheating air or fuel gas to obtain a higher temperature of combustion, or greater economy in fuel. To effect this there are provided two or more set of flues (**regenerators; regenerative chambers**) which are filled with **checker work (checkers)**, *i.e.*, fire-bricks laid in such a way that small passages are left. The products of combustion are passed through one set for a certain period, their heat being absorbed in great part by the checker work, after which the air (or air and gas separately) are passed through in the opposite direction, before entering the furnace, the products of combustion then heating another set. In heating blast in a stove, or removing the heat from blast furnace gas in a washer, for example, application is

usually made of the **counter-current principle**. This is to bring the two substances together so there is always as much difference in temperature as possible between them so that there will be the greatest total transfer of heat. For example with the blast stove, the hearth or chamber where the gases burn is the hottest part and the coolest part is at the stack; the cold blast should enter near the stack and leave through the hearth.

Recuperation is also a system for preheating gases (usually only the air): the products of combustion are caused to pass around and heat iron pipes through which the air for combustion is conveyed to the furnace.

The **mechanical equivalent of heat** is the value for converting heat units into mechanical units (or *vice versa*):

$$1 \text{ B.T.U.} = 778 \text{ foot-pounds.}$$

$$1 \text{ kg. cal.} = 426.9 \text{ kilogrammeters.}$$

Except in certain cases when undergoing critical changes, such as the melting of ice (or the reverse, when water freezes), bodies expand when heated and contract when cooled (*i.e.*, when heat is removed). The **degree of expansion** (or **contraction**) usually varies at different temperatures and in different substances, and is generally expressed as a proportion of the length at a standard temperature (commonly 0°C. or 32°F.). This is termed the **coefficient or factor of expansion** and the range of temperature for which it is correct (or approximately true) should be stated.

If a substance is altered by heat it is said to be **thermolabile**; particularly where decomposition results it is **pyrolytic** (**pyrolysis**); if unchanged **thermostable** or (particularly in the sense of being non-conductive) **refractory**. A body, such as a Welsbach mantle, which glows when heated is said to be **pyrognomic**; one which burns spontaneously, upon contact with air or moisture, **pyrophoric**.

Temperature Measurement.—The temperature of a body is the degree of sensible heat which it possesses, and is an indication of its ability to impart heat to or receive heat from an adjacent body which is respectively at a lower or a higher temperature. It is stated in degrees of a scale (**thermometric** or **pyrometric scale**) based on certain **fixed points**, such as melting points or boiling points, of various substances taken as standards of reference. There are two scales in common use, the **Fahrenheit (English) scale (F)**, and the **Centigrade (Celsius or metric) scale (C)**, and a third, the **Réaumur scale (R)**, which is occasionally encountered; these compare with each other as follows:

	C	F	R
B. P. Water.....	100	212	80
M. P. ice.....	0	32	0
Difference.....	100	180	80
Ratio.....	5	9	4

For conversion from one to another:

$$C = \frac{5}{9}(F - 32) = \frac{5}{4}R.$$

$$F = \frac{9}{5}C + 32 = \frac{9}{4}R + 32.$$

$$R = \frac{4}{5}(F - 32) = \frac{4}{5}C.$$

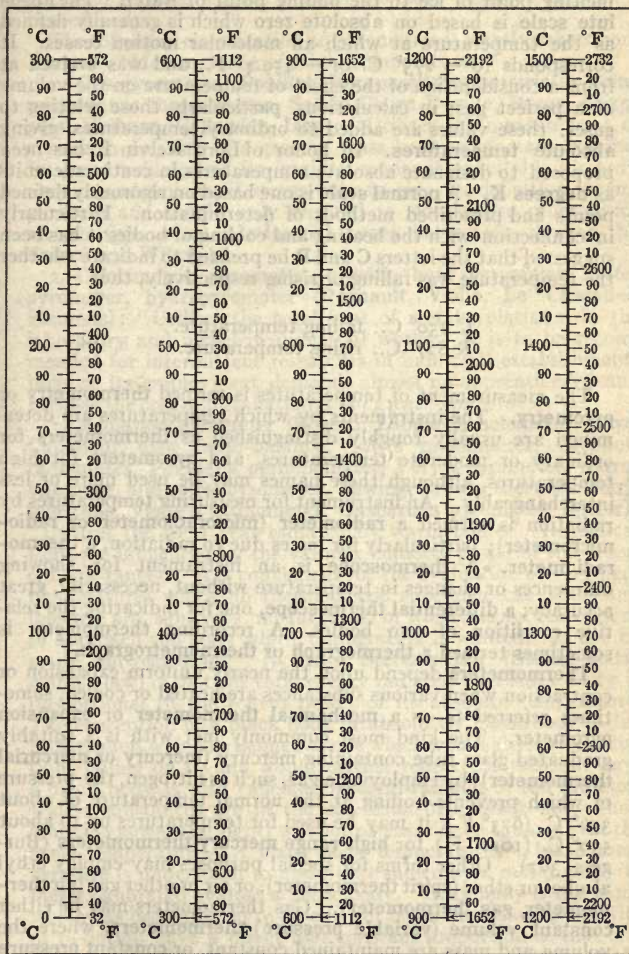


FIG. 24.—Conversion scale for Centigrade and Fahrenheit temperatures. (Tiemann, T. A. I. M. E., 1915.)

De Lisle's scale assigns 150 degrees to the range from the melting point of ice to the boiling point of water. The **absolute scale** is based on **absolute zero** which is generally defined as the temperature at which all molecular motion ceases. It corresponds to -273° C. or -459.4° F., and was arrived at from a consideration of the effect of temperature on the volume of a perfect gas; in calculations, particularly those relating to gases, these values are added to ordinary temperatures, giving **absolute temperatures**. In honor of Lord Kelvin it has been proposed to designate absolute temperatures in centigrade units as **degrees K**. A **normal scale** is one based on rigorously defined points and prescribed methods of determination. Particularly in connection with the heating and cooling of bodies it has been suggested that the letters **C** and **R** be prefixed to indicate whether the temperature was falling or rising respectively, thus

C 750° C.: falling temperature.

R 827° C.: rising temperature.

The measurement of temperatures is termed **thermometry** or **pyrometry**. The instruments by which temperatures are determined are usually roughly distinguished as **thermometers** for ordinary or moderate temperatures, and **pyrometers** for high temperatures, although these names may be used more or less interchangeably. An instrument for measuring temperatures by radiation is termed a **radiometer** (**microradiometer** or **radiomicrometer**); particularly for losses due to radiation, a **thermoradiometer**. A **thermoscope** is an instrument for showing differences or changes in temperature without, necessarily, great accuracy; a **differential thermoscope**, one for indicating the relative condition of two bodies. A recording thermometer is sometimes termed a **thermograph** or **thermometrograph**.

Thermometers depend upon the nearly uniform expansion or contraction when various substances are heated or cooled, sometimes referred to as a **mechanical thermometer** or **expansion pyrometer**. The kind most commonly met with is a suitably graduated glass tube containing mercury (**mercury** or **mercurial thermometer**); by employing a gas, such as nitrogen, the pressure of which prevents boiling at the normal temperature of about 356° C. (673° F.), it may be used for temperatures up to about 550° C. (1020° F.) for **high-range mercury thermometers** (Burgess, 362). Other forms for special purposes may employ ethyl alcohol or ether (**spirit thermometer**), or air or other gas (**air thermometer**, **gas thermometer**). Gas thermometers may be either **constant volume** (**variable pressure**) **thermometers**, where the volume and mass are maintained constant, or **constant pressure** (**variable volume**) **thermometers**, where the mass of gas varies but its pressure and volume remain the same. A **normal thermometer** is one based on a normal scale (see above). A **metallic** (**bimetallic** or **differential**) **thermometer** depends on the different degrees of expansion and contraction of two pieces of different metals connected together. A **chromatic thermometer** is based

on the different colors, due to internal strains, when polarized light is passed through a piece of glass, one edge of which rests on a heated body.

The following classification of pyrometers is largely taken from Burgess' "Measurement of High Temperatures:"

1. Gas pyrometer (Pouillet, Becquerel's volumetric or volumetric thermometer, Sainte-Claire-Deville, Barus, Chappuis, Holborn, Callendar, Day): "Utilizes the measurement of change in pressure of a gaseous mass kept at constant volume. Its great volume and its fragility render it unsuitable for ordinary measurements; it serves only to give the definition of temperature and should only be used to standardize other pyrometers (pp. 9-10). Industrial types have been devised by Bristol and Wiborgh.

2. Calorimetric pyrometer, specific heat pyrometer, water pyrometer, hydro-pyrometer (Regnault, Violle, Le Chatelier, Siemens): "Utilizes the total heat of metals, platinum in the laboratory and nickel in industrial works. It is to be recommended for intermittent researches in industrial establishments because its employment demands almost no apprenticeship and because the cost of installation is not great" (p. 10).

3. Radiation pyrometer (Rosetti, Langley's bolometer, Boys, Callendar disk radio-balance, Joly's melometer, Crooke's radiometer, Pouillet's pyr-heliometer, Féry's pyrometer, mirror telescope, and spiral pyrometer, Thwing, Brown, thermo-electric telescope, Violle's actinometer, Gasparin's pyrometer, Foster): "Utilizes the total heat radiated by warm bodies. Its indications are influenced by the variable emissive power of the different substances. It is convenient for the evaluation of very high temperatures which no thermometric substance can withstand (electric arc, sun, very hot furnaces) or when it is not convenient to approach the body whose temperature is wanted. It can be made self-registering" (p. 10). Stefan's law (Stefan-Boltzmann's law) is that the total energy radiated by a black body is proportional to the fourth power of its absolute temperature. The conception of a **black body** or **absolutely black body** is due to **Kirchhoff** which he defined as one which would absorb all radiations falling on it, and would neither reflect nor transmit any; a black body is also called an **integral radiator** or **full radiator**. Unless substances are in the condition of a black body their **emissive power** (for light) will not necessarily be the same for the same temperature. A **black body temperature** or **black temperature** is understood to mean that shown by a radiation pyrometer calibrated against a black body. **Gray body** is the name which has been applied to a body not black but whose properties of radiation have a direct and constant proportion to that of a black body. Radiation pyrometers may also be based on the electric current set up in a circuit of two dissimilar metals when their junction is heated; this is called a **thermopile**, which has been employed by **Nobili** and **Melloni**.

4. Optical pyrometer (Becquerel, Le Chatelier, Wanner, Holborn-Kurlbaum, Morse thermogage, Féry absorption pyro-

meter and spectral pyrometer, Henning's spectral pyrometer, Shore pyroscope, Mesuré and Noël pyroscope, Crova, stellar pyrometer, modifications of a photometer, flicker photometer, Nordman's heterochrome photometer, pyrophotometer): "Utilizes either the photometric measurement of radiation of a given wave length of a definite portion of the visible spectrum, or the disappearance of a bright filament against an incandescent background. Its indications, as in the preceding case but to a much less degree, are influenced by variations in emissive power. The intervention of the eye aids greatly the observations, but diminishes notably their precision. This method is mainly employed in industrial works for the determination of the temperatures of bodies difficult of access. For example, of bodies in movement (the casting of a metal, the hot metal passing to the rolling mill). It can be used to establish the highest temperatures, and is the best method for use above 1700° C. (3090° F.) in the laboratory and the works" (p. 10). **Draper's law** is that all bodies acquire incipient luminosity at the same temperature. **Selenium** has been employed to measure the temperatures of incandescent bodies due to the fact that its electrical resistance is affected by light.

5. **Electrical Resistance pyrometer** (Siemens, Callendar and Griffith, Waidner and Burgess): "Utilizes the variations of the electrical resistance of metals (platinum) with the temperature. This method permits of very precise measurement to 1000° C. (1830° F.), but requires the employment of fragile apparatus. It merits the preference for very precise investigations in laboratories. As a secondary instrument for the reproduction of a uniform temperature scale throughout the range in which the **platinum resistance pyrometer** can be used, to 1000° C. except in very heavy wire, it is unsurpassed in precision and sensibility. It is also now constructed in convenient form for industrial use" (pp. 10-11). A **logometer** is an instrument designed for the measurement of the ratio of two electric currents (Burgess, 221); **Northrup's ratiometer** is somewhat similar. **Holborn and Wien** used palladium instead of platinum.

6. **Thermo-electric pyrometer** (Becquerel, Barus, Le Châtelier): "Utilizes the measurement of electromotive forces developed by the difference in temperature of two similar electromotive junctions opposed to one another. In employing for this instrument a Deprez-d'Arsonval galvanometer (**galvanometric method**) with movable coil, one has an apparatus easy to handle and of a precision amply sufficient for industrial and many scientific uses. With a potentiometer (**potentiometer method**), an instrument is obtained of the most considerable precision, available for use to 1600° C. (2910° F.), or even to 1750° C. (3180° F.) with proper precautions. This pyrometer was used for a good many years in scientific laboratories, before it spread into general use, where it also renders most valuable service" (p. 11). The two dissimilar elements are termed a **couple**, **thermo-couple**, **thermo-element**, or **thermoelectric pair**. For high temperatures and special work they commonly consist of combinations of

platinum and platinum with about 10% of rhodium (**Le Châtelier's couple**), platinum-palladium, etc. (Becquerel), etc.; these are termed **noble** or **rare metal couples** owing to their comparative freedom from oxidation. **Base metal couples** are those which, for the sake of cheapness, are made of combinations of the more ordinary metals or alloys, such as copper, nickel, iron, etc.; these are usually restricted to the lower temperatures, say not over about 900 or 1000° C. (1650 or 1830° F.) on account of their greater fusibility or oxidizability. Two special alloys for this purpose are **constantan** (**konstantan**, **advance alloy**) with copper 50 and nickel 50, or copper 60 and nickel 40; and **manganin** with approximately copper 84, nickel 4, and manganese 12. **Compound couples** are those which either consist of two or more couples in series, to give greater sensibility, or where (to save expense) cheaper substances are used for the portion not subjected to the maximum temperature. The couple is formed by joining the two wires at one end by twisting or preferably welding together, called the **hot junction** (**H. J.**). At their other ends they are connected to copper wires or suitable lead wires which are connected with the galvanometer or other measuring device; these other ends, or **cold junction** (**C. J.**), of the couple are properly maintained at a constant temperature usually by inserting in melting ice or other substance whose temperature is known as the determination indicates the difference in temperature between the two junctions. Complete expression, however, from the total e.m.f. developed in the thermoelectric circuit requires account to be taken of (1) the **Thomson effect**: the electromotive forces generated due to differences in temperature along a homogeneous wire; (2) the **Peltier effect**: due to the heating of the junction of two dissimilar metals anywhere in the circuit; (3) the **Becquerel effect**: the electromotive forces developed by physical or chemical inhomogeneity in a single wire (Burgess). The electromotive force generated is ascertained either by the **opposition** (**potentiometer**) method or by the **galvanometric method**, the former being the more accurate.

7. **Contraction pyrometer** (**Wedgewood's contraction pyroscope**): "Utilizes the permanent contraction that clayey materials take up even when submitted to temperatures more or less high. It is employed today only in a few pottery works" (p. 11).

8. **Fusible cones** (**Seeger, Orton**): "Utilizes the unequal fusibility of earthenware blocks of varied composition. They give only discontinuous indications. Such blocks studied by Seeger are spaced so as to have fusing points distant about 20° C. They are in general use in pottery works and in some similar industries (p. 11). This method may be classed as **fusing point** or **melting point pyrometry**. In addition to the earthenware cones, similar forms may be made of a series of salts (**Grenet**), or of metals and alloys (**Prinsep**); these are sometimes referred to as **sentinels** or **sentinel pyrometers**.

9. **Pyrometers based on flow or on pressure of air or vapor** (**Hobson, Uhling-Steinbart, Job, Fournier**).

10. **Recording pyrometers:** (Roberts-Austin, Callendar, Le Chatelier, Siemens and Halske). Those which are provided for plotting, either continuously or at intervals, a chart showing times with corresponding temperatures (p. 12).

11. **Temperature colors** are those shown to the eye by incandescent bodies at different temperatures. The color identities for different temperatures have been investigated by Pouillet and are shown below in what is known as **Pouillet's color scale**:

Color names	Degrees C.	Degrees F.
Visible color, first visible red, black red. . .	525	970
Dull red, low red.	700	1290
Red, incipient cherry, blood red.	800	1470
Cherry, cherry red, bright red.	900	1650
Bright cherry.	1000	1830
Dull orange.	1100	2010
Bright orange.	1200	2190
White.	1300	2370
Bright white.	1400	2550
Dazzling white.	1500	2730

Black heat is any temperature below visible color.

12. **Miscellaneous Methods:** **Carnelly and Burton's dilution pyrometer** is based on the increase in the temperature of a constant stream of water led through a furnace or other heated chamber. An **air dilution pyrometer** is usually arranged so an amount of cold air at known temperature is mixed with a known volume of heated blast, etc., and the temperature of the latter determined from the temperature of the mixture. **Uhling and Steinbart's transpiration pyrometer** or **hot blast pyrometer** is based on the varying rate at which a gas will flow through a small orifice when heated to different temperatures. **Threw's pyrometer** is somewhat similar in principle. **Schaffer and Budenberg's thalpotassimeter** or **vapor pressure pyrometer** employs the pressure of the saturated vapor of certain liquids (*i.e.*, when both liquid and vapor are present together). **Wiborgh's thermophone** is a contrivance consisting of a small quantity of an explosive enclosed in a refractory material which is thrown into a furnace, the temperature being calculated from the length of time before the explosion occurs. An **acoustic signal** is an arrangement consisting of a wire connected with an electric clock; when the wire is melted an alarm is given. A **spike indicator**, used to determine the temperature of a fused salt bath, is an iron rod which is dipped in the bath, and the temperature calculated from the amount congealed and the corresponding time required to dissolve it off, conditions being maintained uniform (Brearly). **Sauveur and Whiting's thermomagnetic selector** was a device to determine those rails (or similar objects which were finished at a temperature below the critical, so that their magnetic properties were restored; it was arranged to stamp such rails.

Heat Balance.—Of a blast furnace: see page 36.

Heat of Combustion.—See pages 201 and 203.

- Heat Crack.**—See Crack.
- Heat of Disgregation.**—See page 202.
- Heat Energy.**—See page 199.
- Heat of Expansion.**—See page 202.
- Heat of Formation.**—See page 200.
- Heat of Fusion.**—See page 201.
- Heat Interception, Zone of.**—In a blast furnace: see page 36.
- Heat of Ionization.**—See page 201.
- Heat Measurement.**—See page 201.
- Heat of Neutralization.**—See page 201.
- Heat Refining.**—See page 213.
- Heat Relief.**—See page 288.
- Heat of Solution.**—See page 201.
- Heat, Spontaneous Evolution of.**—See page 199.
- Heat Sums.**—Law of: see page 201.
- Heat Test.**—A test, either chemical or physical, representing a heat or melt of steel. This term was formerly applied to a tensile test made on a round (about $\frac{3}{4}$ " in diameter) forged down from a ladle test ingot or rolled from a billet; same as billet test.
- Heat Tinting.**—See page 288.

Heat Treatment (Thermal Treatment).—Heat treatment in its most general sense may be taken to mean the application of heat either to make the metal easier to work by rendering it softer or more ductile, or to secure certain desired (and beneficial) changes in its constitution and physical properties without mechanical work. By common usage, however, the term has become restricted to the latter application, for which the writer has suggested the following definition:

Heat treatment is the change, or the series of changes, in temperature, and also the rate of change from one temperature to another, brought about to secure certain desired conditions or properties in a metal or alloy.

The term "heat treatment" is frequently but incorrectly used in the restricted sense of quenching followed by reheating, as applied to axles, etc.; when so used it is not considered to apply to annealing or any other treatment properly covered by this term.

In connection with what follows the article on Metallography should be consulted for explanations of certain special terms necessarily used. For processes or terms employed chiefly for one class of product reference should be made to special articles, such as Malleable Castings, Sheets and Tin Plate, Special Steels, and Wire.

Heat treatment, like a good rule, will work both ways, and consequently if it is not employed intelligently, or if its presence and effect are overlooked, when material is heated simply for the purpose of working, the results may be disappointing or even disastrous. It should be appreciated that heat treatment acts as an intensifier in the development of the properties of the steel, much as in the treatment of the photographic plate: if the initial quality is good it will be greatly improved, but if bad the final state of that steel is likely to be worse than the first, although

in some cases, if this is known, special corrective steps can be taken which may effect a partial but rarely a complete cure. Whether it will prove beneficial or harmful will also depend upon the degree, the rate, and above all the uniformity of heating and cooling. Too much emphasis cannot be laid upon this question of uniformity; it means the same kind of material treated in the same way to get the same results; these three cardinal points may be tabulated as follows:

1. **Uniformity of material:**

- (a) The same grade—composition within prescribed limits.
- (b) Homogeneity of material—freedom from chemical defects represented by harmful segregation, inclusion of foreign substances, etc., freedom from physical defects, such as piping, cavities, injurious and severe strains which, as an extreme case, have actually developed cracks.

2. **Uniformity of treatment:**

- (a) Suitable equipment, including furnaces, quenching baths, and pyrometers; the capacity should be ample so it will not be overtaxed in handling a given output.
- (b) The heating and cooling must be adjusted so that each piece from end to end throughout the section from outside to center, as well as all the pieces in a lot treated together shall, as nearly as possible be at the same temperature at all times.

3. **Uniformity of results:** If the other two conditions have been met this one is found to follow. Means should, however, be provided for constantly checking results in order that any errors or carelessness will be promptly discovered and corrected. A further discussion of these conditions will be found in connection with the effect of mass.

Heat treatment affects the physical or mechanical properties in two ways, by regulating (a) the constituents, and (b) the grain size. The effect which a given heat treatment will produce varies considerably with the chemical composition; carbon is the principal or dominant element, and certain other elements, such as manganese, chrome, tungsten, etc., are also very noticeable in this respect. The effect of the special elements is considered more particularly under Special Steel.

Special heat treatment may be classified under the four heads; (1) **hardening**, (2) **tempering**, (3) **annealing**, and (4) **grain refining**. Before discussing in detail the first three of these operations, the effect of carbon and grain refining will be considered.

Effect of Carbon.—It has already been stated that carbon is the element which, more than any other constituent of steel, governs or controls its properties. This effect is due to:

- 1. **The condition of the carbon.**
- 2. **The distribution of the carbon.**

As regards its **condition**, the carbon may exist (a) in the free state, as graphite, which in steels is of interest only as a possible impurity; (b) in chemical combination with iron, Fe_3C or cementite; and (c) in solid solution in gamma (or beta) iron in which it is dissolved (**absorbed**) either in its elemental form or more probably as the carbide.

The **distribution** of carbon may be either **homogeneous** or **heterogeneous**. It is homogeneous only when the carbon is in perfect solid solution as in such case it must be completely **diffused** (rarely, **equalized** or **absorbed**) throughout the iron in the same way that salt is diffused when dissolved in water, so that individual particles of it cannot be detected even by the aid of the most powerful microscope; unfortunately, however, a solution, particularly a solid solution, may be more highly concentrated in one portion than in another, due to incomplete diffusion or imperfect mixing, and hence is to this extent heterogeneous. This solid solution is ordinarily normal at high temperatures above the upper critical point A_3 (see Metallography), and if it can be preserved when cold by sufficiently rapid cooling, its homogeneity must also be preserved.

The chief (and unavoidable) cause for heterogeneity is the form known as cementite, either free or as the eutectoid mixture with pure iron or ferrite known as pearlite; it may also be present with other constituents. This condition is reached either by slow cooling from above the upper critical point or by reheating to temperatures inferior to A_{c1} ; the restraint of the atoms is sufficiently removed to permit the transformation of some or all of the iron into the alpha variety. The carbon originally in solution in this portion is thereby automatically expelled or precipitated as cementite. There will therefore result a mixture of cementite and ferrite resembling pearlite with an excess of one of these substances unless of eutectoid composition (about 0.85% carbon); as it has been claimed that true pearlite is only produced by slow cooling, it is suggested that the mixture resulting from reheating be termed **pearloid** (of the nature of pearlite), and in this discussion the distinction will be observed. Unless the temperature is close to A_{c1} there is still too much viscosity to permit the molecules sufficient freedom of movement to cause any marked **segregation** of the ferrite and cementite, so the pearloid has an extremely fine structure. Where the temperature and time of cooling are sufficient, the formation of relatively coarse pearloid will occur. The segregation just referred to is intended in a microscopical sense, and is not, as commonly understood by the term, what is detected by ordinary methods of chemical analysis. In actual practice it is well known that of two pieces of the same steel, one merely annealed while the other is quenched and then reheated to A_{c1} , the latter will possess much better physical properties, not only in regard to strength, but to ductility as well. The cause for this is principally found in the distribution of the carbon, as the material is microscopically more homogeneous, although other factors, such as the effect of grain size, etc., may contribute.

Grain size and growth is affected by heating and by thermal or heat refining; grain growth is also referred to as **crystalline growth**, **growth of crystals** or **crystallization by annealing**. Metals and alloys are composed of a number of crystals or

grains. The irregularity of their form is due to the fact that the growth of each is interfered with by that of the others surrounding it. Therefore, it is only under special conditions that perfect crystals are attained. The size of these grains depends upon the maximum temperature above A_{c1} at which they have been free to develop, subject to the following conditions:

If a piece of steel is heated to a temperature corresponding to the point G in Fig. 25 (due to Howe), and is then cooled, it will be found to have a grain size OL proportional to this temperature. If it is then reheated the grain size will remain the same until A_{c1} has been reached. Immediately on passing this (as at N), the grain is refined to the minimum, that is, from N to J , producing a refined structure. This is known as the refining temperature or refining heat.

If the temperature is still further raised the grain size increases progressively as shown by the curve $J D G$, and this cycle of changes can be repeated indefinitely, provided the steel is allowed to cool uninterruptedly from the maximum temperature above A_{c1} . Except with eutectoid steel which has a single critical point, when the cooling reaches the upper critical point a separation of the excess constituent commences, and continues until the lower critical point is reached, to form an envelope or skeleton structure about what then becomes the eutectoid. On reheating, this excess substance commences to be reabsorbed or dissolved when the lower critical point is passed, but the action is not completed until the

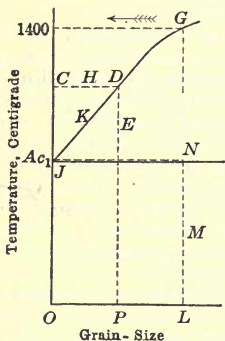


FIG. 25.—Heat refining. (Howe, "Iron, Steel and Other Alloys.")

upper critical point has been reached. Consequently unless this latter temperature is exceeded, portions of the skeleton will remain and prevent a real grain refinement. As a matter of fact hyper-eutectoid steels (with carbon over 0.85%) do not possess this difficulty as apparently the excess cementite crumbles or is broken up after passing the lower critical point, so they can be treated the same as a eutectoid steel. It must be clearly understood that the influence of time on grain size is important. Unless ample time is given at the maximum temperature, a given grain may have the same or even a smaller size than another held longer at a lower temperature.

Metcalf's Experiment.—An experiment to show the effect of temperature on the grain size, known as "Metcalf's Experiment," illustrates this very clearly. A description of this experiment was published by William Metcalf in the *Metallurgical Review* (Vol. I, No. 3, November, 1877), and because of its value as well as the historical interest attaching to it, the following extensive extract is given:

To show this effect we take a bar of steel of ordinary size, say

about inch by half, heat 6 or 8" of one end to a low red heat, and nick the heated part all around the bar at intervals of half to three-quarters of an inch, until eight or nine notches are cut. This nicking is done at a red heat to determine the fracture at the nicks. Then place the end of the bar in a very hot fire, leaving the balance of the bar so much out of the fire as to heat it chiefly by conduction. Heat the end of the bar in the fire to white heat, or until it scintillates, and allow it to remain until the nick furthest from the end in the fire is not quite red, and the next barely red. Now, if the pieces be numbered from one to eight, beginning at the outer end:

No. 1 will be white or scintillating;

No. 2 will be white;

No. 3 will be high yellow;

No. 4 will be yellow or orange;

No. 5 will be high red;

No. 6 will be red;

No. 7 will be low red;

No. 8 will be black.

As soon as heated as above described, let the bar be quenched in cold water, and kept in the water until quite cold. After cooling, the bar should be carefully wiped dry, especially in the notches. An examination of the different parts by the file will show the following, if high (carbon) steel has been used:

No. 1 will scratch glass;

Nos. 2, 3, 4 will be excessively hard;

Nos. 5, 6, will be well hardened;

No. 7 about hard enough for tap teeth;

No. 8 not hardened.

In breaking off the pieces, which should be done over the corner of an anvil and the pieces caught in a clean keg or box to keep the fractures clean and bright, it will be found that:

No. 1 will be as brittle as glass;

No. 2 will be nearly as brittle;

Nos. 3, 4, 5 will break off easily, each a little stronger than the other;

Nos. 6, 7 will be very strong, and much stronger than No. 8, or the bar unhardened.

Place the pieces in the order of their numbers, fitting the fractures, then "up-end" each, beginning with No. 1 and following the order in which they lie, and the result will be the series of fractures, each differing from the other.

No. 1 will be coarse, with a yellowish cast, and very lustrous;

No. 2 will be coarse and not quite as yellow as No. 1;

No. 3 will be finer than Nos. 1 or 2, and coarser than No. 8, and will have a fiery luster;

No. 4 will resemble No. 3 in color and luster, with somewhat finer grain, and will be coarser than No. 8;

No. 5 will be about the same size as No. 8, but will have fiery luster;

No. 6 will be much finer than No. 8, will have no fiery luster, will be hard through and very strong. This is what is called *refined* by hardening.

No. 7 will be refined and hard on the corners and edges, and rather coarser and not quite so hard in the middle. This is about the right heat for hardening taps, milling tools, etc., the teeth of which will be amply hard while there will be no danger of cracking the tool.

No. 8 illustrates the original grain of the bar.

What is known as **Alling's test** is very similar to Metcalf's experiment: A bar, with a longitudinal slot cut on each side, is heated in much the same way, and after quenching is broken along the slot exposing a continuous fracture showing the effect of the varying temperature.

Grain Growth as Affected by Strain.—It was found by Stead in 1898 that iron or very low carbon steel with less than about 0.15% carbon, when heated for a very long time (hours or days) to between 500 and 750° C. (930 and 1380° F.), the grains greatly increased in size and the metal became brittle (hence called **Stead's brittleness**). In 1912 Sauveur experimented with some 0.05% carbon steel which he heated or "annealed" at 650° C. (1200° F.) for 7 hours, after making an impression with a Brinell machine. In regard to his conclusions he states (*Metallog.*, 266): "These observations point to the conclusion that ferrite grains will not grow on annealing below the critical range unless they have been subjected to a certain stress creating a certain **strain**, and that they will not grow if that stress, and therefore the resulting strain, has been exceeded. In other words, they point to the existence of a **critical strain** producing growth, strains of greater or less magnitude being ineffective. The narrow region occupied by the critically strained metal should also be noted as well as the very sharp line of demarcation between the critically strained and the **understrained** metal. The separation of the critically strained from the **overstrained** is not so sharp." The critical strain is also referred to as **critical deformation**, **Sauveur's critical strain**, and Howe refers to "**Sauveur's process of coarsening ferrite** by heating it to below A_3 after a critical degree of plastic deformation."

As a result of his investigations on this subject, Chappell (*J. I. & S. I.*, 1914, 465) draws the conclusions as to the changes involved in the **recrystallization** of severely worked ferrite:

(a) Up to 350° C. no visible reorganization takes place.

(b) From 350 to 500° C. **potential recrystallization** takes place in the shape of disintegration of the deformed crystals into what has been termed **crystal débris**. This is stage I.

(c) Below 500 to 570° C. new crystals are formed among this crystal débris, which new crystals grow rapidly from almost ultramicroscopic dimensions into normally shaped allotrimorphic crystals easily visible at high magnifications. This is stage II.

Grain Size and Mechanical Refining.—For the economical production of various shapes and sections by rolling or forging, it is essential to heat the metal to a relatively high temperature

so it may be as soft and ductile as possible. If the metal were simply cooled from such a temperature it would be coarse-grained, and the cohesion between the grains would be weakened. This would mean increased brittleness and decreased resistance to shock, which would render the material unsuitable for many purposes.

However, when mechanical working occurs, the grains are reduced to a size dependent chiefly upon the temperature at which this work ceases and, in a somewhat less degree, upon the size or mass of the piece, it being of course supposed that the work affected the entire section. The explanation for this is readily appreciated by referring to Fig. 26 (also due to Howe). The grains or crystals of iron in their normal condition are equiaxed and belong crystallographically to the isometric or cubic system, that is, their three axes are at right angles to each other and of equal length. When the length of a piece is increased by rolling or forging, there must be a proportional decrease in the cross-sectional area. The small grains or crystals which make up the structure must be deformed to at least the same degree. This produces a condition of unstable crystallographic equilibrium, since the axes are of unequal length (inequiaxed). To regain the normal state each grain tends to split up into several grains of smaller size, depending upon the shortest axis which limits that of the other two. At the relatively high temperatures ordinarily employed for mechanical working, the molecules have sufficient freedom of movement to bring this about.

The curve Ac_1A is the grain-size curve of Fig. 25 just discussed. If a piece of steel at a temperature, and with corresponding normal grain size, as at A , is sufficiently deformed by a single operation of mechanical working, the grain size will be reduced from A to B , equal to OH . If the piece could then be cooled instantaneously, this size should be preserved. Under ordinary circumstances, however, the cooling requires some time. In this case the grain size, being below the normal for the existing temperature, increases progressively toward that normal size. Unless interrupted, the cooling of the piece and the increase in grain size from B is along the curve BCE . After crossing the curve Ac_1A no change in the grain size takes place, as already explained in connection with Fig. 25. The final size is consequently OE .

If, however, when C is reached, mechanical working is again applied, the grain is reduced to D . By further repetitions of cooling and working the zig-zag curve $ABCDG$ is followed

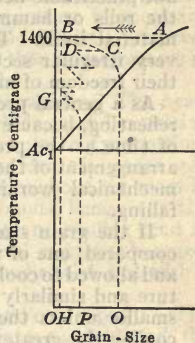


FIG. 26.—Mechanical refining. (Howe, "Iron, Steel and Other Alloys.")

until G is reached. If this is the finishing temperature, the growth of the grain proceeds until, with the temperature steadily falling, the curve Ac_1A is crossed, but this time at a much lower point than before, the final grain size being OP .

It will thus be seen that for pieces of the same size, that is, with the same rate of cooling, the grain size will depend upon the finishing temperature.

Theoretically, it would be desirable to finish just above Ac_1 . but, owing to the rapidly diminishing ductility, this is usually not practicable because of the danger of breaking or overtaxing the rolls or hammer, or of producing excessive strains in the material itself. This last is especially true if the piece is of very irregular section, since the molecules have lost much of their freedom of movement.

As a general proposition, the finest grain must be secured by reheating, because the piece can then be held a sufficient length of time at the proper temperature to enable the necessary rearrangement of the molecules to occur, which is not possible with mechanical working because the temperature is constantly falling.

If the grain size of two pieces of steel of the same size are compared, one of which was worked from a higher temperature and allowed to cool, and the other reheated to the same temperature and similarly cooled, the grain size of the first piece is the smaller unless the cooling is extremely slow; and the faster the cooling the greater the difference. The explanation for this is because the final working reduced the size to below what was normal at that temperature and the temperature had fallen considerably before the grain was of correspondingly normal size; with the second piece the heating was slow enough to permit of a much nearer approach to the normal correspondence between grain size and temperature.

Combined Treatment for Grain Size and Carbon.—From the preceding it will be seen that there can be secured by suitable heat treatment any one of the following possible combinations:

1. Grain size either (*a*) fine or (*b*) coarse, with
2. Carbon either (*c*) in solution (homogeneous) or (*d*) precipitated (heterogeneous); and for 2 (*d*) only, with
3. Microscopic segregation either (*e*) fine or (*f*) coarse.

Having taken up separately the various conditions which are met, we can now consider how heat treatment can be employed to obtain the best results. To this end we secure as far as possible:

1. A fine grain size.
2. Fine and uniform distribution of the carbon and allied constituents.

Only in the case of a eutectoid steel can this combination be met by simple treatment. Assume the complicated case of, say, a 0.50% carbon steel in an ordinary condition which is to be made as soft as possible, and with the carbon in a fine state and uniformly distributed; after this the simpler cases can be readily determined. Such a steel as received will have been slowly cooled after rolling or forging. Its structure consequently will be composed of

relatively coarse grains of pearlite surrounded by, or interspersed in envelopes or bands of excess ferrite, the latter being expelled in cooling through the critical range between Ar_{3-2} , and Ar_1 (*OS* and *PS* in Fig. 38, page 271). The following procedure is then followed which, except for complications frequently encountered which must be specially handled, will approximate the desired results:

1. Heat (at any rate of speed consistent with uniform heating) somewhere above Ac_3 , and cool rapidly. Heating to above Ac_1 would be sufficient to convert the eutectoid portion into a solid solution, but the higher temperature is necessary to effect solution of the excess ferrite; rapid cooling preserves the homogeneous condition. The metal is then homogeneous in composition but is hard and coarse grained.

2. Heat rapidly just above Ac_1 and cool rapidly. The heating below Ac_1 causes precipitation of carbide, and by passing above this point the cementite and ferrite in eutectoid proportions are converted into a solid solution; the excess ferrite is not (or only very slightly) affected, but it is scattered throughout the mass in minute fragments, and not as continuous bands, hence is in the least injurious condition; the rapid heating and cooling tend to prevent microscopic segregation. The metal is partly homogeneous and partly heterogeneous, still relatively hard, but with a fine grain.

3. Reheat rapidly to slightly below Ac_1 and cool rapidly. The solid solution of eutectoid is converted into pearloid and the rapid heating and cooling (as before) tend to discourage segregation; the rapid cooling from below Ac_1 does not cause hardening. The metal is now soft, necessarily heterogeneous but the cementite and ferrite are as uniformly and finely distributed as possible. Q.E.F.

Effect of Mass on Physical Condition and Properties.—In what has gone before it has been assumed that the piece has been small, that is, without appreciable mass, and in most discussions this question is ignored.

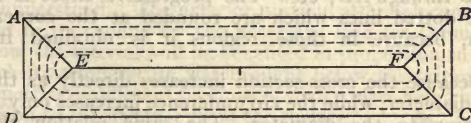


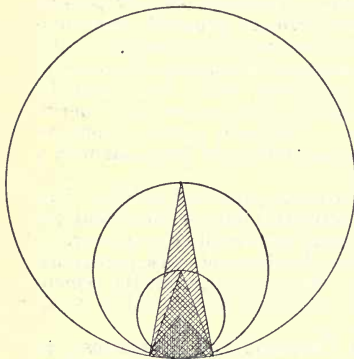
FIG. 27.—Manner of transmission of heat. (Tiemann.)

In practically all experiments which have furnished the information we at present possess, relatively very small pieces were employed. It is possible to heat or cool such pieces nearly uniformly throughout, about as rapidly as desired. When, however, the attempt is made to put into practice the principles so obtained, it is found that a new factor enters largely into the problem, namely, the mass of the object treated. For example, if a piece of fine wire is heated and then exposed to air at the

ordinary temperature, it will be cooled almost instantaneously, while the time required in the case of a large shaft, even when plunged into cold water, will be many minutes.

Under similar conditions the rate of heating and cooling is much less for a large than for a small section, for two reasons:

1. Because the distance to be traversed between the surface and the center, in the absorption or dissipation of heat, is greater. This rate progressively decreases as the temperature of the body, or of one portion of the body in relation to another portion, approaches that of the source of heat or refrigeration, in accordance with one of the fundamental laws of thermodynamics. Fig. 27 is intended to illustrate how the transference of heat occurs between different portions of the surface and the interior. *AB-CD* is a section through an object uniformly heated or cooled



Diameter of circle	Relative Circum.	Relative Areas	Ratio Area to Circum.
1	1	1	1
2	2	4	2
3	3	9	3
4	4	16	4
5	5	25	5
6	6	36	6
7	7	49	7
8	8	64	8
9	9	81	9
10	10	100	10

FIG. 28—Relative Amounts of Heat Transmitted per Unit of Area of Surface.—(Tiemann.)

on all sides. The transference of heat to *ABFE* is through *AB*; to *AED* through *AD*, etc. The progressive effect is indicated by the dotted lines which are rounded at the corners of the section, because in those regions it is obtained from two sides.

2. Because the cross-section increases directly as the square of the diameter, while the circumference increases only in simple proportion to the diameter. The same relation also exists between surface and volume (mass), since these are obtained by multiplying the circumference (or perimeter) and the area, respectively, by the same value representing the length. In Fig. 28 is a table of ratios between circumference and area for circles of diameters of 1 to 10. In the same figure are shown three circles with diameters of 1, 2 and 4. The hatched portions show graphically that the same linear distance on the circumference of each must serve for the transfer of amounts of heat which are respectively 1, 2 and 4; as already explained these ratios are the same if the surfaces and volumes (masses) are substituted.

This may be summarized in the following general law for the transference of heat:

For bodies of similar section the amount of heat transferred per unit of surface is directly proportional to the ratios of their diameters (or similar dimensions of their cross-section).

The preservation in the cold state of the condition which existed at the temperature to which an object is heated (above the critical point) is dependent upon a certain rate of cooling, irrespective of the size or mass of that object. With the means at our command it will readily be appreciated that a point is very quickly reached when no method of cooling can compensate for the increase in mass, so that the rate of cooling decreases with corresponding increase in the actual time required.

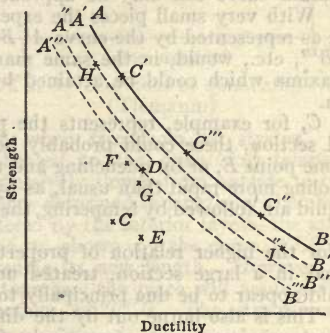


FIG. 29.—Diagram used for discussing effect of mass.—(Tiemann.)

As a direct result the interior of large masses will be cooled so slowly as to have only the properties of smaller masses cooled in the same time, or, in other words, the effect has been that of annealing rather than of quenching, as these terms are commonly understood. The exterior portion, although considerably retarded in its cooling by the necessary transfer through it of heat from the interior will be benefited in proportion to the rate at which its temperature will be brought below the critical range, the properties of different portions of such a piece being in inverse proportion to the distance from the surface.

Fig. 29 is intended to show this state of affairs graphically, but without any claim as to its quantitative or even its qualitative accuracy. It is based on the quality formula $Q = S \times D$ given on page 341. The curve AB is supposed to represent the maximum theoretical relation between strength and ductility for steel of any given composition; steels of other composition would be represented by curves varying progressively from one another. If it be tentatively admitted that this curve is correct, then a piece with the properties corresponding to the point A , with relatively high strength and low

ductility, would be of equal merit with another piece with properties B , where relatively low strength is combined with high ductility; or with a piece with properties represented by any other point on the curve, since the curve is drawn on the assumption of a constant value for the relation between strength and ductility.

If a piece had only the properties C , the strength, according to our assumption, could be increased to C' , the ductility remaining the same; or the ductility could be increased to C'' , the strength remaining the same; or any other maximum relation could be attained, as C''' , on the curve $A B$.

In actual practice or experiment, however, the factor of mass is bound to enter in, even with the smallest obtainable section, so that this maximum curve can only be approached but never quite reached. With very small pieces the experimental maximum might be as represented by the curve $A' B'$; other curves $A'' B''$, $A''' B'''$, etc., would, in the same manner, represent the possible maxima which could be attained by pieces of increasing section.

If the point C , for example, represents the properties of a large untreated section, these could probably be improved by annealing to some point E , or by quenching and tempering to F or G . With cooling more rapid than usual, as by quenching in iced brine or liquid air, followed by tempering, the point D might be reached.

The reason for the higher relation of properties in a small section over that in a large section, treated under the same conditions, would appear to be due principally to the condition of the carbon. This is also borne out by the difference in the properties of test specimens cut respectively from near the surface and at the center of large sections, which has resulted in the clause in forging specifications that "the axis of the specimen shall be located at any point one-half the distance from the center to the surface and shall be parallel to the axis of the object tested," with a view to determining the average values.

Effect of Mass on Strains Produced in Heat Treatment.—Under suitable conditions of heating it is possible to secure a reasonably uniform temperature throughout a fairly large section. If the rate of cooling could then be controlled so that a large section could be cooled as rapidly (that is, in the same time) as a smaller object, the uniformity of the material in the two cases should be the same. As a matter of fact, however, such a state of affairs cannot be attained, as the conduction of heat from the center to the outside of a section of any size is relatively slow for the reasons already given, and cannot be hastened sufficiently by any means at our command. Even if such were not the case, there is another insurmountable obstacle in the path. This is the possible introduction of excessive strains in large pieces, particularly where there is any irregularity of section. Rupture or incipient cracks resulting from this would not be corrected by any heat treatment alone. Such cracks from **irregular contraction** due to **unequal cooling**, are termed **treatment cracks**,

heat treatment cracks, cold cracks, etc. (see Cracks, p. 110); **clinking** is an English term to describe the sound when material cracks from irregular expansion due to too rapid, *i.e.*, **unequal heating**. Fig. 30 is intended to illustrate how such cracks or strains can develop when a large object is too rapidly cooled by quenching or otherwise. For simplicity, only linear expansion and contraction at one end are considered. $ABCD$ is the

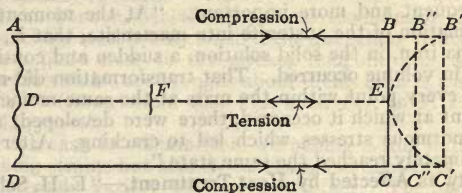


FIG. 30.—Method of development of quenching strains and cracks. (Tiemann.)

original length when free from all strains. $AB'C'D$ is the length when heated to the quenching temperature. If the cooling is progressively slower from outside to center, and each successive layer is deformed in length by the obstruction to full contraction offered by the interior layers, the appearance of the piece would be as shown by the curve $B'EC'$, provided each layer could assume its new length. However, as they are all firmly bound together, the piece will assume the intermediate rectangular section $AB''C''D$. The strains vary from maxi-

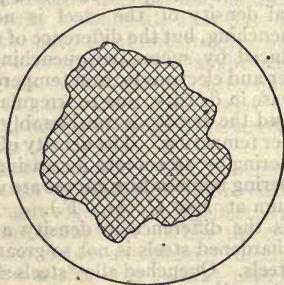


FIG. 31.—Internal quenching crack. (Tiemann.)

imum compression at the outside to maximum tension at the central axis. If this latter strain exceeds the elastic limit, the central portion must stretch and may go far enough to develop a crack, particularly if some flaw already existed, thereby upsetting the equilibrium of forces. The crack will then continue to spread until nearly all the strains have been released. Such an internal quenching crack is shown in Fig. 31 (based on

actual cases of service failures). The shaded portion shows the original extent of the crack; the sound (unshaded) portion was insufficient to withstand the shocks and stresses in service. H. Le Chatelier (*J. I. & S. I.*, 1914, I, 247), in discussing causes of rupture in hardening by quenching, says that while he does not deny the possibility of the two causes from irregular distribution of temperature during quenching, and differences in expansion caused by non-uniform hardening, there is a third cause which is more frequent and more important. "At the moment of the transformation of the austenite into martensite, that is, gamma into alpha iron, in the solid solution, a sudden and considerable increase in volume occurred. That transformation did not take place at every point within the mass at the same moment. At each point at which it occurred, there were developed, momentarily, enormous stresses which led to cracking. After cooling they ultimately reached the same state."

Density as Affected by Heat Treatment.—"E. H. Schulz has studied the changes of volume and form of steel due to heat treatment, a subject concerning which little exact knowledge exists. The following is a summary of the author's main conclusions. In annealing, the density of carbon steel decreases as the carbon percentage increases, but the decrease is not regular, and an irregularity occurs with 0.5% of carbon. By quenching, the density is decreased by an amount which is greater as the carbon increases. Below 800 to 900° C. the volume increases rapidly as the quenching temperature is raised, but above that range the quenching temperature has little effect on the density. In the case of high-carbon steels, quenching in water always confers greater density than quenching in oil, the difference being most marked in steel containing the eutectoid proportion of carbon. The original density of the steel is never restored by annealing after quenching, but the difference of density in the two states can be reduced by successive quenching and annealing. Electrolytic copper and electrolytic iron tempered at 150° C. both show a large increase in density, due to irregularities of a purely physical nature, and the density is considerably influenced by the rate of cooling after tempering. The density of quenched steel is increased on tempering by an amount increasing with the carbon. The density-tempering temperature curves are very irregular, but all show a maximum at 430° C. (810° F.).

"In alloy steels the difference in density as between water-hardened and oil-hardened steels is not so great as in the case of ordinary carbon steels. Quenched alloy steels show no maximum at 430° C., but from that temperature upward the density increases continually. Eutectoid steels tend more than others to develop hardening cracks, on account of their greater volume changes during quenching. Bars increase in length according to the carbon content, and the increase is proportional to the length of the bar.

"When quenched from 960° C. (1760° F.) in water several of the special steels always gave hardening cracks, so that the specific gravity could not be determined. The nickel and chromium

steels show a smaller increase in volume with quenching than plain steels of the same carbon content

"This is also true of the manganese steels, although not to so great an extent, while the chromium-nickel steels shows a proportionally great change of volume. Although these results do not apply to all special steels, yet it is certain that through suitable special additions the change in volume due to quenching can be greatly reduced.

"The author considers that the change in volume brought about by quenching steel is only small if the quenching temperature be within a limit close to the critical temperature. Very great changes in volume are brought about if this limit is even slightly exceeded" (Abstr. from *Zts. Ver. deut. Ing.* in *J. I. & S. I.*, 1915, II, 303-4).

The increase in volume from quenching is due not simply to quenching strains but also to the change in density of steel from one allotropic variety of iron to another. The **temperature-density curve** shows at first a regular decrease of density on heating, then a sudden reversal through a certain range (corresponding closely with the critical), changing back again to a progressive decrease above this. Based on researches along these lines the **Packard Motor Company** has devised a process whereby they are able to (a) increase, (b) decrease, or (c) maintain constant the size of an object by selecting the suitable quenching temperature as demonstrated by means of a round plug machined so it will barely pass through a corresponding hole in a plate.

It should be appreciated that where increase of volume occurs an object tends to assume a spherical form which is known to possess the minimum superficial area for a given volume. As an illustration of this fact, a high-carbon die used in wire drawing, which was originally cylindrical, after say a hundred or more quenchings (for the purpose of restoring the hole), became nearly spherical. This accounts for the slight shortening observed in cylindrical objects, such as shafting, after quenching operations, provided excessive longitudinal strains were not set up sufficient to cause actual rupture, and which were largely removed by subsequent reheating.

We are therefore confronted with the contradictory state of affairs that the larger the section the more vigorous should be the cooling; and the more vigorous the cooling the greater the liability to excessive strains or rupture. While the component particles of the material may be advantageously affected, the object as a whole suffers. From this it is evident that for any given size or section there is a maximum relation between ductility and strength, which decreases as the dimensions increase; that if the strength is maintained constant the ductility must decrease, and *vice versa*, as discussed in connection with Fig. 29.

It must consequently be realized that the possibilities as regards the physical properties of large sections are not so great as in the case of small sections, and this must be taken into consideration in drawing up physical requirements. For, restating the case briefly, under similar circumstances:

1. The condition of the carbon and the grain size depend upon the temperature and the rate of cooling.

2. The rate of cooling depends upon the diameter or thickness of a given section, and probably also to a certain extent upon the length, or, in other words, upon the mass.

3. The rate of cooling through the critical range, and just below the lower critical point, is of much greater importance than during any subsequent tempering (after quenching).

To determine the uniformity of heating, the temperature must be of unquestioned accuracy. Further, the rate of heating must be carefully determined by experiment to secure proper penetration. It will be seen that the principles involved are comparatively simple. The main difficulty in carrying out the operations commercially is found in securing the necessary degree of uniformity. It is for this reason that special equipment is so essential. Of equal importance is the proper material, the composition of which must be definitely known, as variations, particularly in carbon, will result in different physical properties being secured under the same conditions of treatment.

Overheating and **burning** result when steel or iron has been heated to a very high temperature which is respectively moderately close and very close to the melting point. Both these effects are frequently termed overheating, but this should be avoided. The **overheating zone** and **burning zone** are the respective ranges of temperature where these effects occur. In **overheating** the grain is rendered very coarse, and the cohesion between the grains is lessened so the metal is tender; the normal condition can be restored by heat refining alone, or better, in combination with mechanical working. In **burning** the condition may range from extreme overheating to where the more fusible constituents melt and run out from between the grains, giving rise to a shower of brilliant sparks. The former condition can probably, at least partially, be corrected by heat treatment and mechanical working, but steel in the latter condition is hopelessly ruined, and is fit only to be remelted, and is said to be **oxygenated**. If high carbon steel is heated for some time, with access of air, to a temperature not necessarily high enough to cause overheating, some of the carbon becomes oxidized, and the steel is termed **roasted** or **baked**. A similar steel, repeatedly heated and hardened in time acquires a brittle exterior, which must be removed to restore its good qualities, and when in this condition is sometimes said to be **dead**. To give a piece a **short heat** means to heat it for a small portion of its length only, as where one end is to be upset or swedged in. After an object, especially of tool steel has been heated, particularly for a long time and at a high temperature, there is a skin or layer just beneath the scale, which is nearly decarburized, and is called the **bark**; this layer is sometimes as much as an eighth of an inch thick.

Hardening.—This, as commonly understood, consists in imparting to steel an appreciable or useful hardness for which a suitable grade, *i.e.*, a composition (principally carbon and certain special elements) which lends itself to this purpose, is necessary. It may

include cases where the tensile strength and elastic limit of soft steels are raised, but the line is roughly drawn to include such steels as can be made very resistant to abrasion, indentation and bending, where they are to be fashioned into cutting tools, hammers, drifts, crow bars, bearing parts, agricultural implements, and similar objects. Hardening is sometimes secured by cold working, by which means a temporary cutting edge, for example, may be given to even the softest steel or iron, but is ordinarily accomplished by heat treatment alone. In this latter case, with which we are concerned, the material is heated to above a certain critical temperature followed by rapid cooling. The degree of hardness obtained will, in general, vary directly with (a) the percentage of carbon, (b) the rate of cooling, and (c) the temperature above the critical point from which the cooling takes place. If the object is very small it may be sufficient to remove it from the source of heat and expose it to the air or a blast (air cooling, air hardening, and particularly if a blast is used, air quenching), but as a rule this is not sufficiently rapid, and in such cases the article is plunged into some liquid (quenching bath or quenching medium) or sometimes sprayed with it, to remove the heat faster; this operation is known as quenching, quenching hardening, or hardening, qualified properly by the name of the medium employed (unless clear from the context), e.g., water hardening (quenching); lead hardening (quenching). The term cooling is also used in the same manner, as water cooling, oil cooling, air cooling, etc. Water quenching is rarely called water dipping. The temperature to which the object is heated for quenching is referred to as the quenching temperature. The term quenching has been and still is commonly understood to connote the use of water, in the sense of extinguishing, as a fire, or destroying or allaying, as thirst, in both cases as with red hot iron with the idea that this was secured by removing heat. This latter meaning has most strongly persisted in the case of heat treatment, hence the extension of the term to include at first liquid media other than water, and later air, etc. While, as just stated, quenching now properly signifies the rapid extraction of heat, and is therefore commonly used in the same sense as hardening, yet manganese steel or high-nickel steel (both of which are austenitic), for example, plunged into water from a yellow heat, are quenched and toughened, but not hardened; this particular result is termed water tempering or water toughening; in contradistinction the ordinary result of quenching is referred to as quenching hardening. Tempering is sometimes employed (but confusingly) to mean the same as hardening, and in this sense the term temperability has been suggested to indicate the capability of steel of being hardened.

The temperature and the nature of the liquid determine the rate of cooling, and also the temperature to which the object may be cooled. There is no inherent or peculiar virtue or difference, *per se*, in any one medium over another, except what relates to the respective ability to extract heat and so affect the rate of cooling; in other words, it is the rate of cooling which is at

all times responsible for the results, irrespective of the means employed. Iced brine and cold water are two of the most effective, and oil and molten lead are less active in the order given. Since the effect on the rate of cooling of the two last is not so great, being similar to water hardening followed by tempering, the operations in which they are employed are frequently called **oil tempering** and **lead tempering**, but the terms **oil hardening** and **lead hardening** are preferable. As a rule, plain carbon steels where actual hardening is desired, contain carbon over 0.60%; where an increase in strength and elasticity is desired, without a material reduction in ductility, for axles, shafts, etc., the carbon is usually between 0.35 and 0.60%. The temperatures recommended by the A. S. T. M. for annealing operations are as follows:

Range of Carbon Content	Range of Annealing Temperature
Less than 0.12 %	875 to 925° C. (1607-1697° F.)
0.12 to 0.29 %	840 to 870° C. (1544-1598° F.)
0.30 to 0.49 %	815 to 840° C. (1499-1544° F.)
0.50 to 1.00 %	790 to 815° C. (1454-1499° F.)

Double hardening consists in quenching the article twice, usually in oil or water (see double quenching, page 233). Double quenching is particularly applicable to casehardened objects consisting of a low-carbon core with a high critical point, and a high-carbon case with a much lower critical point: by a preliminary high temperature quenching (**regeneration quenching**) the core is refined, followed by quenching from a lower temperature suitable for the core (**hardening quenching**). **Broken hardening**, specially applicable to tools of irregular section, such as milling cutters, consists in quenching in water until the disappearance of color and then transferring to, and completing the cooling in, oil. **Differential or decremental hardening** (sometimes called **differential cooling**) is where the entire object is heated to a hardening temperature but only a portion is hardened by quenching. For example, a common method of hardening chisels is to (a) heat, (b) plunge the point in water until cold, then (c) rub one side on a brick or piece of emery paper to get a bright surface, (d) allow the heat to diffuse from the still hot portion until the proper temper color (see below) is obtained, after which (e) the whole piece is plunged at intervals in the water to prevent further tempering, but so the cooling does not unduly harden the back part which must be relatively soft and tough. About the same result may be reached by **differential heating** (sometimes called **flash heating**), whereby only the portion to be hardened reaches a temperature above the critical, when the whole object is plunged in the quenching bath. If the piece is quenched as soon as the temperature passes the critical point, and is still rising, it is called **hardening on a rising heat**. Since the critical point on cooling is lower than on heating, it is possible, after the temperature has risen above this to hold the piece in air (or otherwise) until the temperature is slightly above the recalescent point and then

quench. Also at a temperature slightly above what is necessary for hardening, there will be greater certainty of the transformation being complete. The hardening effect will not be so great as in the former case but the lower temperature will have less tendency to set up injurious strains; this is called **hardening on a falling heat**. **Press hardening** is employed for thin objects, such as saw blades, and consists in pressing the heated object in dies which serve both to harden and to flatten it. The dies can be so shaped as not to come in contact with parts which are not to be hardened. **Crocodile skin** is the name given to the appearance resulting from oil or grease on the surface which has not entirely burned off during the heating, or leaves a deposit producing a different coloration.

Special Methods of Hardening.—**Caron's method** consists in quenching in hot water (**hot water hardening**), by which, owing to the slower rate of cooling, is secured an effect equivalent to ordinary hardening plus tempering; except with small pieces containing high carbon, a negative quenching effect (see below) will result. In **James Chesterfield's process** coiled strips or tapes are heated in a box, the end projecting through a hole. When hot enough they are pulled out and passed between water-cooled blocks, after which they are tempered by coating with oil which is burned off. In **Clémandot's process** a bar of steel heated to a bright cherry is subjected to great pressure between the faces of a hydraulic press (or otherwise). It was claimed that the steel was thereby rendered harder and of a finer grain (**refining by hardening**) than when hardened in the ordinary manner. This is sometimes called **hardening or tempering by compression or pressure hardening**. It closely resembles press hardening mentioned above. By the **Jarolimek process** the red-hot steel is held in the comparatively dense center of a spray of water until black, and then allowed to cool in the outer less dense portion of the spray at a rate which is claimed to be controllable; or, if the object is of very small size, in the air. **Chas. Gill's method of quenching** was to use easily fusible alloys, such as lead and tin, lead, or tin and bismuth, which were kept at such a temperature that a subsequent tempering operation was unnecessary. **Osmond** suggests molten zinc instead of lead as the former does not give off noxious fumes, is cheaper, and the slightly higher melting point should be more than offset by its possessing three times the specific heat. **Perret's method** (later studied by Jarolimek) was to use a blast of air loaded with water vapor. **Réaumur's process** was to harden the points of tools by sticking them into (and letting them melt) solid lumps of tin or lead. He also suggested gold, silver and copper for this purpose. **Seguin's process** consists in quenching steel, heated to a cherry red, in either (a) dilute sulphuric or hydrochloric acid, or (b) in a mixture of turpentine and water. In the **Terre-Noire process**, projectiles (which were simply cast and bored out) were heated to a red heat, the point only dipped into water until black, and the whole piece then plunged into oil and kept there until cold. This was followed by reheating to a temperature just high enough to remove the

adhering oil. **G. Theodossief's process** consists in quenching in glycerine, either pure or mixed with different proportions of water, and sometimes containing certain salts; the temperature may also be varied depending upon the nature of the steel and upon the results desired. The **Tressider process** (specially applicable for armor plate) consists in applying the quenching liquid in the form of a spray to one or both sides of the heated piece, as desired. A number of other special processes have been patented and suggested from time to time, for example: the utilization of the latent heat of fusion of various mixtures of water or lime with ice, or of ice alone (**Schneider et Cie.**); easily fusible alloys and salts; water covered with a layer of oil. **Electric hardening** consists in heating the piece by means of its resistance to the passage of an electric current, or by an electric arc, after which it is quenched as usual. Electricity may similarly be employed for heating to a lower temperature for tempering (**electric tempering**). The **Lagrange and Hoho process** depends upon the fact that the outer portion of a small piece of steel, forming the negative pole in an electrolytic solution, may be heated to a bright red by the passage of an electric current of fairly high voltage and low amperage, before the interior is sensibly affected; if the current is then interrupted, the electrolyte will serve as a quenching bath.

Tempering.—Also called **letting down, drawing, drawing back, draw-tempering** and **toughening**. Tempering is always preceded by some hardening operation, except in certain special cases where hardening and tempering are combined in one operation. The action which causes a high degree of hardening at the same time produces a considerable amount of brittleness and concomitant strain, and tempering signifies the mitigation or slight reduction of the severity of the hardening operation for the purpose of removing as much as possible of the brittleness and strain, without affecting the hardness more than is unavoidable, leaving the steel relatively hard and tough, instead of very hard and brittle. This is the earliest and preferable meaning of tempering as employed particularly for cutting tools and springs. The treatment necessary consists in reheating to a **tempering temperature** from about 200 to 300° C. (390 to 625° F.) depending upon the purpose for which the material is intended. The heating may be done in air or in some liquid, and the temperature may be measured by a thermometer or a pyrometer, or, if in air, by the oxide tints (**temper colors** or **letting down tints**) which form on a surface freed from scale. The temperatures and names (assigned by H. M. Howe) corresponding to the various colors are as follows:

Temper color.....	Degrees C.	Degrees F.
Pale yellow or straw color.....	220	428
Golden yellow.....	243	469
Purple.....	277	531
Bright blue.....	288	550
Dark blue.....	316	601

It should be appreciated that these temper colors are due to the thickness of the oxide film causing a corresponding interference of light; hence holding for a longer period serves to cause a thicker oxide film with a resulting change in appearance. The effect of time on tempering, *i.e.*, from holding at a given temperature will depend somewhat upon the temperature itself and also the degree of previous hardening. At lower temperatures the condition of metastable equilibrium is more complete, therefore, the tendency to normal equilibrium is greater.

The tempering may be effected in the case of small objects by a heated plate (**tempering plate**) of cast iron or steel upon which the objects are allowed to rest until they reach the desired temperature. **Blazing off**, **burning off**, or **oil flaring** is a method of tempering sometimes employed for springs, etc.; it consists in heating the object coated with oil, either from the quenching bath or otherwise, until it reaches a temperature just high enough to cause the oil to burn readily in the air.

In **James Horsfall's process** for tempering steel wire for pianos, etc., the wire was drawn to nearly the desired diameter, heated to redness, and quenched in water or oil. It was then plunged into molten lead; etc., until it had been sufficiently tempered, after which the drawing was completed. For other special methods of tempering see under **Hardening** (above) and **Annealing** (below). Pieces quenched in a bath, maintained at the temperature to which they would otherwise be reheated if quenched cold, are sometimes said to be **mild tempered** or **quasi tempered**.

Annealing.—This term is commonly understood to mean a reheating operation followed by slow cooling to effect one or more of the following objects: (*a*) completely undoing the effect of hardening (either thermal or mechanical), leaving the steel in its softest and most ductile condition: (*b*) removing any strains set up by too rapid cooling, particularly if the rate has been different in different parts of the piece: and (*c*) refinement of the grain. For the first two it is sufficient if the annealing temperature is below the lower critical point, say not over about 600 to 650° C. (1110 to 1200° F.), but for the last the temperature must be raised to above the upper critical point, except in special treatments preceded by quenching as described below (for refining temperatures see table on page 228). In the last case, also, the rate of cooling must be slow until the temperature is below the critical range, after which increasing the rate has no effect upon the hardening: but as rapid cooling is liable to cause strains, particularly in pieces which are large or of irregular form, it is generally slow. At times, however, to hasten the operation, when the object has become black in color it is plunged in water, which is termed **water annealing** or **negative quenching**. Ordinarily in annealing the temperature is carried to slightly above the critical point, to obtain the benefit of all three results mentioned above. As there is such a difference in the methods (and results) covered by the simple term annealing, it is customary to indicate more definitely what kind is intended: **ordinary** or **commercial annealing** is a term somewhat loosely used to mean reheating to some tem-

perature either slightly below or above the critical range followed by slow cooling either in air or otherwise according to the size of the object; where the material is to be rendered soft the terms **soft annealing**, **dead annealing** or **dead soft annealing** are used; the method of cooling may also be indicated, as **air cooling**, **furnace cooling** or **annealing**, **lime cooling** or **annealing**, etc. Where a substance such as lime or ashes is employed, the heated article is buried in it and allowed to remain until cold or nearly so; the same with furnace annealing. A form of annealing known as **normalizing** consists in reheating to a temperature above the critical range, holding at that temperature a certain length of time, and then cooling in air: it is commonly used to secure uniform conditions on material treated in various ways or where, as in the case of billets, the finishing temperature and amount of hot working have resulted in a very coarse grain; this term was suggested by Arnold, and **equalizing** was suggested by Stead as more suitable but has not come into any extended employment. **Flash annealing** or **skin annealing** is the name sometimes given to a rapid heating operation designed to soften only the outer portion or skin. Fine material, such as wire or thin sheets, is usually protected from the oxidation which would result if heated directly in the air, by enclosing in a suitable metal box or pot: this is called **close annealing**, **box annealing**, or **pot annealing**. The **Jones process** consists in annealing in boxes or retorts in which a non-oxidizing gas is maintained. In **William Smith's process** for annealing wire before finishing, the heating was conducted in a furnace in which a wall prevented the flame from striking the wire. This was subsequently taken out and allowed to cool in oxide of manganese, after which the drawing was completed.

Combined quenching and reheating operations are employed to add to the advantage of annealing in securing high ductility with almost complete absence of internal strains, those accruing from quenching consisting in smaller grain and finer condition of pearlite. These consist essentially of a quenching operation, the same as for hardening, but not necessarily so vigorous, followed by a reheating above what is employed for tempering as described above. The first step (quenching) is sometimes designated as **grain refining treatment**, and the second as **tempering**, although **toughening**, **drawing back**, **drawing**, or **reheating**—particularly **toughening**—are preferable to avoid confusion. The entire operation is also commonly referred to as **toughening**, and to indicate the quenching medium, the terms **air toughening**, **water toughening**, or **oil toughening** are used (unfortunately these last three terms are also used to indicate where hardened material is tempered to about a yellow temper color and then cooled in the give medium). **Annealing** is also used in the same sense. **Tough hardening** was the name suggested by Brinell for this treatment as applied to mild steel. **Double annealing** was first suggested by Wallerant (**Wallerant's process**) and consists of quenching in water, oil, or other suitable medium from above the upper critical point, followed by reheating to about 500 to 650° C. (930 to 1200° F.). **Negative hardening** (Osmond) is somewhat similar:

soft steel, if brittle, particularly from heating which has been too long or at too high a temperature, is rendered much more tough and ductile by heating to about 800° C. (1470° F.) and plunging it into boiling water, no hardening ensuing. This term (and **negative quenching**) is also used where the object is so large or the medium so slow in its action (*e.g.*, hot water, oil or molten lead) that hardening in any degree does not result (see special hardening processes). The **Terre-Noire process** for tempering hoops, etc., consisted in (*a*) heating to a yellow (temper color) heat, and plunging into oil; (*b*) reheating to a bright or a dull cherry red and plunging again into oil. Various processes have been devised for accelerating the rate of cooling through the critical range. **Tschernoff's process** consisted in cooling rapidly until black, for small objects in air, for larger objects oil or water depending upon the size, then finishing slowly so that during the second stage the hardening would be undone and the severe strains removed. In the **Coffin axle process** the axle is allowed to cool at the ordinary rate and is then reheated to just above the upper critical point, quenched in oil until its temperature is at the lower critical point, and then cooled in air. This treatment, besides refining the grain, also renders the axle very much tougher. In one experiment it was shown that the elastic limit had been increased by this method over 46%, the tensile strength, elongation, and reduction of area remaining nearly constant. **Coffin's rail process** consists in immersing the rail in water, immediately after leaving the rolls, until its temperature has fallen to the lower critical point, submerged jets of water playing upon the thick head to equalize the rate of cooling. It is then allowed to cool slowly in the air. **Sandberg's process** for rails is very similar to Coffin's rail process, cold air being blown on the head, after leaving the rolls. The **Kennedy-Morrison process** was devised for the purpose of giving rails a finer structure, and consisted in holding them on the tables a short time before the last pass to give them a lower finishing temperature. But as the reduction in the last pass is very slight, the effect obtained is also slight. **Garnaut and Siegfied's process** for hardening and refining bars appears to be deserving of very little consideration. It depends upon (*a*) forging a heated bar covered first with common salt, and afterward with a miscellaneous mixture, (*b*) reheating and rehammering, and (*c*) reheating and quenching in an aqueous solution of various substances.

In commercial work the furnace charge for annealing is called the **annealing charge**; for quenching, the **quenching charge**; and for drawing back or toughening after quenching, the **tempering charge** (sometimes also **annealing charge**).

Heat Treatment Crack.—See page 222.

Heat Treatment, Effect of on Density.—See pages 224 and 448.

Heat Unit.—See page 199.

Heat of Vaporization.—See page 202.

Heat Weight.—See page 201.

Heater.—(1) The man in charge of a heating furnace; (2) a piece of preheated iron laid upon an object at the part where it is to be

bent when it cannot be heated in a furnace direct; it is also used for skin-drying molds (Eng.).

Heath Process.—See page 113.

Heathfield Process.—See page 371.

Heating Coke.—See page 97.

Heating Crack.—See Crack.

Heating Curve.—See Curve.

Heating Curve Method.—Of determining critical points: see page 265.

Heating Furnace.—See page 184.

Heating Furnace Cinder.—See Slag.

Heating Methods of Etching.—See pages 286 and 288.

Heaton Process.—See page 386.

Heavy Alloy.—See Alloy.

Heavy Metal.—See Alloy.

Heberlein Pot.—See page 44.

Heerzeel and Paulis Process.—See page 386.

Helfenstein Furnace.—See page 158.

Helsby Method.—See page 503.

Helve.—See Hammer.

Hematite.—(1) Iron ore: see page 243; (2) pig iron: see page 344

Hemicrystalline Crystal.—See page 122.

Hemihedron.—See page 122.

Hemimetamorphosis.—See page 122.

Hemipelic Structure.—See page 125.

Hemiprismatic System.—Of crystallization: see page 120.

Hemitrope.—See page 124.

Hen and Chickens Method.—Of Casting: see page 61.

Henderson Process.—See page 386.

Henning's Spectral Pyrometer.—See page 208.

Heräus Furnace.—See page 158.

Hering Furnace.—See page 158.

Hérault Furnace.—See page 159.

Hess's Law.—See page 200.

Heterocellular Structure.—See page 126.

Heterochrome Photometer, Nordman's.—See page 208.

Heterogeneous; Heterogeneity.—Not of the same composition throughout; not uniform.

Heterogeneous Distribution of Carbon.—See page 213.

Heterogeneous Equilibrium.—See page 328.

Heterogeneous Steels.—See Homogeneous Steels.

Heterogeneous System.—See page 327.

Heteromorphic.—See page 122.

Heterotomous.—See page 124.

Heussler Alloys.—See Alloy.

Hewitt Process.—See page 380.

Hexad.—See page 86.

Hexagonal System.—Of crystallization: see page 120.

Hexahedrite.—See page 292.

Hexavalent.—See page 86.

Heyn and Baur's Method.—For sulphur prints: see page 288.

Heyn's Reagents.—For etching: see page 287.

- Hibbard Method.**—For fluid compression: see page 63.
- High Bloomary.**—See page 142.
- High Boil.**—See page 376.
- High Carbon Steel.**—See page 455.
- High Furnace (rare).**—Blast Furnace.
- High Gage.**—See page 186.
- High Grade.**—Sometimes used for high carbon.
- High Grade Fireclays.**—See page 396.
- High Heat Tools.**—See page 446.
- High Heat Treatment.**—In Taylor-White process: see page 446.
- High Phosphorus Steel.**—Steel containing a considerable percentage of phosphorus, or more than is permitted by the given specification.
- High Pressure Combustion.**—Using forced draft.
- High Range Mercury Thermometer.**—See page 205.
- High Resistance Steel.**—See page 443.
- High Silicon Iron; Pig.**—See pages 344 and 354.
- High Silicon Softener.**—See page 347.
- High Speed Steel; Tool Steel.**—See page 446.
- High Sulphur Steel.**—Steel containing a considerable percentage of sulphur, or more than is permitted by the given specification.
- High Temper Steel.**—See Temper.
- High Tension Steels.**—See page 443.
- Hilgenstock Process.**—See page 386.
- Hilpert and Colver-Glauert's Reagent.**—For etching: see page 287.
- Hinsdale Process.**—(1) For casting: see page 62; (2) for fluid compression: see page 63.
- Hiorth Furnace.**—See page 160.
- Hobson Pyrometer.**—See page 209.
- Hoerde Process.**—See page 386.
- Hofer Process.**—See page 141.
- Hoist.**—See page 33.
- Holborn Gas Pyrometer.**—See page 207.
- Holborn-Kurlbaum Optical Pyrometer.**—See page 207.
- Holborn and Wien Pyrometer.**—See page 208.
- Hold the Heat.**—See page 314.
- Hole.**—(1) Of a crucible furnace: see page 114; (2) in wire drawing: see page 507.
- Hole Furnace.**—See page 114.
- Holland Process.**—See page 73.
- Holley Movable (Removable) Bottom.**—See page 17.
- Hollow.**—Of steel, seamy or laminated.
- Hollow Fire.**—See page 79.
- Hollow Forging.**—See Forging.
- Hollow Pressed Axle.**—See Mercader Hollow Pressed Axle.
- Hollow Roll.**—See page 404.
- Holloway Process.**—A method for reducing metallic sulphides by blowing air through them while molten (**Bessermerizing**), the sulphur acting as the fuel to supply the necessary heat; not a success for sulphides of iron.
- Holo-** (prefix).—See page 122.
- Holoaxial.**—See page 122.

- Holocrystalline.**—See page 122.
- Holohedral.**—See page 122.
- Holoisometric.**—See page 122.
- Holosiderite.**—See page 291.
- Holosymmetric.**—See page 122.
- Holsters.**—See page 403.
- Homocellular Structure.**—See page 126.
- Homoeomorphism.**—See page 121.
- Homogeneity Test.**—See page 476.
- Homogeneous Distribution of Carbon.**—See page 213.
- Homogeneous Equilibrium.**—See page 328.
- Homogeneous Metal (obs.).**—A name formerly applied to crucible or other steel, made in a molten condition, in contradistinction to the heterogeneous condition of blister steel.
- Homogeneous Nickel Steel Armor Plate.**—See page 8.
- Homogeneous Steel (obs.).**—(1) Used occasionally to distinguish from casehardened or cemented steels; of same composition (particularly carbon) throughout; in this connection casehardened or cemented steels might be termed **heterogeneous steels**; (2) free from blowholes, solid; (3) a variety of crucible steel easily bent and worked.
- Homogeneous System.**—See page 328.
- Homogenize.**—See page 328.
- Homohedral.**—See page 122.
- Honeycombed.**—See page 55.
- Hooke's Law.**—See page 334.
- Hooked Fracture.**—See page 178.
- Hoop.**—See Coil.
- Hoop Mill.**—See page 415.
- Hopper.**—A door or trap at the bottom of a chute or shaft by means of which the contents can be dumped out or their descent regulated: see also page 32.
- Horizontal Heating Furnace.**—See page 184.
- Horizontal Regenerators.**—See page 312.
- Horizontal Testing Machine.**—See page 469.
- Horn.**—See page 430.
- Horse.**—See Salamander.
- Horseshoe Iron.**—See page 378.
- Horsfall Process.**—See page 231.
- Hot.**—(1) Of pig iron in the molten or fluid condition; molten metal; (2) of steel when it is hot enough for rolling or forging, or when it is finished at a high temperature; (3) of working, when metal is heated, in contradistinction to cold working.
- Hot Bed.**—See page 414.
- Hot Bend Test.**—See page 476.
- Hot Blast.**—See Blast.
- Hot Blast Charcoal Iron.**—See page 343.
- Hot Blast Cupola.**—See page 182.
- Hot Blast Furnace.**—See page 39.
- Hot Blast Iron; Pig.**—Pig iron smelted with hot blast.
- Hot Blastman.**—See page 38.
- Hot Blast Pyrometer.**—See page 210.

- Hot Blow.—See page 20.
- Hot Blowing Iron; Metal; Pig.—See page 20.
- Hot Crack.—See Crack.
- Hot Drawn.—Of tubes: see page 491.
- Hot Ductility.—See page 331.
- Hot Etching.—See page 286.
- Hot Flame Weld.—See page 503.
- Hot Forging.—Used only in contradistinction to cold working.
- Hot Galvanizing.—See page 370.
- Hot Hanging.—Of a blast furnace: see page 35.
- Hot Iron.—See pages 20 and 343.
- Hot Jacket.—See page 36.
- Hot Junction.—Of a thermocouple: see page 209.
- Hot Melting.—See page 376.
- Hot Metal.—Pig iron from the blast furnace before it has solidified; also called direct metal, more particularly in the sense that it is to be used in this condition in some refining process.
- Hot Punching.—See Forging.
- Hot Rolling.—Used only in contradistinction to cold working.
- Hot Saw.—A circular power saw for cutting hot steel.
- Hot Scaffold.—See page 35.
- Hot Scale.—A scale for weighing material while hot.
- Hot Short; Shortness.—See Brittleness.
- Hot Spot.—See pages 36 and 58.
- Hot Stable State.—See page 327.
- Hot-top Sinkhead.—See page 56.
- Hot Water Hardening.—See page 229.
- Hot Working.—Working metal after heating it to a suitable temperature, in contradistinction to working it cold.
- Housing; Housing Cup; Pin; Screw.—See page 403.
- Howe's Formulæ.—For elongation: see page 338.
- Howell Mill.—See page 434.
- Hudson (J. J.) Process.—See page 77.
- Hughes (Wm. B.) Process.—See page 318.
- Humbert Process.—See page 159.
- Humfrey's Amorphous Iron Theory.—Of hardening: see page 281.
- Humid Analysis; Process.—See page 82.
- Hunch Pit.—See page 316.
- Hungry.—Of pig iron rich in silicon and phosphorus; if used for puddling it requires more ore or oxides for their oxidation and removal.
- Hunt Process.—See page 380.
- Huntington-Heberlein Pot Process.—See page 44.
- Huntsman Process.—See page 113.
- Huntsman Steel (obs.).—Crucible steel, after the inventor, Benjamin Huntsman (1746).
- Husgafvel's High Bloomary.—See page 142.
- Huth Process.—See page 62.
- Hyaloid (rare).—Glassy or transparent.
- Hdraesfer Process.—See page 369.
- Hydrate Ore.—See page 244.
- Hydraulic Forging.—See Forging.

Hydraulic Press.—See Press.

Hydraulic Shears.—See page 412.

Hydrochloric Acid.—For etching: see page 287.

Hydrogen.—H; at. wt., 1; melt. pt., -257° C. (-431° F.); boil. pt., -253° C. (-423° F.); sp. gr., 0.0695 (air = 1); 1 liter weighs 0.089873 gram, called 1 **crith**. It is a colorless, odorless, and tasteless gas, and is the lightest substance known. It has a powerful affinity for oxygen and, in combination with it, occurs as water. It is absorbed or occluded by iron to a considerable extent, and tends to make the metal brittle.

Hydrogen Company's Process.—See page 370.

Hydrogen Point.—See page 264.

Hydrogen Theory.—Of passivity: see page 364.

Hydrohematite.—See page 244.

Hydro-metallurgy.—Pyro-metallurgy, *q.v.*

Hydrometer.—An instrument for measuring the specific gravity of liquids, consisting of a graduated tube, one end of which is loaded so the tube will remain upright.

Hydro-Pyrometer.—See page 207.

Hydrosiderum (obs.).—Or **wassereisen**; names suggested by Mayer (1782) for phosphide of iron which he discovered in pig made from bog ore, and which, at the time, he thought was a new metal.

Hydrothermal Fusion.—See page 201.

Hygrometer.—An instrument for measuring the percentage of moisture in gases, more particularly air; there are various types.

Hygrometric Moisture; Water.—See Water.

Hygroscopic.—Having an affinity for moisture.

Hygroscopic Moisture.—See Water.

Hyper- (prefix).—In chemistry: see page 88.

Hyper-aeolic Steel.—See page 273.

Hyper-eutectic Cast Iron.—See page 271.

Hyper-eutectic Steel.—See page 271.

Hyper-eutectoid Steel.—See page 273.

Hypertectic.—See page 269.

Hypertectic Point.—See page 269.

Hypo- (prefix).—In chemistry: see page 88.

Hypo-aeolic Steel.—See page 273.

Hypo-eutectic Alloys.—See page 271.

Hypo-eutectic Cast Iron.—See page 271.

Hypo-eutectic Steel.—See page 271.

Hypo-eutectoid Steel.—See page 271.

Hysteresis.—Retardation of magnetization (**magnetic hysteresis**).

The persistency with which certain bodies tend to retain their previous condition. Professor Ewing uses the word in a more general sense of a dissipation of energy occurring in any cycle of operations (I. A. T. M.), see pages 269 and 327.

Hysteresis Gap; Temperature.—See page 265.

I

- I.—Chemical symbol for iodine: see page 84.
- In.—Chemical symbol for indium: see page 84.
- Ir.—Chemical symbol for iridium: see page 84.
- I. A. T. M.—International Association for Testing Materials.
- I. A. T. M. Iron-Carbon Diagram.—See page 271.
- I. D.—Inside diameter.
- I. E. E.—Institute of Electrical Engineers (Eng.).
- ic (suffix).—In chemistry: see page 88.
- ide (suffix).—In chemistry: see page 88.
- Ideal Gas.—See Gas.
- Idiomorphic Crystal.—See page 122.
- Idle Roller; Idler.—See page 407.
- Igwey's Reagent.—For etching: see page 287.
- Igneous Fusion.—See page 201.
- Ignition; Ignition Point.—See page 202.
- Illingworth Method.—See page 63.
- Illumination; Illuminator.—See page 285.
- Ilmenite.—See page 245.
- Image.—See page 285.
- Imbricated Structure.—See page 126.
- Immiscible.—Incapable of mixing.
- Impact.—(1) General: see page 333; (2) coefficient of: see page 481.
- Impact Crushing Tests.—See page 481.
- Impact Energy.—See page 481.
- Impact Shear Test.—See page 482.
- Impact Stress.—See page 333.
- Impact Test.—See page 481.
- Imperatori Process.—See page 142.
- Imperfect Cleavage.—See page 124.
- Imperfect Elasticity.—See page 330.
- Imperfection.—Defect.
- Imperial Wire Gage.—See page 188.
- Impregnation.—The absorption or combination of one substance with another, *e.g.*, the impregnation of iron with carbon; sometimes used in the sense of absorbing all possible.
- Impregnation Zone.—See page 293.
- Improved Wire.—See page 509.
- Impurity.—A substance contaminating, or detracting from the purity of, another substance. It is a **mechanical** or a **chemical** impurity depending upon whether it is simply intermixed or is chemically combined.
- In Blast.—Of a blast furnace: see page 37.
- Inactive Iron.—See page 364.
- Incandescent.—Glowing with intense brilliance, *e.g.*, incandescent carbon is carbon at a white heat.
- Incandescent Welding.—See page 503.
- Incipient Combustion.—See page 202.

- Incipient Fusion, Zone of.**—See page 36.
- Inclusion.**—Something included or enclosed in a substance, such as gas or mechanically suspended foreign matter: see page 57.
- Incompatibility Theory.**—See page 289.
- Incomplete Combustion.**—See page 202.
- Incomplete Crystal.**—See page 122.
- Incomplete Equilibrium.**—See page 326.
- Incomplete Heterogeneous Equilibrium.**—See page 327.
- Incomplete Purification.**—Not carried to its greatest possible extent, as in pig washing.
- Incongruent Freezing.**—See page 267.
- Index.**—Of corrosion: see page 107.
- Indian Steel.**—See Wootz.
- Indifferent Equilibrium.**—See page 327.
- Indirect Heating Furnace.**—See page 181.
- Indirect Processes; Recovery Processes.**—In the manufacture of coke: see page 96.
- Indirect Resistance Heating.**—See page 153.
- Indistinct Cleavage.**—See page 124.
- Individual Deviation.**—Of slipping: see page 283.
- Induction Furnace; Heating.**—See page 153.
- Indurate; Induration.**—To harden; hardening.
- Inequiaxed Crystal; Grain.**—See page 217.
- Inequilibrium.**—See page 326.
- Inert Gas.**—See page 70.
- Influence of Time.**—On grain size: see page 214.
- Infusion Method of Hardening.**—See page 69.
- Infusorial Earth.**—See page 396.
- Ingate.**—See page 299.
- Ingot.**—See page 53.
- Ingot Crack.**—A crack in the side of an ingot formed during cooling.
- Ingot Iron.**—(1) The term formerly suggested for iron products low in carbon produced in a molten condition; still employed in some foreign countries in this sense; (2) a trade name for open hearth steel low in carbon and impurities.
- Ingot Metal.**—(1) Metal cast in ingots; (2) ingot iron.
- Ingot Nickel.**—See page 353.
- Ingot Steel (rare).**—Medium or high carbon steel cast in ingots.
- Ingot Tumbler.**—A receptacle mounted on a buggy to convey ingots from the soaking pits to the rolling mill. It is arranged to spill and tip the ingot out when it reaches the roll table.
- Ingotism.**—See page 57.
- Initial Stress.**—See page 333.
- Inoculation.**—See page 268.
- Inorganic Chemistry.**—See page 82.
- Inoxidizing Coating; Process.**—See page 362.
- Inset Sprue.**—See page 299.
- Inside Gage.**—See page 186.
- Insuluminum.**—See page 372.
- Intake.**—(1) The place where the gas enters a furnace; (2) in hydraulic work, where water enters a construction.
- Integral Radiator.**—See page 207.

- Intensity of Stress.**—See page 333.
- Intercrystalline Rupture.**—See page 123.
- Intergranular Cement.**—See page 281.
- Intergranular Deformation; Flow.**—See page 281.
- Intergranular Fracture.**—See page 178.
- Intergranular Motion.**—See page 282.
- Interior Shrinkage.**—See page 54.
- Intermetallic Alloy; Compound.**—See Alloy.
- Intermittent Brittleness.**—See Brittleness.
- Internal Crack.**—See Crack.
- Internal Crystal.**—See page 127.
- Internal Defect.**—See page 333.
- Internal Fissure.**—See Crack.
- Internal Force.**—See page 332.
- Internal Fracture.**—See pages 179 and 333.
- Internal Friction.**—See page 267.
- Internal Orientation.**—See page 127.
- Internal Rupture.**—See pages 333 and 491.
- Internal Strain; Stress.**—See pages 281 and 332.
- Internal Surface of Weakness.**—See page 283.
- Internal Tension.**—See page 281.
- Internally Blown Converter.**—See page 19.
- Interpenetration.**—A general term for those actions by which one portion of matter is distributed either wholly or in part through a space containing matter generally of a different kind (I. A. T. M.): see page 124.
- Interpolation.**—See Curve.
- Interrupted Cleavage.**—See page 124.
- Interstrain; Interstrain Theory.**—In connection with hardening: see page 281.
- Interstratal Movement.**—See page 282.
- Intimate Mixture.**—See page 83.
- Intra-crystalline Fracture.**—See page 178.
- Intra-crystalline Rupture.**—See page 123.
- Intra-granular Flow.**—See page 281.
- Intra-pearlitic Flow.**—See page 281.
- Intrusion.**—Material forced into a cavity from the surrounding wall.
- Intumescence.**—Particularly of certain crystals on heating; swelling up.
- Invar.**—See page 451.
- Invariant System.**—See page 327.
- Inverse Ratio.**—In testing: see page 475.
- Inversion.**—See page 271.
- Inversion Temperature.**—See pages 108 and 327.
- Inverted Molds.**—See page 59.
- Invisible.**—A name given by H. M. Howe to the condition when the interior of a furnace or crucible and the bodies contained in it are at the same temperature, and the bodies are therefore invisible.
- Inwall.**—See page 32.
- Iodine.**—One of Osmond's reagents: see page 287.
- Ion; Ionic Dissociation; Theory.**—See page 89.
- Ionid.**—See page 89.

Ireland Process.—See page 142.

Irestone.—See page 243.

Iridescent Ore.—See page 244.

Irish Temper.—See Temper.

Iron.—Pig iron, *q.v.*

Iron.—Fe; at. wt., 56; melt. pt., 1505° C. (2741° F.); sp. gr., 7.84 to 8.139. It is rarely found in the metallic condition in nature except as meteorites (*q.v.*); its chief occurrence is in combination with oxygen (see Iron Ore). The pure metal has a white lustrous appearance, does not harden appreciably on quenching, and is strongly attracted by a magnet, although it cannot itself be made magnetic except when containing carbon, or while an electric current is passed around it. The pure metal is merely a metallurgical curiosity. Nearly pure iron is now regularly produced electrolytically (see Electrolytic Iron). In certain cases combinations of iron and oxygen act as an acid to form salts. The derivatives of the hypothetical ferrous acid, $H_2Fe_2O_4$, are termed ferrites, *e.g.*, $ZnFe_2O_4$, zinc ferrite; another hypothetical acid, ferric acid (H_2FeO_4) forms salts known as ferrates. For producing pure iron **Peligo's method** was to reduce heated ferrous chloride with hydrogen, while in **Pommarède's method** zinc was substituted for hydrogen.

Irons.—See page 291.

Iron of Bessemer.—Name suggested for iron or low carbon steel made by the Bessemer (pneumatic) process.

Iron Blast Furnace (rare).—Used only to distinguish it from a copper or a lead blast furnace.

Iron Blower.—See page 492.

Iron Cancer.—See page 106.

Iron-Carbide Solution.—In hardening: see page 281.

Iron-Carbon Diagrams; System.—See page 271.

Iron Carbonyl.—See Carbon.

Iron-Cementite Diagram.—See page 271.

Iron Change.—An allotropic change occurring in the condition of iron.

Iron Company's Process.—See page 138.

Iron Glance.—See page 243.

Iron Glass.—See page 292.

Iron-Graphite Diagram.—See page 271.

Iron Hardenite.—See page 275.

Iron Hat.—See page 245.

Iron-Iron Hydroxide Eutectic.—See page 265.

Iron Ladle.—See Ladle.

Iron Man (Eng.).—A name given by workmen to certain mechanical devices which replace hand labor, such as charging machines or mechanical puddlers: see page 379.

Iron Meteorite.—See page 291.

Iron Mine.—See page 243.

Iron Mold.—See page 296.

Iron Nitride.—See page 279.

Iron Notch.—See page 32.

Iron Ochre.—See page 244.

Iron Ore.—See also Ore. Rarely called (Eng.) ironstone, iron mine, or irestone. Iron ores, as a rule, contain from 25 to 70% of iron; if less than 40% they must first be concentrated (part of the gangue removed), and if less than 25% they cannot be considered commercially, as the cost of smelting is too great. Concentration may consist in washing, *i.e.*, employing water to effect a separation according to the relative specific gravities, or, in the case of magnetic ores, by some form of **magnetic separation**, the iron being attracted by a magnet while the gangue is unaffected; in both cases the ore must be in a moderately fine condition. In the case of carbonates, or ores containing carbonaceous matter, roasting is resorted to. At the present time in this country the ores as mined average slightly over 50%, the Lake ores running higher than those in the South, sometimes over 60%. In considering the iron minerals a division is made according to whether or not they are available for the iron industry. Iron ores may be classified as follows:

I. Chemical composition:

1. Oxide.
2. Carbonate.
3. Arsenide.
4. Chromate.
5. Phosphate.
6. Sulphide.
6. Titanate.
8. Tungstate.

II. Phosphorus content (practically all the phosphorus is reduced in making pig iron): will yield pig containing:

9. Not over 0.1% of phosphorus: **Bessemer ore, acid Bessemer ore (rare), hematite (Eng.)**.
10. Over 0.1% of phosphorus: **non-Bessemer ore, basic Bessemer ore (foreign); cold short ore (Eng.)**.

III. Nature of the gangue:

11. **Silicious ore:** high silica.
12. **Dry ore (Eng.):** low silica.
13. **Calcareous ore:** high lime and bases.
14. **Red short ore:** high sulphur.
15. **Self-fluxing ore:** where the proportion of lime, magnesia, alumina, and silica are such that no addition (or very little) of flux is needed for smelting.
16. **Self-roasting ore:** where sufficient carbonaceous matter is present for roasting without the necessity for extraneous fuel.

Commercial ores:

Oxides.—(1) Anhydrous ferric oxide, Fe_2O_3 , containing when pure 70% Fe. In color it varies from a brilliant black to a brick red. It is ordinarily known as **hematite, hæmatite (Eng.), red hematite, or red iron ore**; more rarely as **red iron mine (Eng.), red mine stone (Eng.), bloodstone, or red slag ironstone (Eng.)**. On account of certain characteristics the following names are sometimes used: **specular iron ore or iron glance, when black and**

lustrous; **iridescent ore**, also lustrous, but having peacock colors, and may be hematite or limonite; **micaceous hematite**, or **micaceous iron ore**, a pure form, usually gray in color, and having a scaly structure; **oölitic ore**, having the appearance of fish eggs, consisting of particles of sand or limestone covered with ferric oxide, either anhydrous or hydrated; **pisolitic ore**, where the particles are of slightly larger size; **fossil ore**, **fossiliferous red hematite**, or **red fossil ore**, often self-fluxing; **kidney ore** or **reniform iron ore**, having the shape of kidneys; **frondescent hematite**, having a radiating structure; **martite**, pseudomorphous after magnetite; **rubble ironstone**, having a conglomerate structure.

Oxides.—(2) Hydrated ferric oxide, $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$ (the various names employed do not always indicate a definite percentage of water). They vary in color from a light yellow to a dark blackish brown, and may be soft and pulverulent or hard and compact: **Limonite**, **goethite**, **brown hematite**, **brown iron ore**, **bog ore**, **bog iron ore** or **lake iron ore** (Sweden); **turgite** or **hydrohematite** is a variety usually classed as limonite. On account of their shape, varieties are sometimes called **bean ore**, **pipe ore**, or **milliolithic ore** (granulated).

Oxides.—(3) Magnetic oxide, Fe_3O_4 (FeO , Fe_2O_3), containing when pure 72.4% Fe; a black hard mineral occurring in large masses or granulated, and strongly attracted by a magnet: **magnetite**, **magnetic iron ore**, **lodestone**, **black iron sand**, **iron sand**, or **ologist ore**.

Carbonates.— FeCO_3 , when pure containing 48.3% Fe, usually roasted to drive off the carbonic acid, when a mixture of ferrous and ferric oxides results; occurs usually in granular masses of a gray or brown color; commonly called **siderite**, **spathic ore**, **spathic iron ore**; rarely **sparry ore**, **sperry ore**, **spathic carbonate**, **chalybite**, **sphærosiderite**, **brown ore**, or **white ironstone**; on account of certain characteristics the following names have been applied: **black band** (Eng.) or **pottery mine** (North Staffordshire), contains coal and occasionally some limestone; **argillaceous siderite**, **argillaceous iron ore**, **clay band** (Eng.), **clay band ironstone** (Eng.), or **clay ironstone** (Eng.), contains considerable amounts of clay.

Minerals which have little, if any, application as a source of iron:

Arsenide.—**Leucopyrite** or **lollingite** is an arsenide of varying composition, sometimes containing nickel, etc.; **scorodite** is a combination of ferric oxide, arsenic oxide, and water.

Chromates.—**Chromite**, **chromic iron**, or **chrome iron ore**, FeO , Cr_2O_3 , is a massive black mineral resembling magnetite; it is very infusible and is used as a refractory (*q.v.*); it is the principal source of chromium.

Phosphates.—**Vivianite** or **blue iron earth** is a ferric phosphate.

Oxides.—**Franklinite**, **dodecahedral iron ore**, or **manganomagnesian magnetite**, is an oxide of iron in combination with zinc (of which it is a source) and manganese; it is a hard black mineral resembling magnetite. **Ochre**, **iron ochre**, or **red ochre** are oxides occurring in an earthy pulverulent condition, and are

used principally as paints. **Gossan, Gozzan, or iron hat** is a hydrated oxide of iron forming the cap of deposits of copper pyrites due to the mineral having been decomposed (weathered) and the copper leached out. **Laterite** is a hydrated oxide of iron occurring in India; it is soft when cut, becoming hard on exposure, and is used principally for making bricks.

Sulphides.—**Iron pyrites, pyrite, or yellow pyrites** has the formula FeS_2 ; when burned in the manufacture of sulphuric acid the residue, consisting of ferric oxide containing an extremely small percentage of phosphorus, is sometimes used in the production of low phosphorus pig, and is known as **purple ore** or **blue billy**. **Marcasite** or **white iron pyrites** has the same formula as pyrite, but differs in crystalline form. **Arsenopyrite** or **mispickel** has the formula $FeAsS$. **Pyrrhotite, magnetic pyrites, or mundic** is a combination of various sulphides of iron, and usually contains nickel, of which it is an important source. **Copper pyrites** or **chalcopyrite** is a sulphide of iron and copper, used as an ore of copper. **Melanterite** or **copperas** is crystallized ferrous sulphate, $FeSO_4 \cdot 7H_2O$.

Titanates.—**Ilmenite, menaconite** or **titanic iron ore** is composed of oxides of iron and titanium; it is used to a limited extent as an ore of iron.

Tungstates.—**Wolframite** is a tungstate of iron and manganese and is the principal ore of tungsten.

Manganese Ores.—The dividing line between manganiferous iron ores and manganese ores was formerly taken at 44% Mn. Later, ores with as little as 40% Mn have been termed manganese ores, and those below this figure, manganiferous ores. The following classification was proposed in "Memoirs of the Geological Survey of India," 1909, and is applicable to all ores containing over a combined total for manganese and iron of 50%:

	Mn%	Fe%
Manganese Ores.....	40 to 63	0 to 10
Ferruginous Manganese Ores.....	25 to 50	10 to 30
Manganiferous Iron Ores.....	5 to 30	30 to 65
Iron Ores.....	0 to 5	45 to 70

Ores of Steel was an old name applied to ores considered especially suited for the manufacture of wrought steel (as distinguished from wrought iron).

Iron Oxide.—See pages 279 and 396.

Iron Phosphide.—See page 279.

Iron-Phosphorus Diagram.—See page 272.

Iron Pyrites.—See above.

Iron of Réaumur.—Name suggested for malleable cast iron.

Iron Sand.—(1) Ore: see page 243; (2) in molding: see page 296.

Iron Side.—Of a converter: see page 18.

Iron Silicate; Silicide.—See page 279.

Ironstone; Ironstone Meteorite.—(1) Ore: see page 243; (2) meteorite: see page 291.

Iron Sulphide.—See page 279.

Irregular Contraction.—See page 222.

Irregular Fracture.—See page 179.

Irreversible Alloy ; Process ; Transformation.—See pages 265 and 327.

Irritant.—A term proposed by Dumas to describe the action of special elements present in iron alloys, chiefly the metals nickel, manganese, chromium, and tungsten, though silicon, a non-metal could be added—namely, that they were irritants to the non-metal carbon. These metals were, generally speaking, not powerful in themselves, but only when carbon was present.

Irving Furnace ; Process.—See pages 142 and 160.

Ischewski's Reagent.—For etching: see page 287.

Isobar.—The line in a diagram showing equal barometric pressure.

Isocarb.—The line in a diagram showing equal carbon content.

Isodictyal Structure.—See page 126.

Isodimorphism.—See page 121.

Isolated Crystal.—See page 123.

Isolation.—In cementation: see page 70.

Isomer ; Isomeric ; Isomeride ; Isomerism.—See pages 85 and 86.

Isometric System.—Of crystallization: see page 120.

Isomorphism.—See page 121.

Isomorphous Mixture.—See page 270.

Isophos.—The line in a diagram showing equal phosphorus content.

Isothei.—The line in a diagram showing equal sulphur content.

Isotherm.—The line in a diagram showing equal temperature.

Isothermal Freezing.—See page 267.

Isothermal Transformation.—See page 327.

Isotropic ; Isotropy.—See page 330.

Italian Process.—See page 141.

-ite (suffix).—In chemistry: see page 88.

Izod Test.—See page 482.

J.

- J. de P. Gage.**—See page 188.
- Jack Shaft.**—See page 407.
- Jacket.**—(1) The iron sheathing of a furnace; (2) the brick covering of a boiler.
- Jaggard Hardness Test.**—See page 480.
- Jamb Coke.**—See page 97.
- Japan Lacquer.**—See page 365.
- Jar Machine.**—See page 301.
- Jarolimek Process.**—See page 229.
- Jemmy (Eng.).**—A short crowbar.
- Jenkins (C. F.) Process.**—See page 373.
- Jig.**—See Ore.
- Job Pyrometer.**—See page 209.
- Jockey Weight.**—Of a testing machine: see page 469.
- Jog, Jogless.**—See Curve.
- Johnson Elastic Limit.**—See page 470.
- Johnson Process.**—For spheroidizing graphite: see page 38.
- Joint.**—See page 502.
- Joint Board.**—See page 297.
- Joint Foliation.**—See page 124.
- Joint Strength.**—See page 282.
- Joist.**—A name rarely used for a beam or I-beam.
- Joly Meldometer.**—See page 207.
- Jones and Jones Process.**—See page 380.
- Jones Mixer.**—See Mixer.
- Jones Process.**—(1) For fluid compression: see page 63; (2) of heat treatment: see page 232; (3) step process: see page 142.
- Jones' Reagent.**—For etching: see page 287.
- Josserand and Jacquet Process.**—See page 418.
- Journal.**—Of a roll: see page 403.
- Jumbo.**—The cooler for the cinder notch of a blast furnace.
- Jump.**—(1) In blast furnace practice: see page 35; (2) in connection with sheets: see page 430; (3) in welding: see page 502; (4) to upset, as the end of a bar.
- Jumper (Eng.).**—Also called monkey; (1) a dolly, *q.v.*; (2) the sparks from a ladle of cast iron.
- Jump Up (Eng.).**—Upsetting a bar, etc., or increasing the cross-section by striking it on the end.
- Junction Shaft (obs.).**—A spindle in a rolling mill.
- Juxtaposition Twin.**—See page 124.

K

- K.**—(1) Chemical symbol for potassium (Latin, *kalium*), *q.v.*;
 (2) absolute temperature scale: see page 205.
- Kr.**—Chemical symbol for krypton: see page 84.
- K. C. Armor.**—Krupp cemented armor: see page 9.
- Kalamein, Kalameined.**—See page 373.
- Kamacite.**—See page 291.
- Kaolin.**—See page 396.
- Kapfl Process.**—See page 62.
- Kathode.**—See page 89.
- Kation.**—See page 89.
- Keen Impact Ball Tester.**—See page 478.
- Keep's Test.**—(1) For cast iron: see page 483; (2) hardness test: see page 480.
- Keeper.**—See page 38.
- Keller Furnace.**—See page 160.
- Keller-Leleux Process.**—See page 160.
- Keller Test.**—See page 484.
- Kellogg Process.**—See page 492.
- Kennedy-Morrison Process.**—See page 233.
- Kentledge.**—Pig iron shipped on a vessel as ballast.
- Kern Process.**—See page 113.
- Kernel.**—See page 126.
- Kettle.**—See page 431.
- Kick In.**—See page 406.
- Kidney.**—See page 17.
- Kidney Ore.**—See page 244.
- Kieselguhr (German).**—See page 396.
- Kill.**—(1) To hold steel in a ladle, furnace, or crucible until no more gas is evolved and it is perfectly quiet; the steel is then said to be dead: see page 113; (2) in the cementation process: see page 71; (3) of wire: see page 508.
- Killeen Distributor.**—See page 32.
- Kiln.**—See page 181.
- Kilogram Calorie.**—See page 199.
- Kilogram-Centigrade Heat Unit.**—See page 199.
- Kimball Process.**—See page 73.
- Kirchhoff's Black Body.**—See page 207.
- Kirkstall Bars ; Process.**—See page 418.
- Kish.**—See Carbon.
- Kjellin-Colby Furnace.**—See page 155.
- Kjellin Furnace.**—See page 161.
- Kloman Process.**—See page 418.
- Knobbed Iron.**—Iron produced by the knobbling process: see page 79.
- Knobbling Fire ; Furnace ; Process.**—See page 79.
- Knoth Slag Process.**—See page 384.
- Knowle Process.**—See page 143.

- Kögel Mill.**—See page 418.
- Komm Method.**—See page 501.
- Konstantan.**—See page 209.
- Konstantinoff's Iron-Phosphorus Diagram.**—See page 272.
- Kourbatoff's Reagents.**—For etching: see page 287.
- Kraff and Sauve Process.**—See page 73.
- Krupp Cemented Armor.**—See page 9.
- Krupp Furnace.**—See page 114.
- Krupp Process.**—(1) For armor plate: see page 9; (2) for fluid compression: see page 63; (3) for pig washing: see page 383; (4) for steel: see page 318.
- Kryoscopy.**—Name suggested by Sauveur for that branch of metallography concerned with what happens when metallic alloys are allowed to cool.
- Kuffler Process.**—See page 370.
- Kurzwernhart and Bertrand Process.**—See page 61.
- Ladle.**—A large vessel or pot for holding, transporting, and pouring molten material. Ladles are made of steel or iron plates with suitable refractory lining, usually (a) inverted and (b) for casting and cast iron, and (c) cast iron for slag. Those for casting (iron ladle) and for slag (slag ladle) are emptied by tipping them (top pouring ladle). Those for steel (steel ladle) are practically always provided with a hole (nozzle) in the bottom (bottom pouring ladle) through which the contents are discharged. In the latter the flow is regulated by a stopper consisting of a steel rod enclosed in special hollow iron pipes (above bricks) the brick on the lower end which fits into the hole in the ladle, called the stopper head, and is generally composed of a mixture of graphite and clay; the upper end is connected with a lever on the outside of the ladle. When through faulty setting or some obstruction, the stream of steel cannot be shut off completely, it is called a running stopper. The small particle of steel which usually solidifies on the outside of the nozzle, interfering with the stream, is called a bug or fly. A full ladle is a top pouring ladle of small capacity, usually suspended under a trolley, and the filling of small molds. This is also called a shank, and the verb to shank or shank off means to fill such a small ladle from a larger one. A chilled head is one which, because of the cooling of the steel, and particularly of its solidifying round the stopper head, cannot be poured through the nozzle (except sometimes by picking it with an iron bar) and must be poured over the top of the ladle.
- Ladle Additional.**—See Recrystallization.
- Ladle Analysis.**—See page 82.
- Ladle Barrow.**—A wheelbarrow for carrying a ladle of molten cast iron in a foundry.
- Ladle Pit.**—See page 312.
- Ladle Test.**—See page 82.
- Lag.**—See page 204.
- Lagless.**—See page 206.
- Lagerung and Hono Process.**—(1) For descaling: see page 206; (2) for welding: see page 207.

L

L.—Longitudinal, of test pieces, etc.; also length.

La.—Chemical symbol for lanthanum: see page 84.

Li.—Chemical symbol for lithium: see page 84.

Lu.—Chemical symbol for lutecium: see page 84.

La Chaléassière Process.—See page 63.

Labile Equilibrium; Range.—See pages 269 and 327.

Laboratory.—(1) A place fitted up for making chemical and physical tests of material; (2) the hearth of an ordinary furnace or a blast furnace.

Lackawanna Deseaming Process.—See page 418.

Lacquer.—(1) for protection: see page 365; (2) in wire drawing: see page 508.

Ladle.—A large vessel or pot for holding, transporting, and pouring molten material. Ladles are made of steel or iron plates with a suitable refractory lining, usually (a) fire-bricks and clay for steel and cast iron, and (b) cast iron for slag. Those for cast iron (**iron ladle**) and for slag (**slag ladle**) are emptied by tipping them (**top pouring ladle**). Those for steel (**steel ladle**) are practically always provided with a hole (**nozzle**) in the bottom (**bottom pouring ladle**) through which the contents are discharged. In the latter the flow is regulated by a **stopper** consisting of a steel rod enclosed in special hollow fire-bricks (**sleeve bricks**); the brick on the lower end which fits into the hole in the ladle is called the **stopper head**, and is generally composed of a mixture of graphite and clay; the upper end is connected with a lever on the outside of the ladle. When, through faulty setting or some obstruction, the stream of steel cannot be shut off completely, it is called a **running stopper**. The small particle of steel which usually solidifies on the outside of the nozzle, interfering with the stream, is called a **bug** or **fly**. A **bull ladle** is a top-pouring ladle of small capacity, usually suspended under a larger one, to facilitate the filling of small molds. This is also called a **shank**; and the verb to **shank** or **shank off** means to fill such a small ladle from a larger one. A **chilled heat** is one which, because of the cooling of the steel, and particularly of its solidifying around the stopper head, cannot be poured through the nozzle (except sometimes by **plucking** it with an iron bar) and must be poured over the top of the ladle.

Ladle Additions.—See Recarburization.

Ladle Analysis.—See page 82.

Ladle Barrow.—A wheelbarrow for carrying a ladle of molten cast iron in a foundry.

Ladle Pit.—See page 312.

Ladle Test.—See page 82.

Lag.—See page 264.

Lagless.—See page 269.

Lagrange and Hoho Process.—(1) For quenching: see page 230; (2) for welding: see page 503.

- Lake Iron Ore.**—See page 244.
- Lake Superior Charcoal Irons.**—See page 351.
- Lamella** (pl. *Lamellæ*).—See page 126.
- Lamellar Eutectic.**—See page 269.
- Lamellar Martensite.**—See page 276.
- Lamellar Structure.**—See page 126.
- Lamina** (pl. *Laminæ*).—See page 126.
- Laminated.**—(1) Of steel, a defect where there is a separation into layers; (2) composed of separate sheets or plates in layers for armature cores and structural parts.
- Laminated Fracture.**—See page 178.
- Laminated Pearlite.**—See page 274.
- Laminated Structure.**—See page 126.
- Laminating Roller.**—An adjustable roller in a rolling mill for regulating the thickness of sheets.
- Lamination.**—See page 124.
- Lancashire Process.**—See page 77.
- Lancashire Tuyere.**—See page 31.
- Lanceolate.**—Lance-shaped; tapering gradually. This term might be discarded (I. A. T. M.).
- Landlocking Type.**—Of freezing: see page 55.
- Lane Process.**—See page 386.
- Langlade Process.**—For employing blast furnace gas for heating purposes; it consists in passing it through water to reduce the proportion of contained steam, and also to wash it.
- Langley's Bolometer; Radiation Pyrometer.**—See page 207.
- Langloan Process.**—Also called Addie process; for the recovery of tar and ammonia from the gas of a blast furnace using raw coal.
- Langmuir's Film Theory.**—See page 200.
- Lap; Lap Seam.**—See pages 405 and 426.
- Lap Weld.**—See pages 489 and 502.
- Lap-welded Pipe.**—See page 489.
- Lapper.**—Of a sheet: see page 430.
- Large Bessemer Converter.**—See page 23.
- Large Calorie.**—See page 199.
- Larkin Process.**—See page 143.
- Larry.**—A car with a drop bottom, running on a track, used for carrying ore, coal, etc., sometimes provided with scales for weighing the contents; also called **lorry**: see page 32.
- Lash-Johnson Process.**—See page 143.
- Latent Heat.**—(1) General: see page 199; (2) of fusion: see page 201; (3) of vaporization: see page 202.
- Lateral Cleavage.**—See page 124.
- Lateral Grain Boundary.**—See page 283.
- Laterite.**—See page 245.
- Lattens.**—See page 433.
- Lattice Structure.**—See page 126.
- Lauder (Geo.) Process.**—See page 21.
- Laureau Converter.**—See page 24.
- Laureau Process.**—See page 143.
- Laurent's Hypothesis.**—See page 70.
- Lauth Mill.**—See page 414.

- Lauth Process.**—See page 64.
- Laval Furnace.**—See page 161.
- Law's Method.**—For sulphur prints: see page 288.
- Lawrencite.**—See page 292.
- Le Blanc's Theory.**—Of passivity: see page 364.
- Le Chatelier Pyrometers.**—(1) Calorimetric: see page 207; (2) couple: see page 209; (3) optical: see page 207; (4) recording: see page 210; (5) thermoelectric: see page 208.
- Le Chatelier's Reagents.**—See page 187.
- Le Chatelier's Theory.**—(1) Of equilibrium: see page 328; (2) of hardening: see page 280.
- Le Fer Process.**—See page 166.
- Lead.**—Pb; at. wt., 207; melt. pt., 325° to 335° C. (617° to 649° F.); sp. gr., 11.3. It is rarely found in the uncombined state; usually in combination with sulphur or oxygen. The pure metal is bluish white in appearance, and very soft and malleable; it is possessed of only a moderate degree of strength. It is not found alloyed with iron except as an impurity. In the molten condition it is sometimes used in tempering; in combination with tin it is employed for coating thin sheets which are then called *terne plates* (see page 432).
- Lead Burning.**—Soldering: see page 505.
- Lead Hardening ; Quenching ; Tempering.**—See pages 227 and 228.
- Leading Spindle.**—See page 407.
- Leaker.**—See page 492.
- Lean.**—(1) Of ores: low grade; having a small percentage of metallic contents; (2) of clays, etc.: lacking in binding properties or plasticity; (3) of cinder: see page 35; (4) of coal: See Coal.
- Least Principal Stress.**—See page 332.
- Leckie Process.**—See page 143.
- Ledeburite.**—See page 277.
- Lees Coating ; Liquor.**—See page 508.
- Lencauchez Process.**—See page 318.
- Lenticular.**—Having the shape of a lens or lentil.
- Leplay's Hypothesis.**—See page 70.
- Lesser Calorie.**—See page 199.
- Let Down.**—(1) To dilute, *e.g.*, pig iron is let down with scrap to reduce the percentage of carbon, etc.; (2) of carbon, to reduce or remove; (3) of hardness, to remove to a certain extent by tempering.
- Letting-down Tints.**—Temper colors: see page 230.
- Leucopyrite.**—See page 244.
- Levaz Converter.**—See page 24.
- Leveling.**—Of blast: see page 34.
- Lever Shears.**—See Shears.
- Liberty, Degree of.**—See page 327.
- Lie Back.**—See page 36.
- Liebermeister Process.**—See page 143.
- Lift.**—See page 33.
- Lift Hammer.**—See Hammer.
- Lifting Table.**—See page 408.
- Light Alloy ; Metal.**—See Alloy.

Lignite.—See Coal.

Lilienberg Process.—See page 63.

Lime.—(1) Rarely the chemical element, calcium; (2) limestone, *i.e.*, the raw stone; (3) burnt lime, or the oxide; see page 396.

Lime Annealing.—See page 232.

Lime Bath.—See page 507.

Lime Cooling.—See page 232.

Lime Dinas Brick.—See page 395.

Lime Set.—See page 35.

Limestone.—(1) As a flux: see page 175; (2) as a refractory: see page 396.

Liminate Roller (Eng.).—Same as laminating roller, *q.v.*

Liming.—See pages 342 and 507.

Limit Gage.—See page 186.

Limit of Linear Elasticity; Proportionality.—See page 334.

Limiting Concentration.—See page 108.

Limiting Stress.—See page 333.

Limonite.—See page 244.

Lindenthal Process.—See page 318.

Lines.—Of a blast furnace: see page 27.

Line Down; Line Up; Liner.—See page 414.

Lining.—(1) Of a blast furnace: see page 27; (2) in puddling: see page 376; (3) of rolls (verb): see page 414.

Lining.—The inside portion or skin; in a furnace, etc., that portion which comes in contact with the charge and protects the walls proper from fusion or corrosion. They must be of such a nature as not to be softened appreciably at the temperature employed, and, as a rule, should be only slightly affected (if at all) by the components of the charge. They may be of metal (*e.g.*, cast iron for ladles which hold blast furnace slag), but generally consist of earthy material applied in a crushed condition, or as rocks or bricks. **Acid linings** may be of sand, silicious rocks, or silica bricks; **basic linings**, of crushed burnt dolomite, or magnesite (more rarely of lime), magnesite bricks or basic slag, etc.; **neutral linings** of coke or chrome ore either crushed or in bricks. Linings for most types of furnace are applied in a crushed condition, sometimes moistened with a little water, or mixed with a little pitch or tar, and sintered or set in place by the high temperature to which they are exposed. **Basic bottoms, slag bottoms, cinder bottoms, or oxide bottoms** for heating furnaces consist of scale, cinder, or ore. Owing to the scale which melts and runs off the pieces of iron or steel being heated, the bottom in time becomes excessively thick, and is occasionally reduced to the proper proportion and also leveled off by raising the temperature until a sufficient amount has been melted off. If the bottom has a slope, so that nearly all the scale runs out of the furnace as fast as it forms, it is called a **dry bottom**; if allowed to collect and tapped out only at intervals, a **wet bottom**, or **fluid bottom**. **Acid bottoms** or **sand bottoms** are composed of various grades of sand which usually contain enough impurities to cause them to set. Their thickness is gradually increased by the melted scale from the metal, in spite of the fact that this causes a certain amount of cor-

rosion. They are leveled off by throwing in a little coke and by raising the temperature, the joint action serving to melt and flux away the upper layers. A **coke bottom** is made of crushed coke rammed into place, usually mixed with a little cinder or tar to cause it to set when heated; in the case of soaking pits, crushed coke or coke dust is loosely thrown on the bottom of the pits.

Linkage Formula.—See page 86.

Lintel Plate.—See page 27.

Lip.—The depression in the edge of a ladle through which the contents are poured.

Liquation.—See pages 55 and 68.

Liquid Blacking.—See page 298.

Liquid Cements.—See pages 67 and 69.

Liquid Compression.—See page 63.

Liquid Contraction.—See page 53.

Liquid Crystal.—See page 123.

Liquid Furnace.—Containing a molten bath, such as a fused salt or metal, in which the object is submerged; used particularly in heat treating work.

Liquid Solution.—See page 270.

Liquid Squeezed.—See page 64.

Liquid State.—See page 81.

Liquidoid.—See page 270.

Liquidus; Liquidus Curve.—See page 268.

Liquor-Bright Process.—See page 508.

List; List Pot.—See page 432.

Lithosiderite.—See page 291.

Littoral Region.—In the freezing of alloys: see page 54.

Live Load.—See page 468.

Live Pass.—See page 405.

Live Roller.—See page 407.

Lively.—Of molten steel in the ladle or molds: bubbling or rising to a certain extent, due to the evolution of gas.

Load.—See page 332.

Loading Test.—See page 477.

Loam.—See pages 296 and 396.

Loam Brick; Cake.—A slab or cake of loam used in molding.

Loam Molding.—See page 300.

Local Elastic Limit.—See page 282.

Local Elongation.—See page 474.

Localized Corrosion; Selective Corrosion.—See page 106.

Lock Joint.—A joint or seam in tubes, sheets, cans, etc., produced by folding the edges over together.

Locus (pl. Loci).—See Curve.

Lodestone.—See page 244.

Logometer.—See page 208.

Lohmann Bath; Process; Lohmannizing.—See page 373.

Lollingite.—See page 244.

Lombardy Process.—See page 78.

Long-tailed Monkey.—See Monkey.

Long Ton.—See Ton.

Long Tuyere Converter.—See page 24.

- Longitudinal Rolling.**—See page 414.
- Longitudinal Seam.**—See Seam.
- Longitudinal Test Piece.**—See page 469.
- Look over a Heat.**—In crucible practice: see page 114.
- Loop.**—See page 135.
- Looping; Looping Mill.**—See page 416.
- Lorry.**—See Larry.
- Lost Head.**—See page 299.
- Lost Pass.**—See page 405.
- Lost-wax Process.**—See page 301.
- Loup.**—See page 135.
- Low.**—Of springs which upon testing are more or less flattened (not good).
- Low Carbon Steel.**—See page 455.
- Low Gage.**—See page 186.
- Low Grade.**—Sometimes used for low carbon.
- Low Grade Fireclays.**—See page 396.
- Low Heat Treatment.**—In the Taylor-White process: see page 446.
- Low Phosphorus Pig.**—See pages 344 and 346.
- Low Process.**—See page 118.
- Low Steel (rare).**—Soft or low-carbon steel.
- Low Temper Steel.**—See Temper.
- Lower Freezing Point.**—See page 267.
- Lowering Temperature.**—See page 447.
- Lucas Process.**—See page 143.
- Lüders Lines.**—See page 283.
- Ludlum Furnace.**—See page 162.
- Ludwik's Method.**—For determining hardness: see page 478.
- Lug.**—A knob or projection on a smooth surface used for picking it up, etc.
- Lugging (Eng.).**—Of material which tears or does not cut crisply.
- Lump.**—(1) The ball from a direct process: see page 135; (2) a product in puddling (obs.): see page 378; (3) a piece of ganister, etc., forming part of a refractory lining: see page 395.
- Lumpy.**—Of rails, or bars, short kinked or wavy.
- Lurmann's Closed Front Arrangement.**—See page 32.
- Lurmann Front.**—See page 32.
- Luster; Lustre.**—A term used in describing the character of the reflections obtained from the fractured surfaces of minerals and rocks (I.A.T.M.).
- Lute.**—A mixture of fireclay, etc., used to seal up cracks when heat is to be applied, *e.g.*, between a crucible and its cover to make an air-tight fit; also the operation.

M

- Mg.**—Chemical symbol for magnesium, *q.v.*
- Mn.**—Chemical symbol for manganese, *q.v.*
- Mo.**—Chemical symbol for molybdenum, *q.v.*
- M. C. B.**—Master Car Builders (association).
- M. P.**—Melting point.
- McCance's Interstrain Theory.**—Of hardening: see page 281.
- McClenahan Process.**—See Flux.
- McCloud Process.**—See page 419.
- McConnell (Niven) Process.**—See page 318.
- McDonald Distributor.**—See page 32.
- McHaffie Process.**—See page 258.
- McKenna's Formula.**—For quality: see page 340.
- McKenna Process.**—See page 419.
- Machine Cast Pig.**—See page 342.
- Machine Molding.**—See page 301.
- Machine Puddled.**—Wrought iron made in a mechanical puddler: see page 379.
- Machining.**—See Cold Working.
- Macintosh Process.**—See page 73.
- Macle.**—See page 124.
- Macro-Metallography.**—See page 263.
- Macroscopic.**—Or **megascopic**: a term used in contradistinction to microscopic, to imply that the character in question is visible to the naked eye (I. A. T. M.).
- Macroscopic Analysis.**—See page 284.
- Macroscopic Etching.**—See page 286.
- Macroscopic Metallography.**—See page 263.
- Macroscopic Strain.**—See page 280.
- Macroscopic Structure.**—Or **macrostructure**: see page 289.
- Macroscopically Amorphous.**—See page 127.
- Macrostructure.**—See page 289.
- Macrostructure Etching.**—See page 286.
- Magdolite.**—See page 397.
- Magma.**—See page 125.
- Magnesia.**—(1) As a flux: see page 175; (2) as a refractory; see page 396.
- Magnesia Brick.**—See page 397.
- Magnesian Limestone.**—See page 397.
- Magnesite ; Magnesite Brick.**—See page 396.
- Magnesium.**—Mg.; at. wt., 24; melt. pt., 632.6° C. (1141.9° F.); sp. gr., 1.7. It is a silvery white metal with a very strong affinity for oxygen, for which reason it is employed as a deoxidizer for copper; in the case of steel, however, it has not proved to be as satisfactory as aluminum, as the reaction is very violent.
- Magnet Steel.**—See page 450.
- Magnetic Alloy.**—See Alloy.
- Magnetic Analysis.**—See page 284.

- Magnetic Concentration.**—See Ore.
Magnetic Hardness.—See page 450.
Magnetic Iron Ore.—See page 244.
Magnetic Method.—For determining critical points: see page 266.
Magnetic Oxide Theory.—Of puddling: see page 378.
Magnetic Pyrites.—See page 245.
Magnetic Separation.—See Ore.
Magnetic Steel.—See page 450.
Magnetic Transformation.—See page 264.
Magnetite.—See page 244.
Magnite.—See page 399.
Magnobrent.—See page 399.
Main Spindle.—See page 407.
Major Calorie.—See page 199.
Major Shrinkage.—See page 54.
Make Bottom.—See page 313.
Make a Cast; Heat.—Melting iron in a cupola for foundry work.
Malleability.—See page 331.
Malleable.—(1) Malleable castings (*q.v.*); (2) pig iron suitable for making into malleable castings: see page 346.
Malleable Bessemer.—See page 346.
Malleable Cast Iron.—See below.

Malleable Castings.—Also called **malleable iron**, **malleable cast iron**, **malleable**, or **malleablized cast iron**; more rarely **temper (tempered) castings** or **run steel**. They are castings in which the combined carbon of white cast iron has been converted into an amorphous, uncombined condition by special heat treatment without fusion, leaving the iron soft and to a certain extent malleable. The process was discovered by Réaumur, and hence the product was at one time known as **Réaumur iron**. The carbon exists in small spots or patches which do not break up the continuity of the iron matrix nearly so much as the large thin plates of graphite in ordinary gray cast iron which serve as cleavage planes. This form of carbon is termed **temper carbon** or **temper graphite**, more rarely **annealing carbon**.

The process consists essentially in heating white cast iron castings (**hard castings**), in which practically all the carbon is in the combined condition, to a temperature above about 750°C . (1380°F .), but below its melting point, say under 1100°C . (2010°F .), when the conversion of the carbon to the amorphous uncombined condition takes place, apparently due principally to the silicon (assisted by the heat) of which a certain percentage must be present. If the castings are heated too hot, and in consequence become softened and deformed, they are said to **fall**. A mixture of pig iron to give the desired composition is melted in a cupola, an air furnace (reverberatory), or a furnace similar to that used in the open hearth process, and is then poured into the molds. When an open hearth furnace is used, and it is first put into service, the initial heat, called a **pill heat**, is usually cast into pigs for remelting, as it is not certain whether the metal will be satisfactory. When the charge consists chiefly of runners and defective castings, it is termed a **sprue heat**.

The castings are usually less than an inch in thickness, so the cooling will be sufficiently rapid to prevent the formation of graphite. The original shrinkage is about double that of gray castings, but about half of this is recovered upon annealing. After cleaning, they are packed in some material, such as ore or clay, contained in a box called a **sagger** or **annealing pot**, to protect them from the air and so prevent excessive formation of scale which would produce what are termed **scaled castings**. **Réaumur's process** ("of softening cast iron"), which is also that used principally abroad (hence, **European** or **old European process**), employs new iron ore which causes, in the case of thin castings, most of the carbon to be oxidized and removed (**decarbonizing process**), so that, on breaking, the fracture is nearly white throughout (**white-heart malleable** or **casting**). In this country (**American process**) the packing material is generally made up of two or three parts of old ore (**burnt ore** or **spent ore**), which has only a slight oxidizing effect, and one part of new ore. This restricts the oxidation of the carbon to that in the outer layers, so that the carbon in the interior is simply changed to the amorphous condition, and the fracture shows a white outside skin with a black interior, from which comes the name **black-heart malleable** or **casting**.

The heating operation (**annealing**) requires a number of days and is performed in an annealing furnace or oven, the boxes being arranged so the flame may play around them as completely as possible; the flame usually enters at the top of the furnace and leaves at the bottom along the side, and then passes through flues underneath.

In the **Terreault and Hilzinger process** the cast iron is melted in crucibles with about 0.25% of sodium chloride and the castings are poured in the ordinary way. They are then placed in annealing boxes and packed in scale which has first been soaked in a 7.5% solution of ammonia (*J. I. & S. I.*, 1911, I, 605). The **McHaffie process** does not appear to differ essentially from ordinary practice.

Malleable Coke Iron.—See page 345.

Malleable Iron.—(1) Wrought iron; (2) malleable cast iron: see above; (3) pig iron suitable for making into malleable castings: see page 346.

Malleable Pig Iron.—See page 344.

Malleable Wrought Iron.—Wrought iron, *q.v.*

Malleablized Cast Iron.—See page 257.

Manganese.—Mn; at. wt., 55; melt. pt., 1207° C. (2200° F.); sp. gr., 7.42. It is found in combination with oxygen, and usually in conjunction with iron. The pure metal has a grayish white color, with a slight tinge of red, and is hard and brittle. It is obtained as an alloy with iron called ferro-manganese or spiegel, rarely manganese (see page 352), and very recently with silicon, called silico-spiegel (see page 354). It has a stronger affinity for oxygen and sulphur than has iron. Next to carbon it is the most important constituent of steel. In ordinary amounts its most valuable property is in removing oxygen existing in the steel

either as a gas or in direct combination as oxide (see page 393). As a desulphurizing agent, see page 386. In ordinary steel the manganese varies from about 0.30 to 1.00%; below 0.30 the removal of oxygen does not seem to be sufficiently thorough (except with steel made in a crucible or in an electric furnace, etc.), while above 1.50%, and up to about 6 or 7%, the hardness and the brittleness under shock increase so rapidly that the material is not of commercial value. Above the limit mentioned, and up to about 15%, a curious reversal takes place, the metal remaining very hard, but becoming tough upon suitable treatment; this metal is called manganese steel (see page 451). Above about 16 or 17% the metal becomes more brittle again. Manganese in increasing amounts raises the saturation point of iron for carbon. For influence on corrosion: see page 366.

Manganese Additions.—See Recarburization.

Manganese Carbide.—See page 279.

Manganese Carbon Iron; Steel.—A term rarely employed for ordinary steel or cast iron containing not over about 1.50% or 2.00% of manganese, to distinguish it from manganese steel which has over about 10% of manganese.

Manganese Ore.—See page 245.

Manganese Silicate.—See page 279.

Manganese Spot.—See Hard Spot.

Manganese Steel.—See page 451.

Manganese Steel Lines.—See page 127.

Manganese Sulphide.—See pages 279 and 289.

Manganic.—Manganese in chemical compounds having the higher valence III.

Manganiferous.—Containing or carrying manganese.

Manganiferous Cementite.—See page 279.

Manganiferous Iron Ore.—See page 245.

Manganin.—See page 209.

Mangano-Ferrite.—See page 272.

Mangano-Magnesian Magnetite.—See page 244.

Manganous.—Manganese in chemical compounds having the lower valence II.

Mangle (Eng.).—A set of straightening rolls for plates, etc.

Manipulator.—See page 411.

Mannesmann's Equilibrium Diagram.—See page 272.

Mannesmann Process.—See page 490.

Mantle (Mantel) Ring.—See page 27.

Manufacturing Coal.—See Coal.

Many-blow Test.—See page 482.

Marcasite.—See page 245.

Marel Brothers Process.—See page 64.

Margarite Structure.—See page 125.

Mariotte's Law.—See Gas.

Marking.—**Branding:** where rolls are engraved and brand appears on rolled piece in raised characters; **stamping:** where characters are forced into the surface. Both are called **marking** which also includes painting, tagging or other means of identification.

Marquette d'Encrenée (Fr.).—See page 135.

- Martens and Heyn's Reagent.**—For etching: see page 288.
- Martens' Reagents.**—For etching: see page 287.
- Martens Test.**—For hardness: see page 480.
- Martensite.**—See pages 275 and 276.
- Martensite Carbon.**—See page 276.
- Martensite Steel.**—Steel containing gamma iron.
- Martensitic Special Steels.**—See page 445.
- Martensitization.**—See page 276.
- Martensitizing Methods of Hardening.**—See page 279.
- Martien Process.**—See page 386.
- Martin and Beavis Mill.**—See page 420.
- Martin Furnace.**—See page 310.
- Martin Process.**—See page 310.
- Martin-Siemens Process.**—See page 310.
- Martin-Siemens Steel.**—Open hearth steel.
- Martite.**—See page 244.
- Mass Effect.**—On the physical condition of material: see page 219.
- Massenez Process.**—(1) For steel: see page 22; (2) for desulphurizing: see page 386.
- Massive.**—Amorphous; not crystalline.
- Massive Cementite.**—See page 273.
- Massive Ferrite.**—See page 272.
- Massive Magnesite.**—See page 397.
- Massive Structure.**—See page 125.
- Massut (Russian).**—The residue from the distillation of crude petroleum at a temperature of about 300° C. (572° F.); it has a specific gravity of about 0.90 to 0.91, and burns in an open vessel at about 100° to 130° C. (212° to 266° F.); it has a calorific power of about 10,000 calories, and is composed of about 87% of carbon, 12% of hydrogen, and 1% of oxygen.
- Matcher; Matching.**—See page 430.
- Mathias Deseaming Process.**—See page 418.
- Matrix.**—(1) The die or mold used to give the desired form to an object; (2) in metallography, the ground mass or principal substance in which a constituent is embedded.
- Matter.**—(1) Definition: see page 81; (2) state of: see page 81.
- Matthiessen Process.**—See page 143.
- Matweieff's Reagent.**—For etching: see page 287.
- Maul.**—A large wooden hammer used for flattening plates while hot; a beetle.
- Maximum Fiber Stress.**—See page 337.
- Maximum Load; Stress.**—See page 335.
- Maximum Temperature.**—And grain size; see page 213.
- Meager Coal.**—See Coal.
- Mean.**—Average or normal.
- Mean Calorie.**—See page 199.
- Mean Stress.**—See page 333.
- Mechanical Amorphizing.**—See page 282.
- Mechanical Brittleness.**—See Brittleness.
- Mechanical Equivalent of Heat.**—See page 204.
- Mechanical Hardness.**—See page 331.

- Mechanical Impurity.**—See Impurity.
- Mechanical Methods of Etching.**—See page 286.
- Mechanical Mixture.**—See page 83.
- Mechanical Process.**—Working, as rolling or forging, as distinguished from some chemical or metallurgical process.
- Mechanical Puddler; Puddling Furnaces; Rabble.**—See page 379.
- Mechanical Refining.**—Improving the quality of steel or wrought iron by reducing the size of the grain by working the metal while cooling until the temperature has about reached the critical point; sometimes called hammer refining: See page 216.
- Mechanical Stirrer.**—See page 379.
- Mechanical Thermometer.**—See page 205.
- Mechanical Tinning Pot.**—See page 432.
- Mechanical Treatment.**—For producing solid castings: see page 59.
- Mechanical Twin.**—See page 124.
- Mechanical Working.**—Usually referred to in connection with its effect on the physical properties as distinguished from that produced by heat treatment alone.
- Mechanically Combined Water.**—See Water.
- Mechanico-chemical Methods of Etching.**—See page 288.
- Medicine Room.**—See page 115.
- Medium Carbon Steel.**—See page 455.
- Medium Grade Fireclays.**—See page 396.
- Medium Steel.**—See page 455.
- Medium Temper Steel.**—See Temper.
- Megascopic.**—Macroscopic, *q.v.*
- Meiler.**—See Charcoal.
- Melanterite.**—See page 245.
- Meldometer, Joly.**—See page 207.
- Mellen Rod-casting Process.**—See page 65.
- Melloni Thermopile.**—See page 207.
- Melt.**—(1) To fuse; (2) a heat or charge of steel.
- Melt High; Low.**—See page 314.
- Melter.**—The man in charge of a crucible furnace, cupola, or open hearth furnace.
- Melting.**—See page 201.
- Melting Down Refinery; Melting Finery.**—See page 383.
- Melting Furnace.**—Any furnace in which metals can be melted, more especially cast iron.
- Melting Heat.**—See page 71.
- Melting Hole.**—Of a crucible furnace: see page 114.
- Melting House (Eng.).**—A department in a steel works for making crucible steel.
- Melting Point.**—See page 201.
- Melting Point Curve.**—See Curve.
- Melting Point Pyrometry.**—See page 209.
- Melting Refinery.**—See page 383.
- Menacconite.**—See page 245.
- Mendeleeff's Periodic Law.**—See page 85.
- Mercader Hollow-pressed Axle.**—An axle produced by a process somewhat similar to the Erhardt process. A heated, round

blank, after removal of the scale in a set of cross rolls, is placed in a die having the shape of the finished axle, and a punch is forced (hydraulically) into each end, to a depth sufficient to displace enough metal to fill out the die and also upset the metal at the end for the collars. A few axles were made and placed in service, but the process never really got beyond the experimental stage, due principally to difficulty in keeping the punches concentric with the axis of the axle.

Merchant.—In general, an adjective used to denote material which is finished or for sale, also the appliances for its production.

Merchant Bar.—See page 378.

Merchant Furnace.—See page 39.

Merchant Mill.—See page 409.

Mercurial (Mercury) Thermometer.—See page 205.

Merging.—See page 120.

Merging of Critical Points.—See page 264.

Merit Number.—See page 340.

Meritens (A. de) Process.—See page 369.

Merriman's Formulæ.—For tensile strength: see page 338.

Merrit Plate.—See page 135.

Mesh Structure.—See page 126.

Mesosiderite.—See page 291.

Mesuré and Nouel's Pyroscope.—See page 208.

Metacryst.—See page 122.

Meta-Element.—See page 81.

Metal.—(1) Any metallic element in its reduced form: see page 83; (2) pig iron or steel, more particularly the former, when the meaning is obvious; (3) the product of a refinery: see page 383.

Metal Notch.—See page 32.

Metal Sponge.—See Alloy.

Metal Spraying.—See page 373.

Metal Stove.—See page 34.

Metallic.—Having the properties of a metal, more especially the physical ones, such as luster, opacity, ductility, etc.

Metallic Alloy.—See Alloy.

Metallic Cementation.—See pages 66 and 370.

Metallic Coating.—See page 370.

Metallic Fog.—See page 128.

Metallic Luster.—See page 83.

Metallic Nickel.—See page 353.

Metallic Solid Solutions.—See page 270.

Metallic Thermometer.—See page 205.

Metallicity; Metalleity.—Condition or quality of being metallic.

Metallifacure (obs.).—Metallurgy.

Metalliferous.—Containing a metal, as an ore or deposit.

Metallify.—Smelt or reduce into a metal.

Metalline.—Metallic.

Metallize.—(1) To coat with a metal; (2) to convert or reduce to the metallic state, as an ore; (3) to impregnate with metallic or mineral substances, as wood.

Metallographic Examination.—See page 284.

Metallographic Method.—For determining critical points: see page 265.

Metallography.—That branch of metallurgy which treats of the constitution and the structure of metals and alloys, and their relation to the physical properties. This definition covers the very broad field which it is now recognized that metallography occupies, and any method of research may be employed. When it was a comparatively new science, however, it was familiarly supposed to be concerned principally with the visual examination of the structure of metals and hence was divided into **microscopic** or **micrometallography** where the microscope was employed to secure high magnifications, and **megascopic**, **macroscopic** or **macrometallography** where the naked eye or very low magnifications were used.

The following are briefly the principal events, in their chronological order, which are responsible for our present knowledge of the subject:

1864. Sorby (British Assoc.) published his work on the microscopic examination of iron and steel, which he had commenced the preceding year. This did not bear any fruit until after 1887, in which year he read, by request, a paper on the subject before the Iron and Steel Institute.

1869. Gore (*Proc. Roy. Soc.*) published the results of his experiments on the dilatation of steel at high temperatures. The method employed was a wire stretched horizontally which, by means of a series of levers, indicated the amount of expansion or contraction during heating or cooling. At a dark red, he found on cooling a greater dilatation than immediately above or below that temperature. He called this phenomenon recalescence, because of the momentary brightening which accompanied it. He did not, however, observe the reverse effect during heating.

1873. Barrett (*Phil. Mag.*) carefully checked the work of Gore and found the reverse effect occurred during heating at nearly the same temperature as during cooling. He noted that this point was slight in the case of soft steels.

1880. Hogg stated that quenched steel showed less carbon by the Eggertz color method than the same steel annealed. About this time iron carbide, Fe_3C , was isolated from annealed steel by Weyl, Abel and Mueller.

1885. Osmond and Werth (*Ann. d. Mines*) published their paper on the cellular theory of steel.

In the years immediately following Osmond (*Mem. Artil. et Mar.*) gave the results of his experiments on the transformation of iron and carbon, employing cooling curves obtained by means of a Le Chatelier electrothermic pyrometer.

1886. Pionchon made experiments on the specific heats at different temperatures certain seeming anomalies pointing to allotropic transformations.

1890. H. Le Chatelier published variations in electrical resistance at different temperatures, confirming the results obtained by other methods.

1895. Osmond published (*Bull. Soc. d'Enc.*) his classical

monograph on the "General Method for the Microscopical Examination of Carbon Steels."

1899. Roberts-Austen plotted the first iron-carbon diagram, corrected and amplified by Roozeboom, the following year, on the basis of the phase rule.

Other investigators to whom particular tribute must be paid are Howe, Sauveur, Stead and Arnold.

Iron or steel, when solid, consists of grains or crystals the size of which depends upon the heat treatment and the mechanical treatment they have received. Ordinarily iron or steel is not homogeneous, but is composed of a variety of substances or **constituents** (in the same way that rocks are made up of different minerals) depending upon (a) the proximate chemical composition, and (b) the heat treatment. "The **microscopic constituents** of steels are divided into those that are chemically homogeneous (**metaral**) and those that are chemically heterogeneous (**aggregate**)" (I. A. T. M.).

Allotropic Modifications.—Metallography is based on Osmond's demonstration (**Osmond's theory, allotropic theory**) that iron is susceptible of three allotropic varieties or modifications known respectively as **alpha (α) iron, beta (β) iron, and gamma (γ) iron**, each being normal for a given range of temperature and conditions.

Transformations and Critical Points.—It has been known for some time that the rate of cooling or heating does not always proceed uniformly, but that at certain temperatures (which may vary with different compositions) **retardations** occur, and these are termed **arrestation points, critical points (critical temperatures), transformation points, or transition points**. These are caused by physical changes whereby heat is liberated on cooling and absorbed on heating. There are three principal critical points for iron designated A_1 , A_2 , and A_3 , A_1 being at the lowest temperature. On account of **molecular inertia or lag** (Howe), the changes occur at lower temperatures on cooling than on heating unless the rates are infinitely slow. The transformation at A_2 is also referred to as the **magnetic transformation**. To indicate such conditions Howe has called these theoretical points **Ae**, etc., (*e* standing for equilibrium). In certain grades of iron two or even all three points may occur at the same temperature (**merging of the critical points**), and to show this they are written, e.g., Ar_{3-2} , Ar_{3-2-1} . For hypereutectoid steel Sauveur suggests for the upper critical point "the symbol **A_{cm}** (**Ar_{cm}** on cooling and **Ac_{cm}** on heating), *cm* standing for cementite. At least one writer, however, has designated this point on cooling by the notation **Ar_{mc}**, *mc* standing for massive cementite" (Sauveur, *Metallography*, 166). A point found by Roberts-Austen between 550 and 600° C. for iron and soft steel he called **Ar₀**. "Roberts-Austen detected another evolution of heat in pure iron between 450 and 500° C., the existence of which he ascribed to the presence of hydrogen (**hydrogen point**) resulting in a separation of hydroxide of iron taking place at this critical point. Finally the same observer described one more slight evolution of heat in pure iron

at about 270° C. which he tentatively ascribed to the formation of an iron—iron hydroxide eutectic (*ibid.*, 167). Brinell used the letter *W* for the upper point and *V* for the lower point of the hardening or transformation. Tschernoff used the letter *A* to indicate the temperature above which hardening could be produced by quenching, but below which hardening could not be produced. In some cases a retardation may occur not simply at or near one temperature but over a more or less extended range (critical range or interval, etc.). The rate at which a transformation occurs is known as the speed or velocity of transformation. In some cases while cooling through Ar_1 , there is such a liberation of heat that the temperature may be raised slightly and in the dark a sudden glowing can be observed; this phenomenon is termed *recalescence* (the piece is said to *recalesce*) or rarely *calescence* or *Gore's phenomenon*, and the temperature at which it occurs, the *recalescent point*; to indicate the reverse effect on heating, it is sometimes called the *decalescent point*, *absorption point* or *temperature*, and without reference to heating or cooling respectively the *calescent point*. At this point a softening action takes place which is shown by *Coffin's bend*: if an iron bar, heated above Ar_1 is supported at its ends only, and then allowed to cool, when the temperature reaches Ar_1 it will bend, although this does not occur just above or just below. Alloys (and transformations), where there is a very wide interval (temperature interval, hysteresis temperature, hysteresis gap) between the temperature of the critical point on heating and cooling are said to be *non-reversible* or *irreversible*; where the interval is not so marked, and in contradistinction, *reversible* (Sauveur suggests 100° C. as an arbitrary limit).

Commercial iron is never pure, and the elements (including iron) of which it is composed may exist (a) in chemical combination, forming definite chemical compounds, (b) in solution (solid solution: see below); where one element or substance is dissolved in another in varying proportions, and (c) as mechanical mixtures of elements or compounds. The most important element to be associated with iron is carbon, which has a wider effect on iron than any other, and even when special elements such as nickel, chrome, etc., are introduced its influence still predominates or governs those of the others. A consideration of the various relations between iron and carbon is therefore necessary, not only because they are always in evidence, but also because it will serve to explain the relations of other elements.

Determination of Critical Points.—These may be listed as follows:

(1) **Thermal or cooling and heating curve methods:** Changes in the rates of cooling or heating. Various methods of determination have been devised and also for plotting the corresponding values of time and temperature.

(2) **Calorimetric methods:** Determining the amount of heat evolved at different temperatures.

(3) **Metallographic methods:** Examination of the structure resulting by quenching from various temperatures.

(4) **Thermo-electric methods:** Changes in the thermo-e.m.f. of the specimen and copper when at different temperatures.

(5) **Magnetic method:** Changes in the thermo-magnetic properties.

(6) **Dilatation methods:** Changes in the rate of expansion or contraction.

Freezing and Solidification.—In approaching this subject it will be simpler to study first the somewhat analogous and simpler case of what happens when solutions containing different proportions of water and common salt (NaCl), varying from 0 to 100% of each respectively, are cooled (this is the common example employed, although Howe states that, owing to certain complications, sodium nitrate is better). If pure water is cooled its temperature falls regularly until 0° C. is reached, when freezing occurs (**freezing point**), the temperature remaining constant until all the water has frozen, after which the fall in temperature again proceeds regularly. If a solution containing a small percentage of salt, say about 2% is cooled, freezing does not commence until a temperature below 0° C. has been reached, when, however, the entire solution does not freeze as before. Instead, small portions of nearly pure ice are gradually formed as the temperature is progressively reduced, the remaining solution, in consequence, becoming richer and richer in salt. This gradual separation of ice is known as **selective, progressive or differential freezing**. Finally at -22° C. the temperature remains stationary until the remaining concentrated solution or **mother liquor**, which now contains 23.6% of salt has completely solidified. This last freezing substance consists, not of crystals of salt dissolved in ice, but of separate intimately mixed, microscopic plates of ice and salt. This mixture is termed a **cryosel, cryohydrate** (Guthrie's cryohydrate), **duplex constituent**, or the more general term, **eutectic** (also **eutectic mixture** and **eutecticum**). The temperature at which this occurs is termed the **eutectic point**, and the line joining the points for a series of compositions the **eutectic line**; the time occupied for such freezing is the **eutectic time**. With a higher percentage of salt, say about 10% cooling proceeds to a somewhat lower temperature than in the preceding case before ice commences to separate out; but the final freezing point and the composition of the mother liquor are again -22° C. and 23.6% of salt, respectively, there being of course proportionately more mother liquor. If the solution contains exactly this percentage of salt, cooling proceeds without any separation of ice until -22° C. is reached, when the entire solution freezes out at this temperature. If more than 23.6% of salt is in the original solution, then salt, instead of ice, separates out initially, so that at -22° C. this composition is reached. It will thus be seen that no matter what the initial percentage of salt, the final composition at -22° C. is always the same. The substance initially in excess of the composition of the eutectic (**eutectic ratio**) is called the **excess substance**; the other, the **deficit substance**. The mother liquor, when on the point of forming the eutectic, is sometimes called

the eutectic solution, and eutexia is the name which has been given the act of its formation. A curve for a given composition, plotted to show the rate of cooling, is termed a **cooling curve** or sometimes improperly **recalcescence curve** (the reverse, a **heating curve**); a curve comprising the different critical points for a series of different proportions of the same constituents is known as a **freezing point curve** (the reverse, a **melting point curve**). Where a cooling solution solidifies at one temperature (**congruent freezing**, or **isothermal freezing**), this is termed the **freezing point**; the isotherm corresponding to this freezing point is known specifically as the **tectotherm**; if differential freezing (**incongruent freezing**) occurs, the temperature at which freezing commences, the **upper freezing point**; that at which freezing is completed, the **lower freezing point**; and the range of temperature, the **freezing range**.

Freezing of Alloys.—The same principles apply here as in the case of the salt and water. Only binary alloys will be discussed here. Those containing more than two metals are the same in principle and their additional complications require special

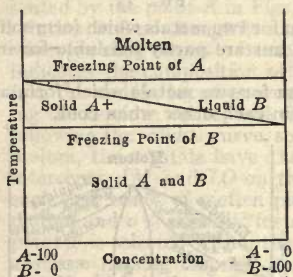


FIG. 32.

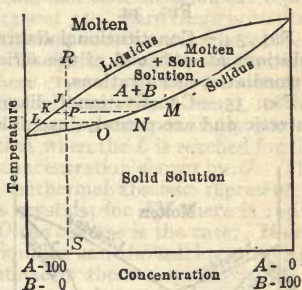


FIG. 33.

FIG. 32.—Constitutional diagram for two metals entirely insoluble in each other when solid.

FIG. 33.—Constitutional diagram for two metals entirely soluble in each other when cold.

methods for illustration and elucidation. Figs. 32 to 37 inclusive show typical diagrams for different kinds of freezing and cooling. The alloy or metal, when heated to a temperature where it is entirely liquid is termed the **molten**. A single metal, a definite chemical compound, and a eutectic each freeze completely at a single temperature. In the last two cases where there is an excess of one of the constituents, or where the alloying metals form solid solutions throughout their series, the freezing is not isothermal but extends over a range of temperature. Fig. 32 shows how each of two metals entirely insoluble in each other has its distinct freezing point which is the same as if alone were present. In figures 33 to 37 inclusive the curves show that, with the excep-

tions noted above, there are two freezing point curves; the upper, or **liquidus**, where freezing commences, and the lower, or **solidus**, where it is completed. In this freezing range alloys are in the **mushy stage** sometimes spoken of. By careful cooling the alloy may not freeze at a temperature below the normal temperature,

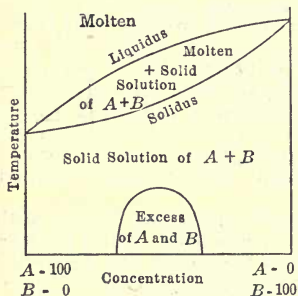


FIG. 34.

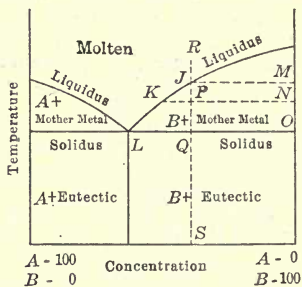


FIG. 35.

FIG. 34.—Constitutional diagram for two metals which form solid solutions at each end of the series but are partly insoluble for intermediate concentrations.

FIG. 35.—Constitutional diagram for two metals which form an eutectic and are entirely insoluble in each other when cold.

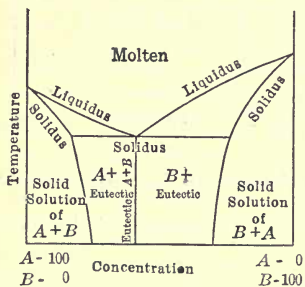


FIG. 36.

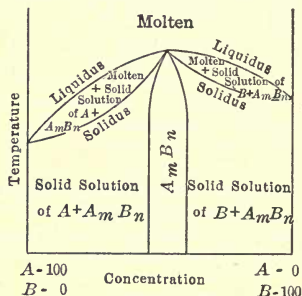


FIG. 37.

FIG. 36.—Constitutional diagram for two metals partly eutectiferous but forming solid solutions at each end of the series.

FIG. 37.—Constitutional diagram of two metals which form a definite chemical compound which is entirely soluble with either metal when cold.

unless the condition is disturbed as by the introduction of a crystal of the alloy (**inoculation**); this is known as **undercooling**, **surfusion** or **superfusion**. This is due to **lag** or a condition of **internal friction** or **molecular friction**, also called **molecular**

inertia or hysteresis (see Phase Rule, page 327); where this does not occur during a change of state or condition, the change is said to be lagless. If cooled still further, freezing takes place spontaneously (spontaneous crystallization) when any disturbance, such as jarring, occurs. These two ranges have been named by Ostwald **metastable range** and **labile range** respectively. The molecular inertia which prevents, or tends to prevent freezing at the normal temperature, acts in accordance with what is sometimes termed the law of **passive resistance**. "Below the solubility curve, and approximately parallel with it, lies a curve representing the temperature at which each solution begins to deposit spontaneously without inoculation with a crystal. To this curve the name **supersolubility curve** has been given. The intersection of two supersolubility curves is called the **hypertectic point**, corresponding to eutectic point" (Desch). Substances separating before the eutectic forms are called **pro-eutectic**; if after the eutectic, **post-eutectic**. Depending upon its structure the eutectic may be **lamellar** or **granular**. To illustrate how these diagrams are used consider what takes place in cooling an alloy whose temperature and concentration are represented by the point *R* in Figs. 33 and 35. Here there is molten solution, and no change in constitution occurs until *J* is reached, when the alloy begins to freeze. The point *M* on the solidus curve indicates the composition of these crystals; as the temperature falls the molten becomes progressively richer in *A* metal, following the liquidus curve, and the crystals correspondingly poorer, following the solidus curve, so that when the *L* is reached for the molten, the crystals have the concentration shown by *O*. The intercepts *JM* and *LO* on the isothermal abscissæ represent in each case 100% of molten plus crystals; for *JM* there is 100% molten and 0% crystals; for *LO* the reverse is the case. If any point *P* is selected within the liquidus and the solidus curve the abscissæ passing through it intersects them respectively at *K* and *N* which indicate the concentration for each; the amount of each is found by the ratio between *PK* and *PN*, thus $\frac{PN}{PK} \times 100 =$

$\%K$, and $\frac{PK}{PN} \times 100 = \%N$. In the case of the cooling of the

alloy which forms the solid solution the original heterogeneity of the crystals is overcome by diffusion unless the cooling is unduly rapid; this is not so complete with subsequent transformations in solid solutions owing to the greater viscosity. With eutectics there persists the simultaneous existence of eutectic and excess substance; the same also in the case of eutectoids formed in solid solutions.

As ordinarily understood a solution is something which is liquid at or near atmospheric temperatures, whereas a molten substance connotes very much higher temperatures. The question is, therefore, really one of degree only, and what is true of an ordinary solution is also relatively true of one which is molten. The term **molten** or **melt** is accordingly used to designate this case in contradistinction to **solid** (at lower or ordinary temperatures).

Where a molten solution solidifies with differential freezing, the upper freezing point (also the curve for a series of different compositions) is termed the **liquidus** (also **liquidus curve**), the lower point and curve, the **solidus** (also **solidus curve**), and the freezing range, the **solidification range**. Where a eutectic (**eutectic mixture**, **eutectic alloy**) is formed, the metal just before final solidification is called the **mother metal**.

Metallic Solid Solution.—It may at first be somewhat difficult to grasp the idea of changes occurring in solid material, but a little thought will show that the principal difference between a solid, such as a metal, and a liquid, is in the degree of mobility of the particles or molecules, as no sharp division can be drawn. From naphtha or alcohol, for example, as one extreme, whose particles are highly mobile, to a heavy oil, to molasses, to lead, to highly heated steel, and finally to the same metal when cold (which can still flow to a considerable extent, as in the case of wire drawing) as the other extreme, the steps are relatively gradual. We therefore properly speak of a **solid solution**, in which the degree of viscosity is high, as similar to a **liquid solution** (in contradistinction), such as the salt solution already discussed, in which the particles have greater freedom of movement. A solid solution, also termed **isomorphous mixture** or **mixed crystals** (according to Professor Howe), "is a solid having the essential properties which characterize liquid solutions as distinguished from chemical compounds. These characteristics are twofold: (1) a solution resembles a definite chemical compound in that its components completely lose their identity and become integrated to form a new substance; (2) solutions differ from definite chemical compounds in that their components unite, not in definite but in intermediate proportions, which vary by infinitesimal gradations from specimen to specimen. The variations in composition between definite chemical compounds are *per saltum*, those between solutions are *per gradum*. The properties of solutions, both liquid and solid, habitually differ much less from the mean of those of their components than from the properties of definite chemical compounds." A **solidified solution** or **congealed solution** is a "homogeneous solution after solidification, irrespective of whether the constituents of the solution in the latter state form a mixture or a solid solution in the true sense of the term" (I. A. T. M.). Metallic solid solutions, from their structure, are sometimes referred to as **crystalline solid solutions**.

For solid solutions the term **eutectoid** (of the nature of or resembling a eutectic) has now been generally adopted, although "eutectic" is still sometimes met with for this particular case; the terms **aeolic** or **benmutic** were suggested but have never come into use. The terms **eutropic mixture** and **eutropic point** (Rinne) were proposed to distinguish changes going on during cooling after solidification from the eutectic changes during solidification itself. To indicate the similar changes leading up to the formation of the eutectoid the upper point (and curve) is known as the **liquidoid** and the lower the **solidoid**.

Cooling of Solid Solutions.—As illustrated by the iron-carbon

diagram (Fig. 38), changes, known as **transformations, inversions, thermal metamorphisms, or transitions** occur similar to those on freezing, giving rise to what are termed **transformation curves**. Where there is a eutectoid, formed by the excess substance being expelled from the solid solution, there is a **selective transformation**; constituents formed before the eutectoid are called **pro-eutectoid**, those afterward, **post-eutectoid**; in the case of iron-carbon alloys the latter is also referred to as the **pearlite or sub-transformation range**.

Iron-Carbon Diagrams.—These are also referred to as **equilibrium, state, or constitutional diagrams** because they serve to illustrate what states are normal under different conditions of temperature and concentration (composition). Howe (*Metallog. of Steel*) points out that such a diagram is made up of two parts:

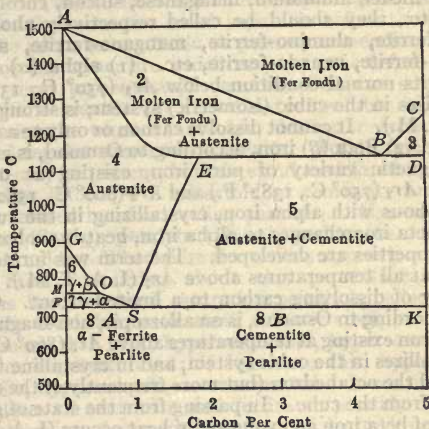


FIG. 38.—Constitutional diagram for iron-carbon alloys.
(I. A. T. M.)

an underscored *V* for the eutectic portion and another underscored *V* for the eutectoid portion. This forms a basis for one classification of iron-carbon alloys: with 4.30% carbon there is eutectic cast iron; with more carbon, hyper-eutectic cast iron; with less carbon, hypo-eutectic steel and cast iron. Considering the lower *V*, with carbon about 0.85% there is eutectoid steel; when the carbon is greater, hyper-eutectoid steel; and if less, hypo-eutectoid steel (this also applies to the matrix of cast iron, *i.e.*, exclusive of any graphite). As cementite is metastable while graphite is stable, there are two forms of diagrams, (a) the iron-cementite or metastable diagram, and (b) the iron-graphite or stable diagram. In Fig. 38 is shown the iron-cementite diagram appearing in the report of Committee 53 of the International Association for Testing Materials (I. A. T. M. diagram). Various diagrams have been gotten up by the following: Iron-

carbon—Benedicks (Sauveur, *Metallography*, 446), Carpenter and Keeling (*ibid.*, 445), Gutowsky, Mannesmann (considered by Howe to be the earliest), Rosenhain (Sauveur, 447), Ruff (*ibid.*, 449), Roozeboom (*ibid.*, 444), Roberts-Austen (*ibid.*, 442-3), Sauveur (*ibid.*, 441), Wittorff (*ibid.*, 450), Upton (*ibid.*, 448); **iron-phosphorus**—Desch (*J. I. & S.*, 1915, I, 195), Konstantinoff (*ibid.*, 194), Saklatwalla (*ibid.*, 193).

Constituents of Iron Alloys.—1. **Ferrite** (Howe): first used for pure iron, now employed to designate that part of iron or steel containing no carbon (or only a trace) in solid solution. It has been suggested by Stead that ferrite when consisting of practically pure iron should be called **ferro-ferrite**. When the iron is associated with considerable quantities of substances with which it forms solutions or isomorphous mixtures, such as phosphide of iron, or nickel, aluminum, manganese, silicon, chromium, vanadium, etc., they should be called respectively **phospho-ferrite**, **nickel-ferrite**, **alumino-ferrite**, **mangano-ferrite**, **silico-ferrite**, **chromo-ferrite**, **vanado-ferrite**, etc. (1) **alpha (α) iron** is pure iron in its normal condition below Ar_2 (750° C., 1382° F.). It crystallizes in the cubic (isometric) system; is strongly magnetic (I. A. T. M.). It cannot dissolve carbon or only to a very limited extent. (2) **Beta (β) iron**, according to Osmond, is an allotropic, non-magnetic variety of pure iron, existing at temperatures between Ar_2 (750° C., 1382° F.) and Ar_3 (860° C., 1580° F.). It is isomorphous with alpha iron, crystallizing in the cubic system. When beta iron changes to alpha iron, heat is evolved and magnetic properties are developed. The term was formerly applied to iron at all temperatures above Ar_2 (I. A. T. M.). It has the property of dissolving carbon to a limited extent. **Gamma (γ) iron**, according to Osmond, is an allotropic, non-magnetic variety of pure iron existing at temperatures above Ar_3 (860° C., 1580° F.). It crystallizes in the cubic system, and in crystalline forms of the cube and the octahedron (but more frequently of the octahedron) derived from the cube. In passing from the state of gamma iron to that of beta iron an evolution of heat occurs (I. A. T. M.). A fourth allotropic modification, **delta (δ) iron** was claimed by Newall in 1887 and Tomlinson in 1888. The transformation point was supposed to occur at about 1000° C. Recently G. Rumelin and K. Fick (*Ferrum*, also *J. I. & S. I.*, 1915, I, 622) state that, in investigating the iron-manganese system, they have detected the δ - γ transformation. **Free iron** was the term proposed by Sorby. The ferrite contained in pearlite is referred to as **pearlitic ferrite**, **eutectoid ferrite**, or **pearlite ferrite**; when not so combined, **free ferrite**, **massive ferrite**, **excess ferrite**, **surplus ferrite**, **non-eutectoid ferrite**, **structurally free ferrite**; what separates out before pearlite is formed, **pro-eutectoid ferrite**. **Total ferrite** refers to all the ferrite present both free and associated.

2. **Cementite** (Howe): a carbide of iron having the formula Fe_3C . It (and the form of carbon) is also termed **Abel's carbide of iron**, **carbon of normal carbide** (Ledebur), **reheated carbon** (Osmond and Werth), **carbon of cementation** (Caron), **cementation carbon**, **cement carbon**, **carbon of annealing**, **normal carbide**,

carbide carbon, cementite carbide. Cementite may exist in fine granules, thin plates, or in comparatively large masses in steel and pig iron. According to Osmond it is the hardest constituent in metal and steel, not colorable by polishing and etching with various reagents (except sodium picrate—see Etching below). Sauveur distinguishes **segregated cementite** and **free cementite** (also called **non-eutectic cementite, surplus carbide, massive cementite**): the former is a constituent of pearlite while the latter occurs independently. As the term “segregated” suggests separation, and as one authority has called free cementite “segregated,” it appears advisable to substitute the term **pearlite-cementite** (I. A. T. M.), **pearlitic cementite** or **eutectoid cementite**, free cementite is also called **non-eutectoid cementite, structurally free cementite** or **excess cementite**. The cementite in the eutectic (when it freezes) is called **eutectic cementite**. Howe suggests for the cementite which separates before the eutectic is formed, the terms **pro-eutectic** or **primary cementite**, and as an analogy for the cementite which may separate before the eutectoid, the term **pro-eutectoid cement**. Sauveur suggests the terms **alpha cementite** for the variety insoluble in iron, and **gamma cementite** when it is soluble; this latter variety has also been called **regular cementite** or **solvite**. **Total cementite** refers to all that may be present, both free and associated.

3. **Pearlite** (Howe).—A eutectoid of cementite and crystallized iron formed by slow cooling past A_1 . Also called **pearly constituent** (Sorby), **pearlyte** (Howe), **perlite** (Osmond), **cryo-carbide** (Arnold). When pure it contains approximately 0.89% carbon. Steel containing about this percentage of carbon (known as the **structural saturation point**), is called **eutectoid steel, aeolic steel, benmutic steel, eutectic steel, and saturated steel**; if more than this, **hyper-eutectoid, hyper-aeolic, hyper-eutectic, or supersaturated**; if less than this, **hypo-eutectoid, hypo-aeolic, hypo-eutectic, or unsaturated**. It consists of alternating plates of cementite and ferrite or possibly sorbite (see below), or grains of cementite embedded in ferrite or possibly sorbite (I. A. T. M.). Normally pearlite should consist of 6.4 parts of ferrite to 1 part of cementite (by weight), but it should be regarded, however, as a variable mixture, for in structural steels containing between 0.5 and 1.0% manganese, the carbon in pearlite varies between 0.6 and 0.9%, and in some tool steels, according to the method of treatment, the pearlite, accompanied by free cementite, may contain 1% carbon (Stead). The range of temperature throughout which pearlite can form is known as the **pearlitic range**. A_1 is essentially a **pearlite point** while the upper limits of hypo-eutectoid steel are **ferrite points** and the upper limit of hyper-eutectoid steel is a **cementite point**. The structure of pearlite depends upon the nature of the cooling which it has undergone. If the cooling is rapid the structure loses distinctness and is called by Arnold **sorbitic pearlite** (usually considered as sorbite, see below); with slower cooling the structure is distinct and is termed **true pearlite** or by Arnold, **normal**; with still slower cooling the structure is coarsened and is known

as laminated pearlite. If the temperature is held for some time just below the lower critical, the two constituents tend to separate into globules, known as spheroidizing or divorcing (divorcing annealing) (Howe) and the structure is termed globular, granular or beaded pearlite (Benedicks). In examining a piece of native iron, Benedicks discovered a structure which he classed as a new micrographic constituent and named oxide pearlite.

4. Austenite (Howe).—The following definitions are suggested by H. M. Howe (*T. A. I. M. E.*, XXIX (1908), 4-7): (a) Generically, the solid solution of iron carbide in iron, stable, for

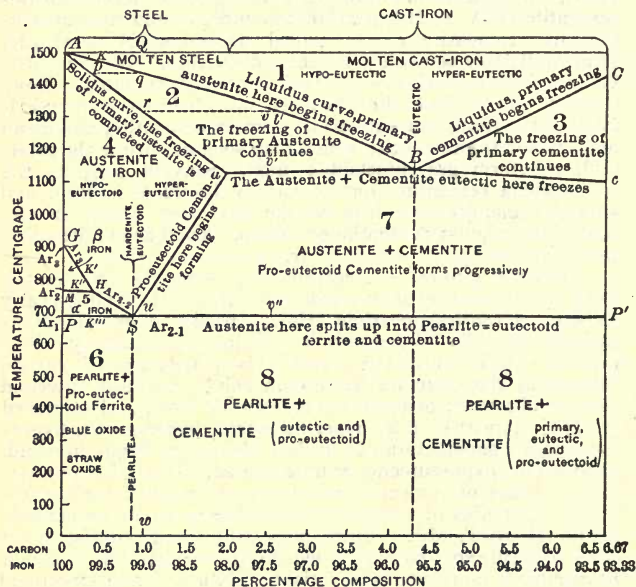


FIG. 39.—The carbon-iron diagram. (Howe.)

instance, above the transformation range A_1 to A_3 . (b) Specifically, this same solid solution as preserved in the cold, more or less decomposed, for instance, by quenching steel containing more than 1.5% of carbon from above 1100°C . in ice water. When the structure of such steel is developed by polishing on parchment moistened with licorice solution or ammonium nitrate after reheating to 200°C ., or by etching with hydrochloric acid in an electric current, the austenite remains white while the zigzag martensite with which it is often associated becomes brown. **Primary austenite**, that which separates from the molten metal in cooling through region 2 of Fig. 39. **Primary cementite**, that

which separates from the molten metal in cooling through region 3. **Eutectic austenite**, that which forms on crossing the boundary aBc in cooling from region 2 or 3 into region 7, and forms part of the eutectic. **Eutectic cementite**, that which forms on crossing the boundary aBc from region 2 or 3 into region 7, and forms part of the eutectic. **Pro-eutectic ferrite**, that which forms from the austenite in cooling through region 5. It is the same as excess ferrite. **Pro-eutectic cementite**, that which forms in the austenite in cooling through region 7, and therefore immediately precedes the eutectoid cementite, *i. e.*, that of the pearlite formed on cooling past A_{r1} . **Primaustenoid**, the network, spines, and other masses rich in ferrite and therefore poor in carbon which in hypo-eutectoid steel persist in undiffused relics of the primary austenite formed in cooling through region 2. So long as they persist, the heat treatment or the mechanical work which the metal has undergone cannot be considered as complete, though it may be sufficient for many purposes. **Primaustenoid**, *adj.*, of or relating to primaustenoid. (For the above Howe claims no originality. He says the second to fifth are already in use in the present or a similar form; he thinks the remainder distinctly new.) The pro-eutectic ferrite is clearly that which Professor Sauveur has called **structurally free ferrite**. Howe has hitherto called it **excess ferrite**. The primary, eutectic, and pro-eutectoid cementite jointly form what Professor Sauveur has called **structurally free cementite**, and Howe has hitherto called **excess cementite**. Indeed, it is the need of subdividing this excess cementite and assigning a specific name, pro-eutectoid, to that which separates in cooling through region 7 that has led (him) to propose the name pro-eutectoid ferrite instead of excess ferrite. The former has the merit not only of matching the corresponding cementite but of indicating the genesis. The eutectoid ferrite and cementite are clearly those which result from the splitting up of the hardenite and are habitually interstratified as pearlite. The carbon dissolved in the austenite, and exclusive of any in the form of cementite, has been termed **dissolved carbon**.

Austenite is sometimes called **mixed crystals**, **gamma iron**, and (wrongly) **martensite**. Primary austenite is also referred to as **pro-eutectic**. Primaustenoid is also called simply **austenoid** or **eutectic austenoid** and **saturated austenoid** to indicate a content of 1.70% C. **Hardenite** is the name given to austenite of eutectoid composition (0.9% carbon), formerly classed as a special case of martensite. Arnold and Read have shown that there are four hardenites: **iron hardenite** ($Fe_{21}Fe_3C$), **vanadium hardenite** ($Fe_{72}V_4C_3$), **tungsten hardenite** ($Fe_{26}WC$), **ferro-molybdenum hardenite** ($Fe_{24}Fe_3Mo_3C$). Edwards interpreted the term **thermal stability** to mean the power which the hardenites possess of resisting the softening action of heat when they are heated to different temperatures. The range in temperature at which austenite exists is known as the **austenite range**. The transformation of hypo-eutectoid steel consists of two parts, the **selective part** and the **eutectoid part** called also the **austenite-pearlite inversion** or **recalescence** (Howe). A steel (usually cer-

tain types of alloy steel) which contains austenite is described as **austenitic**; where free cementite is present, it has been called **cementite-austenitic**; if martensite is also present, **austenite-martensitic**.

5. **Martensite** (Osmond).—A transition form between austenite on the one hand and ferrite and cementite on the other, probably containing all three of these substances, but in varying proportions (Howe). It contains varying amounts of carbon up to about 1.80%. The term **hardenite** was at one time used by Howe for martensite of eutectoid composition (0.80% carbon), and it was also employed for **saturated martensite** with 1.80% carbon. It is harder than austenite and according to Osmond its hardness is probably due to its containing beta iron. It is magnetic; upon polishing, etching, and examining under the microscope it has usually a characteristic structure of intersecting needles parallel to the three sides of a triangle (**acicular martensite**). Howe and Levy found by certain treatments martensite resulted without this structure and suggested, provisionally, the term **emulsion martensite** (**non-acicular martensite**), and where a banded structure resulted, **lamellar martensite**. **Gamma martensite** is the name sometimes given to the form existing only above A_{r1} . It contains carbon dissolved in gamma, and probably also beta (Osmond) iron, this form of carbon being called **hardening carbon**, **hardening carbide**, and **martensite carbon**. It is obtained by rapid cooling from the austenite state or by ordinary cooling with certain elements present which promote lag (**obstructive elements**) such as nickel, manganese, etc. This change to martensite has been termed by Howe **martensitization**. According to Kroll martensite may be simultaneously **osmoditic**, **troostitic**, or **tempering**.

6. **Troostite**.—A transition form between austenite, and cementite and ferrite, occurring while cooling through A_{r3} . It may be obtained by quenching while cooling through this point, and also by reheating martensite at a low temperature considerably below A_{r1} . Upon polishing, etching, and examining under the microscope, it appears as dark colored masses somewhat resembling in form peanuts or links of sausages. Kroll considers it as deposited solvite more or less saturated with gamma iron attached. It has been called by Arnold **emulsified pearlite** or **emulsified carbide**.

7. **Sorbite**.—A transition form between troostite and pearlite, occurring while cooling through A_{r1} . It may be obtained by quenching while cooling through this point and also by reheating to a temperature a little above that for troostite but considerably below what is necessary for the formation of pearlite. Upon polishing, etching, and examining under the microscope, it appears as a brownish colored constituent looking like blurred pearlite, and for this reason has been called **unsegregated pearlite**. It has been referred to by Arnold and Read as "pearlite containing very finely granulated carbide." Sauveur says it is now generally regarded as an uncoagulated mixture of the constituents of troostite and pearlite. It apparently contains (1)

some hardening carbon, that is, carbon or carbide of iron dissolved in beta iron, (2) a considerable quantity of alpha iron, and (3) a considerable quantity of crystallized carbide of iron (cement carbon). Howe terms **sorbitism** the condition when material has a sorbitic structure, *i.e.*, structural fineness, caused by restraining the natural tendency of the structural components to coalesce into larger and larger masses (pearlite), with progressive deterioration of the quality.

8. **Troosto-sorbite** (Kourbatoff).—This is troostite which has not undergone as much transformation as sorbite, but there is no sharp line of demarkation.

9. **Osmondite** (Heyn).—Another homogeneous phase or transition product between troostite and sorbite closely related to the preceding. It is essentially iron in a stressed condition (from rapid cooling), with carbon in the form of hardening carbon. It is also formed by reheating quenched material to about 400° C. and is the condition in which iron is most soluble in dilute acids. **Benedicks' colloid hypothesis** is that osmondite is a colloidal solution of carbide of iron.

10. **Steadite** (Sauveur).—In suggesting this name Sauveur states that Stead writes that in very gray phosphoretic metals the carbon diffuses out of it and a binary eutectic of Fe_3P and Fe containing in solution a little phosphorus is formed. Steadite, the binary eutectic, according to Stead, contains about 10% (10.2%) P and 90% (89.8%) Fe.

11. **Ferronite** (Benedicks).—“Benedicks, for instance, believes, or at least believed at one time, that the pearlite ferrite of some steels could contain as much as 0.27% carbon dissolved in beta iron, whereas free ferrite is in the alpha condition. This carburized and allotropic ferrite Benedicks calls ferronite” (Sauveur). Guillet says that with steels under 0.27% carbon, the ferrite may contain about 0.17% carbon as uncolored patches in the pearlite.

12. **Arnoldite** (Stead).—“If Dr. Arnold had not shown himself so very averse to having people's names introduced into nomenclature he would have suggested that vanadium steels ought to be called **arnoldite steels**, because really their wonderful properties were first brought out and described by Professor Arnold” (Stead).

13. **Ledeburite** (Wüst).—The eutectic which cementite forms with part of the austenoid aggregate and is comparable with pearlite. It contains 52 parts by weight of cementite to 48 parts of 1.70% austenoid (Howe). Bauer and Deiss describe it as the mixed crystals (austenoid)—cementite eutectic with 4.2% carbon, formed at a temperature of about 1130° C. It is produced by the rapid cooling of white cast iron during or just below the point of solidification. Alcoholic hydrochloric acid attacks the plates of mixed crystals (with about 1.76% carbon) the same as martensite; the cementite plates are not attacked.

14. **Graphite**.—Nearly pure carbon occurring in thin curved plates and always amorphous. Graphite is the stable form of carbon and the carbide (cementite) is the metastable form; cer-

tain conditions such as slow or prolonged heating or the presence of certain elements, especially silicon, tend to produce the reaction $\text{Fe}_3\text{C} = 3\text{Fe} + \text{graphite}$, known as **graphitization of cementite**. A variety produced in malleable castings is called **temper carbon** or **annealing carbon**. As opposed to this **graphitic carbon**, Howe has proposed the term **agraphitic carbon**: that commonly known as combined carbon, including both that dissolved in austenite and any present in cementite.

It may be repeated that the **condition of carbon** is (1) in solution above A_1 (or Ae_1) as **hardening carbon**, and (2) below this point as **cement carbon**, or (3) in both cases in the free state as **graphite**. In 1906 Sauveur expressed the opinion (**Sauveur's hypothesis** of the allotropic transformations and of the dissolving power of iron for carbon) that it was far from certain that the liberation of iron from solution must precede, or at least be simultaneous with, the allotropic changes affecting the iron at certain critical temperatures. The hypothesis was advanced that in solution it might first undergo an allotropic modification and then be expelled in its new allotropic form. It is evident that if the allotropic transformation of iron from the gamma to the beta and then to the alpha state precedes its liberation from solution, three solid solutions of carbon in iron are formed during cooling, namely, carbon (or Fe_3C) dissolved (1) in gamma iron, (2) in beta iron, and (3) in alpha iron. The first solid solution is universally called austenite, while this hypothesis leads almost irresistibly to regarding the solid solution in beta iron as martensite and the solid solution in alpha iron as troostite (Sauveur).

"**G. Auchy** (*Iron Age*, 1915, XCV, 50-51) propounds a **chemical theory** to explain the different properties of iron-carbon steels on the assumption of the existence of **ferrated carbides** (compounds of iron and carbide of iron). The carbides, which it is suggested are factors in the problem, are: cementite; the austenites (ferrated Fe_2C compounds); the martensites (similar compounds); and **hardite** (a ferrated Fe-C compound). According to the chemical theory set forth the white-etching constituent of hyper-eutectoid steels is never hard cementite (Fe_3C) but always soft austenite, and the white-etching constituent of hypo-steels above 0.22% of carbon, never ferrite, but austenite. In cast iron, hardite is an intensely hard, unstable, white-etching **percarbide** $\text{FeC}\cdot 5\text{Fe}$, containing 3.45% carbon, formed, if the cooling be rapid, at about 1200°C . by the reaction of 1.76 carbon-austenite upon 6.67 carbon-austenite-cementite. As a matter of fact, the theory that austenites, martensites, and hardite are definitely ferrated chemical compounds need not be insisted on, and they might be regarded as solid solutions in indefinite proportions of Fe_3C , Fe_2C , and FeC respectively in iron. At best, the difficulty may be met by assuming definite ferration at solidification" (*J. I. & S. I.*, 1915, 11, 317-8). To distinguish between cementite which is nearly insoluble in dilute sulphuric acid, and the soluble form of carbon found in osmondite and troostite, Heyn suggested the latter be designated by the symbol Cf.

Miscellaneous Constituents.—Following is a list of the princi-

pal constituents occurring in some cases as impurities or what Hibbard calls **sonims**: "A solid non-metallic portion of matter existing as an impurity in metal. A piece of sand, brick, clay, or such material embedded in metal would be considered as a foreign body, not as an impurity, and therefore not a sonim." A brief discussion of their occurrence will be given under Microstructure. **Manganese sulphide**, MnS ; **iron sulphide**, FeS ; **iron oxide**, FeO , Fe_2O_3 , rarely Fe_3O_4 ; **iron or manganese silicate**, various proportions; **iron phosphide**, Fe_3P and Fe_2P ; **iron silicide**, $FeSi$; various carbides either free or partially replaced by iron, as **manganese carbide**, Mn_3C , also $(FeMn)_3C$; **chromium carbide** Cr_2C_3 , etc. Kirner claims to have found a constituent in steels rich in nitrogen which he calls **flavite**, perhaps **iron nitride**, $Fe_xN_y(?)$.

Hardening Theories.—Various explanations have been offered to attempt to explain why steel may at one time be soft and at another hard. Howe states that "Hardening is usually due to **martensitization**, that is, to enabling the transformation to proceed to but not past the martensite stage, either (1) by cooling carbon steels rapidly from the austenite state; or (2) by the presence of such an intermediate proportion of the obstructing elements, carbon, nickel and manganese, as to cause the transformation to reach only this stage even in slow cooling; or (3) by bringing it to this stage by **subcooling** cold austenitic steel, e.g., in liquid air; or (4) by **overstraining** austenitic steels by cold deformation, so as to stimulate the overdue change from the austenitic to the martensitic state. In addition to these four **martensitizing methods of hardening** there are two others, which we may call (5) and (6). (5) is the hardening of austenitic steels by a regulated **reheating**, which gives mobility enough to allow the transformation to go as far as the hard intermediate state, but not enough to let it reach the final alpha state. This hardening does not always cause martensitization. (6) is the hardening of the malleable metals and alloys in general, gamma and alpha iron included, by **plastic deformation**. There is neither evidence nor reason for believing that this usually acts through martensitization, except in the case of gamma iron" (*Metallography of Steel and Cast Iron*, 176-7). Howe calls groups (1) to (5) the **reversing class**, and (6) the **cumulative class**; (1), (3) and (4) are also referred to as **dynamic**. Sauveur (*Metallography and Heat Treatment of Iron and Steel*, p. 308) makes a general division into **retention theories** (where a former state is more or less preserved) and **stress theories**; he also refers to **solution theories** which involve some form of solid solution (sometimes referred to as **forced solution**), and **carbon theories** where carbon as such (or in combination) is assumed to be responsible.

Osmond's theory, also referred to as the **allotropic, beta or beta iron theory** is based on the assumption that in passing from the gamma state above A_{r3} , to the alpha state below A_{r1} , some of the iron is retained in the hard beta form. Osmond states, "I conclude that hardened steel owes its properties principally to the presence of beta iron, which is hard and brittle by itself at

the ordinary temperature." In view of certain results of Hadfield and Hopkinson, Howe suggests the possibility that "in addition to the non-magnetic beta iron as we know it above A_2 , . . . there is a fourth allotropic form, hard and yet magnetizable in strong fields which we may call **beta II**. On this hypothesis, . . . the transformation is really divisible into two parts, so that the hard state . . . represents **beta I** mixed with gamma, and that of quenched steel represents **beta II** mixed with alpha" (*Metallography of Steel*, 186). Again (p. 196), in regard to the beta theory or hypothesis, "that it is a distinct beta state or states of iron, coordinate with the end states gamma and alpha. Gamma iron alone is dense, beta I and II alone are hard, and beta II and alpha alone are magnetic, both gamma and alpha being isolated easily, but beta thus far always occurring mixed with either gamma or alpha or more often both." **Benedicks' theory** is that so-called beta iron is really a solution of gamma ferrite in alpha ferrite. The **gamma or gamma iron theory** ignores the existence of beta iron and assumes that a certain amount of gamma iron is preserved in solution in alpha iron. The **alpha or alpha iron theory of LeChatelier and Guillet** is that in cooling, carbide of iron is retained in solution in alpha iron.

The **carbon theories of hardening** are directly opposed to the preceding, being based on the contention that the hardening is the result of the carbon, *per se*, and not directly at least to any allotropic condition of the iron. In support of this view it is pointed out that without any carbon iron cannot be usefully hardened, while the effect increases with increase in carbon, at least to a certain point. The **hardening carbon theory** asserts that above A_3 the carbon exists in, and imparts to the steel, a hardened condition which can, in part at least, be retained when cold by sufficiently rapid cooling. **Arnold's sub-carbide theory** supposes the existence above A_3 of a sub-carbide having the formula $Fe_{24}C$, called **hardenite**, which is very hard, and if retained when cold imparts this property to the steel. There was also the **diamond theory**, that hardness was produced, on quenching, by the carbon being converted into minute diamonds by the sudden compression of the metal.

The **carbo-allotropic theory**, in the nature of a compromise between the two preceding, is that hardening is due both to the allotropic condition of the iron, and to carbon in solution, probably as carbide but perhaps as simple carbon, which acts as a brake on the transformation which is thus largely prevented when the cooling through the transformation range is sufficiently rapid.

Stress Theories of Hardening.—In this connection a careful distinction must be made between (a) **macroscopic strain**, that produced by irregularities of cooling a mass or object, which affects different parts, and may result in actual rupture; and (b) **microscopic strain**, which affects the component particles of the grains. **Akerman's theory**, that hardening is due to compressive strains alone (**compression theory**), set up by quenching or other rapid cooling is no longer considered.

Beilby's theory was that the hardness in cold-strained metals, as in the case of wire drawing or of polishing, was due to a **vitreous amorphous phase**, or **thermally metastable state**, sometimes referred to as **Beilby's hard iron**. Somewhat along the same line, Rosenhain and Ewen suggest that the space between the boundaries of crystal faces is filled with an amorphous material or cement (see Plastic Deformation below). **Humfrey's amorphous theory** is that this amorphous condition is brought about by cooling rapid enough to prevent one crystallized form to recrystallize (**decrystallization**) into the other whereby there results an amorphous solution of carbide of iron in alpha iron; the hardness would therefore be due not only to that of the amorphous phase but also to the **iron carbide solution**. The amorphous theory or stress theory in some form is also held by Edwards and Carpenter, A. Le Chatelier, Grenet, and Charpy. **McCance's interstrain theory** is somewhat similar as he claims that there is a solution of carbon in alpha iron (transformed from gamma iron) with some gamma iron; that the iron is crystalline but in a condition of strain due to the arrangement between the alpha and the gamma iron, for which he uses the term **interstrain** to denote the condition of a metal after permanent deformation of any kind; other writers have used the terms **internal tension** and **internal strain**.

Plastic Deformation.—When a metal is subjected to any kind of static stress it is deformed (*a*) temporarily if the stress is within the elastic limit, and (*b*) permanently if the stress is above the elastic limit, provided, of course, it is plastic which is the case, to a certain extent, at least, with all metals (see Physical Properties, page 334). Such **plastic static deformation** caused by overstrain, is due to an actual flow of the material. Howe and Levy (*T. A. I. M. E., L*) distinguish four varieties; (1) **intergranular**, where the several grains, each as a unit, move with relation to each other; (2) **intra-granular**, where the particles of ferrite, cementite, or pearlite, each as a unit, move with relation to each other; (3) **intra-pearlitic**, where the pearlitic ferrite and cementite move with relation to each other; and (4) **crystal unit slipping**, where the minute units move past each other. Howe (*Metallog. of Steel*, 293-4) further divides them into **fluid movements**, where the individual particles move with relation to all the others, and **block movements**, where the motion is by portions, the particles in each being relatively stationary; the movement may also be **crystalline**, if it is concerned with crystalline structure, and **non-crystalline** if without such regard; crystalline, again, may be **rotary** (change of position and of orientation), and **vectorial** (change of position without change of orientation).

Amorphous Cement Theory.—**Beilby's theory of crystalline slip** was that when a metal was overstrained it assumed a temporary fluid or mobile state and then an **amorphous phase** or state which was located between the crystal boundaries and acted as a **cement** (this name seems appropriate as it requires an appreciable time for it to "set") to bind them together (**intergranular**

cement), the amount being in proportion to the overstrain; this cement is supposed to be much harder and stronger than the crystalline material which it joins. This amorphous phase is regarded by Rosenhain and others, from the point of view of the phase rule, as identical with the liquid phase. This cement or amorphous **boundary filling** may lead to what Howe terms **boundary** or **joint strength** which in normal conditions leads to rupture through the grains (**transcrystalline**) instead of following (**intergranular**) the boundaries themselves. Rosenhain holds that there is a **dendritic interlocking** of the adjacent grains which increases the strength when present; there is also evidence (Howe) that there is **contact confusion of orientation** (**strong contact-metal theories**). Howe points out (*Metallog. of Steel*, 191-2) that **amorphizing** (becoming amorphous) may be either **mechanical** by cold working or overstrain, or **crystallographic**, by the occurrence of the transformation in cooling at so low a temperature that, on the breaking up of the gamma iron crystals by the transformation itself, the resultant alpha iron particles cannot re-orient themselves and hence remain amorphous. According to Howe and Levy (*loc. cit.*), while Beilby's theory satisfactorily explains the phenomena of **simple overstrain** (stress applied in one direction), it does not in the case of **reversing overstrain** (first in one direction and then in the opposite), as the former strengthens the metal and its effect can be obliterated by annealing at a relatively low temperature, while the latter does not strengthen the metal nor is its effect obliterated by such treatment.

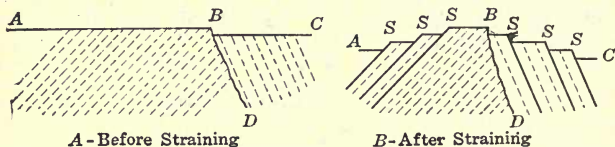


FIG. 40.—Diagram of the formation of slip bands (Rosenhain).

The work of Ewing and Rosenhain, followed by that of others, has served to explain the mechanism of plastic deformation. This occurs, when the **local elastic limit** has been exceeded, by the **slipping** of one layer or portion of a crystal or grain over another portion along **slip planes**, **gliding planes** or **cleavage planes** (**motion planes**), an **interstratal** (between strata) **movement**, producing what are known as **slip bands** (Ewing and Rosenhain's slip theory). These are shown in Fig. 40. (Rosenhain, *Phys. Met.*, 243) "which is intended to indicate in a very approximate manner the condition of a cross-section of two adjacent crystals before and after plastic straining. The upper sketch represents the unstrained crystals, whose smooth upper (polished) surface is indicated by the line ABC—the **step** at B is the slight difference of level between adjacent crystals formed as the result of etching; the boundary between the

crystals is represented by the full line *BD*, while the potential planes of gliding or slip, differently oriented in each crystal, are indicated by the dotted lines. After straining, slip has taken place on some of these slip planes, and minute steps have consequently been formed in the surface at the points marked *s, s, s* in the lower figure—these steps will, of course, slope in different directions in different crystals. Seen from above, by normal illumination, these short, steep, sloping surfaces will appear simply as narrow black lines" (Rosenhain, *Phys. Met.*, 243-4). **Simple slip** or **primary slip** is where only one has occurred; **secondary slip** is where there has been further slipping. As the straining is increased up to the point of rupture the bands become more numerous and confused, with a roughening of the surface apparent to the naked eye. This appearance is sometimes termed **micro-flaws**. The result of the internal strains produced by plastic deformation is indicated by **surface deformations** or **bands** (**flow lines** or **lines of stress**), which have been called **Lüders lines**, corresponding with slip bands; they differ from the Neumann bands or narrow twins (see Crystallography, page 127) in that they are obliterated by etching.



FIG. 41.—Varieties of slipping.
(Howe and Levy.)

Howe uses the term **common lines** (*loc. cit.*, 298-9) and **common paths of deformation** as those which are of the same family as the theoretical, based on the nature and direction of the forces acting; and **specific lines** or **paths**, those actually followed, differing materially from the theoretic by reason of **internal surfaces** of weakness. Howe and Levy (*T. A. I. M. E.*, I, 542) illustrate in Fig. 41 two types of slipping which they call respectively **close order in line** and **open order en echelon**; they state that if the alternate strata are brittle, compression parallel to the stratification converts the first into the second.

Howe states (*Metallog. of Steel*, 312-3) "In a given grain the slip bands usually have a **dominant direction**, which may be followed closely, as when the slip bands are both closely parallel and nearly straight, or may be deviated from materially. In this deviation the slip bands may remain nearly parallel, in which case the deviation is of the whole system of slip bands, a **systematic deviation**; or they may deviate independently of each other, giving us **individual deviations**. By the **terminal grain boundaries** I mean those toward which the dominant direction of the slip bands runs; by the **lateral** ones I mean those along which it runs." Howe's explanation of **Osmond and Cartaud's Slip Band Theory** is as follows (*Metallog. of Steel*, 339); it is "in effect incomplete twinning, a rocking or rotating

of the units which compose each of the slices of metal involved in the movement, each unit about its right-hand side, together with a lifting of each unit by its own rocking and by that of those at its right. . . . In this view there is no slip plane, but a succession of gliding planes. . . . The direction of the motion is approximately normal to the riser [of the step], instead of being parallel to it as in simple slip. This may be called the **wheeling [slip theory]** as distinguished from Ewing and Rosenhain's slip theory of slip bands."

Metallographic Examination.—The methods are as various as opportunity offers or expediency indicates. They may be classified into:

(1) **Optical analysis:** Determining the constituents, structures, forms, appearances, etc., by the eye alone or assisted by suitable magnifying devices.

(2) **Thermal analysis:** A study of the nature of metals and alloys by means of heating and cooling curves, changes in specific heat, etc.

(3) **Magnetic analysis:** Determination of changes in nature affecting the magnetic properties.

(4) **Physical analysis:** Determination of the properties by the usual methods of testing.

(5) **Chemical analysis:** Both proximate and ultimate; generally in conjunction with one of the other methods.

Optical Analysis.—Also termed **visual analysis**. This is divided into (a) **macroscopic** or **megascopic analysis**, which relates to an examination of appearances sufficiently large to be visible to the naked eye or when enlarged only a few diameters (the dividing line usually being placed at about 5 diameters); subjects which belong to this class are ordinary fractures, certain structures, crystalline formations, etc.; (b) **microscopic analysis** where minute structures require the aid of high magnifications; there are various synonyms or associated terms; **microscopy**, **micrography**, relating to the study of minute objects by the aid of the microscope; **micrology**, practically the same as the preceding, except that the examination need not always be visual; **micrometry**, the measurement of minute objects, or quantities, **quantitative microscopy**; **microtechnique**, the methods employed; **metalloptic**, microscopy as applied to metals; **micro-metallurgy**, micrology as applied to metals. The minute characteristics are termed the **micro-character**, their formation the **microstructure**; where the structure is too minute to be resolved by the most (or any but the most) powerful magnification, it is said to be **ultramicroscopic**. Photographic reproductions are called **photomicrograph** (frequently erroneously **micro-photograph**; this really means a photograph reduced to such small size that it must be viewed through a magnifying glass); **micrograph**, **microphotogram** (rare), **photogram**, and **microgram**. The terms **visual microscopy** and **photomicroscopy** or **photo-micrography** are sometimes used to distinguish respectively between the use of the eye only and photographic reproduction. A distinction is usually made (applying to macroscopic work)

between **photograph** and **print**; the former is a reproduction by photographic means (that is, indirect), while the latter is by direct contact with the object itself, as in the case of sulphur prints. A form of **microscope** particularly adapted to the examination of metals has received the special names **metalurgical microscope**, **metallscope**, and **micrometallograph**. A **simple microscope** is one which has only one lens (or set of lenses), a **compound microscope** is one which has two such lenses, one near the object (**objective**), and the other for the eye of the observer (**eye-piece**). The ordinary or **single microscope** has only one tube, etc.; the **binocular** or **stereoscopic binocular microscope** consists of two instruments mounted to give a stereoscopic (perspective) view. As metal specimens are opaque the light to make the surface sufficiently visible (**illumination**) cannot be transmitted through them but must be directed on the surface itself by a reflecting or refracting device called an **illuminator**. Usually, particularly with very high powers, the illumination is **vertical** or **normal**, that is, perpendicular to the surface; in some cases to reveal irregularities in the surface by throwing projections into relief, an **oblique illumination** is employed where the light strikes at an angle less than 90 degrees. The picture of the object shown by the microscope is termed the **image**. The **power** of a microscope is usually expressed in **diameters**, that is, the number of times the linear dimension of an object is magnified. To **resolve** a structure is to bring out its detail (constituents, etc.) by the use of a sufficiently high power. Within the past few years the General Electric Company has experimented with the **x-ray** for the detection of internal defects, particularly of castings. **Radiographs**, employing Coolidge tubes, have been made with considerable success; **stereoscopic radiographs** have also been made with a view to determining also the depth at which the defects occurred.

Preparation of Specimens.—Where high-power microscopes are to be employed it is necessary to have a plane surface free from all scratches, although for ordinary purposes very special care and precautions are not always necessary. This is effected, after preliminary preparation by cutting and filing, by **polishing**, an operation consisting in applying various abrasives (such as emery, rouge, etc.) of successive degrees of fineness until the desired result is secured. It is naturally much more difficult to remove all scratches in the case of very soft material on account of its greater susceptibility to being affected by chance specks of dust, etc.; great care must therefore be exercised to maintain cleanly conditions and the specimen must be carefully washed after each step to prevent any coarse abrasive from being introduced into the next finer grade; it is also of assistance to have the direction of polishing at each stage at right angles to that of the preceding. **Burnishing** and **buffing** as ordinarily applied are simply comparatively crude polishing operations to produce a high luster on articles of jewelry, etc., and usually result in myriads of fine scratches and also tend to smear the

metal on the surface. Certain constituents are revealed by polishing alone owing to differences in coloration (this is particularly true of some non-ferrous alloys) such as graphite or manganese sulphide, or where there is a marked difference in hardness; by using a soft backing to carry the abrasive the softer parts are worn away to a greater depth, forming a bas-relief (**relief polishing**). The treatment with different chemical reagents, etc., with a view to developing differences between the various constituents by the coloration or appearance which they assume and the degree to which they are corroded, is known as **etching**.

Etching.—This is usually done when the specimen is cold (**cold etching**); however, methods have been advised for use when the metal is at a high temperature (**hot etching**) in order to develop the structure when in that condition. Etching to develop the structure for subsequent examination under the microscope may be termed **microscopic** or **microstructure etching**; in contradistinction to this is **macroscopic** or **macrostructure etching**, which is for the purpose of developing the structure (such as segregation, porosity, seams, etc.) by examination by the eye alone. H. Le Chatelier divides etching methods or reagents into three classes: (*a*) where superficial combination with the metal takes place, no solution occurring; (*b*) where the metal is dissolved and effects a simultaneous deposition of another metal; (*c*) where there is simple solution, the crystal surfaces being developed. While "etching" connotes a corroding process, other methods, such as heat tinting, owing to the similarity of their purpose, are usually, and conveniently, included in this classification. The various methods employed may also be classified as follows, according to the means employed:

1. **Mechanical methods**: Polishing alone; the softer constituents are worn away to a greater depth.

2. **Chemical methods**: The different constituents are differently affected in corrodibility or coloration.

3. **Mechanico-chemical methods**: Simultaneous abrading and corroding action.

4. **Electrolytic methods**: An electric current is employed to assist in the corroding action.

5. **Heating methods**: Thin oxide films of different thicknesses are produced, resulting in different colorations, or other reactions are caused.

6. **Deposition methods**: Certain constituents are coated by the deposition of another metal in solution, with or without the assistance of an electric current.

7. **Printing methods**: This is included although perhaps belonging more properly under methods of examination. It consists in applying a chemical reagent which reacts on one of the constituents to form a compound which, in turn, reacts on a second reagent applied on a sheet of paper or cloth applied directly to the surface of the specimen.

Mechanical Methods of Etching.—As already mentioned these consist in using a very soft backing for carrying the abra-

sive; they are principally used with non-ferrous alloys where there is a marked difference in hardness between the various constituents.

Chemical Methods of Etching.—**Baykoff's method**, for hot steel, is to employ hydrochloric acid (HCl) gas. **Benedicks' reagent**: 5% solution (alc.) of metanitrobenzol sulphonic acid; darkens martensite more than austenite. **Heyn's reagents**: (a) copper-ammonium chloride: 10 grams in 120 c.c. water; (b) also ammoniacal copper-ammonium chloride: as in (a) with sufficient ammonia (NH₄OH) added to dissolve the blue precipitate which first forms; (c) (with Martens) alcoholic hydrochloric acid: 1 c.c. hydrochloric acid (1.19) in 100 c.c. absolute alcohol. **Hilpert and Colver-Glauert's reagent**: sulphurous acid; 3 to 4% of a saturated aqueous solution of sulphur dioxide in water or alcohol. **Igewsby's (Ischewski) reagent**: 5 grams picric acid in 100 (also given as 95) c.c. absolute alcohol. **Jones' reagent**: molten zinc; after immersion any adherent zinc or dross removed partly by mechanical means and partly by dilute sulphuric acid. **Kourbatoff's reagents**: (a) 3% (about) aqueous solution of sodium picrate with an excess of caustic soda (NaOH); solution to be used boiling; (b) nitric acid in a solution consisting of a mixture of various alcohols etc. **H. Le Chatelier's reagents**: (a) an acidulated aqueous solution of ferric chloride; (b) an aqueous solution of potassium bitartrate; (c) a mixture of equal parts of a 50% aqueous solution of sodium carbonate and a 10% aqueous solution of lead nitrate; (d) glycerine for composing the solution with nitric, hydrochloric, or picric acid; (e) **phosphorus reagent**, consisting of: absolute methyl alcohol, 100 c.c., cupric chloride (CuCl₂, 2H₂O) 1 gram, magnesium chloride (MgCl₂, 6H₂O), 4 grams, HCl (conc.) 2 c.c., H₂O, 18 c.c. **Martens' reagents**: (a) 4 c.c. nitric acid (1.14) in 100 c.c. absolute alcohol; (b) see Heyn's reagents. **Matweieff's reagent**: boiling, neutral, aqueous solution of sodium picrate. **Osmond's reagents**: (a) tincture of iodine; (b) 10% aqueous solution of hydrochloric acid. **Portevin's method**: etching first in a solution of 10 grams copper-ammonium chloride in 120 c.c. water, followed by use of 10% solution of nitric acid in water. **Robin's reagent**: saturated alcoholic solution of picric acid. **Rohl's reagent**: for ferrous sulphide (FeS), 1% amyl alcohol solution of organic acids. **Saniter's reagent**: molten calcium chloride for hot etching. **Sauveur's reagent**: concentrated nitric acid washed off in a stream of water. **Sorby's reagent**: very dilute aqueous solution of nitric acid. **Stead's reagents**: (a) for phosphorus, cupric chloride, 10 grams, magnesium chloride, 40 grams, hydrochloric acid 20 c.c., alcohol, q. s., 1000 c.c.; (b) 20% sulphuric acid, followed by cleaning in nitric acid. **Whiteley's reagent**: for phosphorus, 0.04 gram cupric oxide (CuO) dissolved in 6 c.c. of strong nitric acid and methylated spirits added to make up 200 c.c. **Yatsevitch's reagent**: for high speed tool steel, 10 c.c. hydrogen peroxide solution (commercial) mixed with 20 c.c. of a 10% aqueous solution of sodium hydrate.

Mechanico-chemical Methods of Etching.—The method originated by **Osmond** is termed **polish-attack** (sometimes **attack-polishing** and **polish-etching**) and at first consisted in rubbing the specimen on parchment (stretched on a board) soaked with an aqueous extract of licorice root and calcium sulphate; later **Osmond** and **Cartaud** substituted a 2% aqueous solution of ammonium nitrate.

Electrolytic Methods of Etching.—These consist, in general, in making the specimen the anode and employing a very weak current, the electrolyte being composed of various substances. The cathode is usually a strip of platinum or a platinum dish used as the container. They may be considered modifications of the strictly chemical methods. **Martens** and **Heyn** employ 1 c.c. of hydrochloric acid in 500 c.c. of water; **Osmond** recommended a gentle current in connection with his chemical method (b). **Weyl's** method belongs to this class.

Heating Methods for Developing Structure.—Heating a specimen in hydrogen, air, etc., to develop the structure on a polished surface, by oxidizing or otherwise affecting the different constituents, originated with **Osmond** (**heat relief**), and was perfected by **Stead** especially in his researches on phosphorus, and consisted in heating in air after a brief preliminary treatment with dilute acid; termed **heat tinting**, **temper tinting**, or **air tinting**.

Deposition Methods of Etching.—**Rosenhain** and **Haughton's** reagent: ferric chloride (Fe_2Cl_6), 30 grams, HCl (conc.) 100 c.c., cupric chloride (CuCl_2), 1 gram, stannous chloride (SnCl_2), 0.5 gram, H_2O , 1 liter; a film of copper is deposited, the thickness (and coloration produced) varying with the different constituents.

Printing Methods.—These methods are used to illustrate the macrostructure. A method, termed **nature printing**, has been used to a limited extent; the surface is deeply etched with a suitable reagent from which prints (**nature prints**) are taken with ink as from a wood block or copper etching in ordinary printing work. A method for making **sulphur prints** was devised by **Heyn** and **Bauer**: a piece of silk, wet with a solution containing mercuric chloride and hydrochloric acid, is pressed on the polished surface of the specimen; the acid acts on any sulphide present, generating H_2S which, in turn, reacts with the mercury salt to form the black precipitate of sulphide of mercury; the location and intensity of the stains indicate the position and (roughly) the extent of the sulphur present. **Baumann's** method replaces the silk with ordinary photographic paper moistened with dilute sulphuric acid, the hydrogen sulphide generated forming similar dark spots by reacting with the silver salt. **Law** applies a coating of gelatine impregnated with an acid solution of a soluble salt of lead, mercury, or cadmium which forms a discolored precipitate as before; the result is viewed under the microscope. **Roger's** method is designed for the examination of fractures; it consists in backing an emulsion of gelatine and silver bromide with clay which, after dipping in acid, is applied and then withdrawn.

Structures.—The **macrostructure** may be sufficiently revealed by simply cutting the desired section, as in the case of blowholes, pipes, and cracks; cutting and then polishing when the details sought are smaller or more obscure; etching to reveal so-called **flow lines** which indicate to a certain extent the working to which the material has been subjected, particularly in the case of cold working or where the material has been severely distorted, in this latter case assisted by the lines of slag (wrought iron) or manganese sulphide if much is present. The macrostructure may also reveal the presence of foreign substances, such as inclusions of dirt or slag in steel, or of pieces of steel in wrought iron (see also Fractures). The **microstructure** is made up of crystals or grains (see Crystallography) which, in turn, are composed of constituents whose presence and arrangement will depend upon the composition and heat treatment. Various types of structure are considered more generally under Crystallography. Non-metallic inclusions, such as slag, manganese sulphide, etc., are detected by the absence of a metallic luster when polished. **Manganese sulphide** usually has a dove-gray color; owing to its lower melting point, it occurs in globules in castings, and also because of its plasticity, drawn out as rods or strings in worked material. Arnold has given the names **sulphide areas** and **sulpho-films** to microscopic constituents containing sulphur. Sometimes there is present what is termed a **banded structure**, consisting of a series of bands or lines of ferrite, white or slightly discolored, and frequently containing such inclusions. These lines are termed **ghosts**, **ghost lines**, **ferrite ghosts**, **phantoms**, **shadow lines**, or **ghost structure**; if very minute, **micro-ghosts** or **micro-ghost lines**. These lines are usually considered as due to dissolved phosphorus which has expelled all carbon on slow cooling, hence sometimes referred to as **phosphorus banding**; Stead calls **white ghost lines** those whose appearance he considers due to cooling too rapidly to prevent the expulsion of all carbon from the more phosphorized areas. Howe states (*Metallog. of Steel*, 563) in regard to what he terms the **incompatibility theory**: "some seem inclined to explain these phenomena by a supposed incompatibility between carbon and phosphorus, so that austenite migrates away from the phosphoric bands when within the transformation range, and that cementite does when below that range. In support of this the slower cementation of phosphoric than of non-phosphoric iron may be cited." A considerable quantity of phosphorus may occur in solution in the ferrite; it may also appear free (**free phosphide**) as an iron phosphide forming a eutectic (particularly in the case of high phosphorus cast irons).

Metallo-metallic Compound.—See Alloy.

Metalloid.—See page 83.

Metalloptic (rare).—See page 284.

Metalloscope.—See page 285.

Metallurgical Microscope.—See page 285.

Metallurgy.—The commercial production, preparation and treatment of metals and alloys.

Metalman (obs.).—A worker or dealer in metals.

Metamagnetic Alloy.—See Alloy.

Metamerism.—See page 85.

Metamorphic Theory.—Of hardening; carbon theory: see page 279.

Metamorphism.—See page 122.

Metaral—See page 264.

Metastable Diagram.—See page 271.

Metastable Equilibrium; Range.—See page 269.

Metathetical Reaction.—See page 87.

Metcalf's Experiment.—See page 214.

Meteoric Iron.—See page 291.

Meteoric Stone.—See page 291.

Meteorites.—Mineral and metallic bodies of extra-terrestrial origin found on the earth's surface. They are recorded according to their geographical location (nearest town, etc.) and, when known, the date of their fall. When discovered by means of their flight they are called **falls**; if detected from the nature of their structure, **finds**. According to their form they may be designated **codonoid**, bell-shaped; **conoid**, cone-shaped; **cricoid**, ring-shaped; **gnathoid**, jaw-shaped; **onchnoid**, pear-shaped; **ostracoid**, shell-shaped; **peltoid**, shield-shaped; **styloid**, columnar etc.

There are three grand divisions:

- I. **Aërolites**: consisting largely of stony matter (principally silicates), and usually also of a slight amount of metallic matter.
- II. **Siderolites**: a transition group, composed of nearly equal parts of stony and of metallic matter, with the metallic portion generally in a sponge-like mass enclosing the stony material in the pores.
- III. **Siderites**: essentially metallic, in the form of an alloy composed principally of iron with which nickel and cobalt are always associated, and frequently also gold, platinum, lead, and some of the rarer elements such as gallium, selenium, palladium, etc.

The chemical composition varies widely, as is shown by the following analyses:

Aërolite (Fayette County):

SiO ₂	37.70%
Fe.....	3.47
FeO.....	23.83
Al ₂ O ₃	2.17
P ₂ O ₅	0.25
CaO.....	2.20
MnO.....	0.45
MgO.....	25.94
NiO.....	1.59
CoO.....	0.16
Co.....	0.09
S.....	1.30

Siderolite (Llana del Inca):

Metallic		Earthy	
Fe.....	89.77%	SiO ₂	28.08%
Ni.....	9.17	Al ₂ O ₃	12.74
Co.....	0.61	FeO.....	42.52
		NiO.....	2.90
		MnO.....	0.20
		CaO.....	9.33
		MgO.....	1.98
		P ₂ O ₅	2.25

Siderite:

(Welland)		(Puquois)	
Fe.....	91.17%	.....	88.67%
Ni.....	8.54	.....	9.83
Co.....	0.06	.....	0.71
S.....	0.07	.....	0.09
Cu.....		.....	0.04
P.....		.....	0.17
Si.....		.....	Tr.
C.....		.....	0.04

Various other names and classifications have been used or suggested. The terms **aërolite**, **siderolite** (abbreviated from **aërosiderolite**), and **siderite** (abbreviated from **aërosiderite**) were suggested by Maskelyne; Daubrée proposed **siderites** for those that contained iron, and **asiderites** for those which did not; siderites were again divided with decreasing contents of iron into **holosiderites** (all iron), **syssiderites**, and **sporadosiderites** (traces). Siderites are also termed **irons** and **iron meteorites**; aërolites **stones**, **stone meteorites** or **meteoric stones**; while siderolites, a transition between the other two, may be known as **iron stones**, **iron-stone meteorites**, **lithosiderites** or **mesosiderites**.

The metallic iron in meteorites may be referred to as **meteoric iron** in contradistinction to ordinary or **terrestrial iron**. The study of this subject has been called **aërolitics** (Maskelyne), **astrolithology** (Shepard), and **meteoritics** (Farrington).

The physical structure as revealed by the microscope after polishing and (sometimes) etching varies widely, and a great many distinct classes are recognized, of which the most important for the siderites are as follows:

(1) **Octahedrites**, or those with an octahedral structure composed of two sets of parallel lines at right angles to each other, called the **Widmanstätten** (or **Widmanstättenian**) **structure** or **lines**. These lines are due to the presence of three distinct iron-nickel alloys, known as the **triad**: (a) **kamacite**, a broad central band (containing from 4.8 to 7.4% of nickel), with narrow borders of (b) **taenite** (containing from 16.7 to 38.1% of nickel), and filling in the interstices or **fields** where these bands intersect. (c) **plessite**, a mixture of the other two. The most prominent of the secondary structures which occur in the fields are referred to as **combs**.

(2) **Hexahedrites**, or those with a cubic (isometric) structure or cleavage, composed of lines intersecting at an angle of 120° , also formed by the triad, and known as the **Neumann bands** or **lines**.

(3) **Ataxites**, or those having an interrupted or indistinct structure.

For a complete list of the various minerals and non-metallic substances found, some comprehensive treatise should be consulted such as those by Cohen or Farrington.

Aside from the triad there are various other alloys, of which the more important are:

Cohenite, from the Magura meteorite, corresponds to the formula $(\text{Fe, Ni, Co})_3\text{C}$, and from the Glorietta Mountain meteorite $(\text{Fe, Ni, Co})_4\text{C}$.

Troilite, iron sulphide, FeS , usually found as separate nodules, but occasionally in bands or plates.

Rhabdite, a phosphide of iron and nickel, sometimes containing cobalt, for which the formula is $(\text{Fe, Ni})_3\text{P}$.

Daubr elite, a sulphide of iron and chromium.

Lawrencite, a protochloride of iron, generally found as an excrescence.

Schreibersite, a phosphide of iron and nickel; the composition is, as a rule, constant, and is expressed by the formula $(\text{Fe, Ni Co})_3\text{P}$; it occurs in the form of plates, and usually surrounding all nodules of troilite.

Pallasites which most nearly resemble iron meteorites, consist of a sponge-like mass of nickel-iron, the pores of which are filled with chrysolite. The proportion of metal to silicate varies in different falls and in individuals of the same fall. A structure peculiar to about 90% of all stone meteorites consists of rounded grains or **spherules**. These are named **chondri** (sing., **chondrus**); or if very minute, **chondrules**. Meteorites largely made up of these are known as **chondrites**; if not, **achondrites**. In structure chondri may themselves be granular, porphyritic or coarsely or finely fibrous. They may consist of a single crystal individual (**monosomatic**), or of several individuals (**polysomatic**) (Farrington). During their passage through the atmospheric envelope surrounding the earth, meteorites become highly heated, and if metallic, a certain amount of oxidation occurs, part of the material being lost in transit, and what remains forming a crust or coating. The term **iron glass** has been suggested by Reichenbach for the fused oxidized coating sometimes found on iron meteorites. Under the microscope, in section, the crust of most iron meteorites presents three and sometimes four well-marked zones. The outermost, called the **fusion zone**, is thin as compared with the others; it is glassy, black, and opaque to brown and transparent. Beneath this lies a broader transparent zone in which the constituents of the meteorites appear little if any changed, called by Tschermak the **absorption zone**. The next and last is a broad zone of black, opaque, spotted appearance. It may be so broad as to make up four-fifths of the width of the crust; the constituents of the meteorite appear in normal condition, but impregnated

with black, generally opaque matter, and is called by Tschermak the **impregnation zone** (Farrington).

The surface furrows or pits in meteorites are termed **piezoglyphs**.

- Meteoritics**.—See page 291.
Metric Scale.—See page 204.
Metric Ton.—See Ton.
Meyer Process.—See Recarburization.
Micaceous Hematite: Iron Ore.—See page 244.
Micro (abbrev.).—Microscopic, etc.
Microcellular Structure.—See page 126.
Microcharacter.—See page 284.
Microchemistry.—See page 82.
Microcryptocrystalline.—See page 126.
Microcrystalline (-crystallitic).—See page 126.
Microcrystallography.—See page 126.
Micro-flaws.—Due to slipping: see page 283.
Micro-ghost; ghost Line.—See page 289.
Microgram.—See page 284.
Microgranitoid.—See page 126.
Microgranular; Granulitic.—See page 126.
Micrograph.—See page 284.
Micrography.—See page 284.
Microlite.—See page 122.
Micrology.—See page 284.
Micromeritic.—See page 126.
Micrometallograph.—See page 285.
Micrometallography.—See page 263.
Micrometallurgy.—See page 284.
Micrometer Caliper: Gage.—See page 187.
Micrometry.—See page 284.
Microphotogram: Photograph.—See page 284.
Microporphyritic.—See page 126.
Microradiometer.—See page 205.
Microsclerometer.—See page 480.
Microscope.—See page 285.
Microscopic Analysis.—See page 284.
Microscopic Constituents.—See page 264.
Microscopic Etching.—See page 286.
Microscopic Metallography.—See page 263.
Microscopic Segregation.—See page 213.
Microscopic Strain.—See page 280.
Microscopic Structure.—Or microstructure: see page 284.
Microscopically Cellular; Crystalline.—See page 127.
Microscopy.—See page 284.
Microspherulitic.—See page 126.
Microstructure.—See pages 284 and 289.
Microstructure Etching.—See page 286.
Microtechnique.—See page 284.
Microtome.—An instrument for mounting specimens for microscopic examination.
Middleboro Pig Iron.—See page 349.
Middleton and Hayward Furnace.—See page 380.

- Middleton Process.**—See page 502.
- Middlings.**—See page 432.
- Migratory Elements.**—See page 70.
- Mil.**—See page 187.
- Mild Cement.**—See page 67.
- Mild Centered Steel.**—Steel cast with the center of softer material than the outside: see page 64. This term might also be applied to steel which has had the outside carburized by cementing or casehardening.
- Mild Ferro-Chrome.**—See page 352.
- Mild Steel.**—See page 455.
- Mild Tempered.**—See page 231.
- Miles Dry Blast Process.**—See page 31.
- Mill.**—(1) The equipment of a rolling mill; (2) in general, a steel or other plant.
- Mill Bar (obs.).**—Muck bar as distinguished from finished wrought iron or merchant bar: see page 377.
- Mill Cinder.**—See Slag.
- Mill Fix (Eng.).**—See page 376.
- Mill Furnace.**—See page 377.
- Mill Iron.**—Pig iron suitable for puddling or for the basic open hearth process.
- Mill Scale.**—See Scale.
- Mill Tap.**—See Slag.
- Milliolithic Ore.**—See page 244.
- Mine Pig.**—See page 350.
- Mineral.**—Ore; a term used in mining.
- Mineral Carbon Blacking.**—See page 298.
- Mineral Wool.**—See Slag Wool.
- Minor Calorie.**—See page 199.
- Minor Shrinkage.**—See page 54.
- Minus Gage.**—See page 186.
- Mirror Iron.**—See page 355.
- Mirror Telescope, Féry.**—See page 207.
- Miscible.**—Capable of mixing.
- Mispickel.**—See page 245.
- Missing Carbon.**—See Carbon.
- Mitis Castings; Process.**—Castings made of steel to which a little aluminum has been added to render it quiet; originally made of steel manufactured by the Mitis process: see page 113.
- Mitscherlich's Law.**—See page 121.
- Mixed Cement.**—See page 67.
- Mixed Crystals.**—See pages 270 and 275.
- Mixed Gas.**—See page 362.
- Mixed Process (rare).**—(1) Duplex or other combination steel process: see page 317.
- Mixer.**—Sometimes called **Jones mixer**, after the inventor, also receiver or reservoir. It is a large vessel for holding molten pig iron, with a capacity of about 75 to 300 tons, and resembles a tilting open hearth furnace. It is built of steel or iron plates lined with basic or acid material, and is usually heated with gas. Working doors or **paddling doors** (Eng.) are provided so lime or

scrap to be melted up may be thrown in, etc. The pig iron as it comes from the blast furnace in ladles is poured in through a trough, and the vessel is emptied by tipping it sufficiently. It may have one or all of the following objects:

1. Simply to keep the iron molten until it is desired for use.
2. To obtain iron of more uniform composition by mixing the product of several blast furnaces.
3. To effect a certain amount of desulphurization. This requires about an hour or more, and a manganese content of about 1% or over.

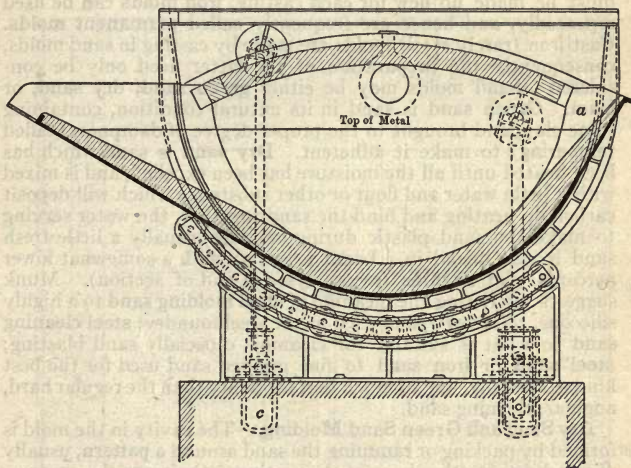


FIG. 42.—Mixer.

Mobile State.—See page 281.

Modern High Speed Tools.—See page 446.

Module (obs.).—Modulus.

Modulus.—(1) Of compressibility or compression: see page 334; (2) of cubic compressibility: see page 335; (3) of elasticity: see page 334; (4) of elasticity for shear: see page 335; (5) of extensibility: see page 335; (6) of flexibility: see page 335; (7) of longitudinal extension: see page 335; (8) of resilience: see page 335; (9) of rigidity: see page 335; (10) of rupture: see page 477; (11) of shear: see page 335; (12) of specific extension: see page 335; (13) of stiffness: see page 335.

Moffat Furnace.—See page 160.

Moh's Scale.—Of hardness: see page 478.

Moisture.—See Water.

Molar Solution; Volume; Weight.—See page 83.

Mold; Molding.—Molding (obs.—melting cast iron in a cupola for foundry work) is the art of preparing molds (also called matrices

—sing., **matrix**—for special purposes), *i.e.*, cavities in suitable materials which are to be filled with molten metal for the production of objects of the desired shape known as **castings** (*q.v.*). The reasons for casting instead of rolling or forging are (*a*) lower cost in certain cases, (*b*) intricacy of shape, and (*c*) with cast iron, the impossibility of forming it in any other way. Molds for castings of cast iron or steel are commonly made of **cast iron** (steel molds have been used to a limited extent) or **sand**; the two first are principally for steel ingots, while the last is for more complicated pieces, and for very large or special-shaped ingots. **Sand molds** must be made up new for each casting; **iron molds** can be used repeatedly, and hence are frequently called **permanent molds**. Cast iron (rarely steel) molds are made by casting in sand molds, consequently the preparation of the latter need only be considered. Sand molds may be either **green sand**, **dry sand**, or **loam**. **Green sand** is sand in its natural condition, containing some clay, and brought to the proper degree of dampness (called **tempering**) to make it adherent. **Dry sand** is sand which has been heated until all the moisture has been expelled, and is mixed with a little water and flour or other substance which will deposit carbon on heating and bind the sand together, the water serving to make the sand plastic during molding; usually a little fresh sand is also mixed in. **Loam** is a clay with a somewhat lower percentage of alumina (see analyses at end of section). Munk suggests restricting the meaning of **steel molding sand** to a highly siliceous, refractory sand used in the steel foundry; **steel cleaning sand** to what is suitable for cleaning, especially sand blasting; **steel sand** or **iron sand** to fine grained sand used for the best kind of cleaning, and of much better quality than the regular hard, angular, cleaning sand.

Dry Sand and Green Sand Molding.—The cavity in the mold is formed by packing or **ramming** the sand around a **pattern**, usually of wood, having the shape of the casting. Owing to the contraction which the metal undergoes in cooling, it is necessary to make the cavity, and hence the pattern, slightly larger than the casting is to be. To assist in laying out the work, a special rule (**molders' rule**, **contraction rule**, **pattern makers' rule**, or **shrinkage gage**) is used. This is marked off in feet and inches as usual, but really measures slightly more than it indicates to provide for the necessary contraction without the trouble of making a separate calculation for each dimension of the casting. **Double shrink** is the extra allowance for contraction required in preparing a metal pattern which is first made from a wooden pattern, and the final casting from this. To permit of the removal (**drawing** or **delivery**) of the pattern without unduly tearing the sand surrounding it, it must be provided with a slight taper (**strip**, **draft**, **draught**), *i.e.*, it must be larger at the top than at the bottom. To assist in its withdrawal, a hook is usually screwed into the top by means of which it is gently pulled out, at the same time being **rapped** with a hammer or piece of wood. **Rapping in** is where the flask is first filled with sand, a small portion removed, and the pattern then knocked in. A pattern is said to be **under-cut** when the

bottom part is larger than the top (the opposite of being tapered), which prevents its removal from the sand, and in this case coring must generally be resorted to. The sand is held in a box or frame of wood or metal called the **flask**, **molding box**, or **casting box**. Depending upon the nature and the size of the casting, the flask is divided into two or more parts; the top is called the **cope** or **case**, the bottom the **drag**, **bottom part**, or **nowel** (Eng.), and any intermediate parts, **cheeks**. The various parts of the

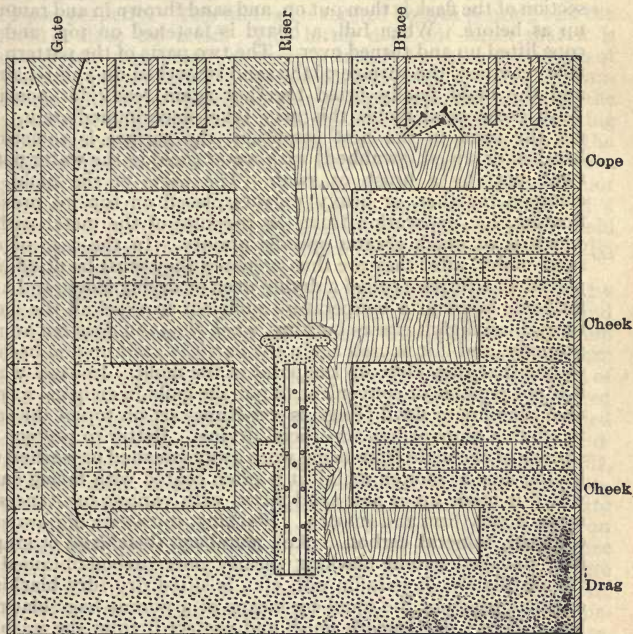


FIG. 43.—Section of flask and pattern.

flask usually consist of sides without any top or bottom, and while they are being alled boards or bottom plates are clamped on to prevent the sand from falling out until it is rammed into a compact mass.

If the casting is small and perfectly simple, it may be possible to have the pattern in one piece, but ordinarily it is necessary to divide it into two or more parts to facilitate its removal from the sand. In ramming up the mold, the bottom part of the pattern is laid with the joint side down on a board (**bottom board**, **joint board**, or **odd side board**), the bottom part of the flask is

inverted over it, and sand is thrown in and rammed around the pattern until the flask is full. A board is now laid on top, the whole turned right side up, and the bottom board (which is now on top) removed, exposing the joint side of the pattern flush with the sand. The other part of the pattern is now accurately fitted to this by means of pegs in one part fitting into holes in the other. Over the surface of the sand in the drag a little fine dry sand (**parting sand**) or powdered charcoal is sifted to enable the two parts of the mold to be separated later. The top (or next) section of the flask is then put on, and sand thrown in and rammed up as before. When full, a board is fastened on top, and the cope lifted up and turned over. The two parts of the pattern are now removed, the surface of the sand smoothed up and repaired, and the mold finally fitted together again ready for pouring. With green sand molds this may take place immediately. To get the sand in the best condition, the surface is sometimes brushed or wiped (**swabbed**) with water (held in the **water pot** or **swab pot**) by a brush or swab. The parts of the mold are clamped together, or heavy weights placed on top, to prevent **floating**, *i.e.*, separation from the pressure of the metal within, which is of much greater specific gravity. In the case of dry sand molds, after they are thus prepared they must be **dried**, *i.e.*, placed in a furnace called a **drying oven** or **drying stove**, and kept for some hours at a temperature sufficient to expel all the moisture; if too high it causes **burning**, when the sand does not adhere properly, and if it is used again the particles split up and become so fine that they close up the pores in the mold. In cases where it is not possible or convenient to put the mold in an oven, a portable coke fire or **devil** (Eng.) is sometimes set on top of the sand to effect a more or less superficial drying. Better to protect the surface of the mold from being worn away (**washed** or **washed up**) by the flow of molten metal, it is often coated with **facing sand**, which is made up of new sand mixed with various substances to make it very firm and smooth. **Blacking**, consisting of powdered charcoal, mineral carbon (coke), **plumbago** (blacklead or graphite), so-called **patent blacking** (nearly pure carbon obtained by the distillation of paraffin oil), etc., is sifted dry (**dry blacking**) on the surface of the mold by means of a porous bag (**blacking bag**), to give it a smooth finish and protect it from the washing action of the metal; if mixed with water it is called **wet blacking**, **liquid blacking**, or **black wash coating**, and is applied with a brush, called a **wet brush** to distinguish it from the **dry brush** used to dust loose sand from the cracks in molds. Green sand molds are sometimes **skin dried** by applying some combustible liquid, such as kerosene, and igniting it.

As the metal during solidification and also the mold always evolve a quantity of gas, the walls of the mold must be porous to permit it to escape, as otherwise the casting would be injured, at least in appearance. The sand is kept more or less open and fine holes are also punched with a wire (**vent wire**), these holes being termed **vent holes**, and the operation **venting** or **ventilation**.

If the molten metal is poured directly into the top of the mold,

it is called **top pouring**, and the mold is said to be an **open top mold**; this is the usual method for casting ingots. With sand molds, however, this would be apt to tear the surface, and therefore the metal is introduced through a pipe or tubular opening at one side called a **runner, feeder, git, guit, gate, ingate, inset sprue, tedge, or pouring gate** which connects with the bottom of the mold proper by an opening known as a **gate or feeding gate**. At the top of the runner is an enlarged depression (**pouring basin**) to receive the metal from the ladle and insure its entering the runner properly. This method is termed **bottom pouring** and the mold a **close top mold**. This latter does not mean that it is completely closed over, as there is usually an extension on top of the mold proper called the **sinkhead, lost head, or riser**, and connected with it by the **rising gate or flow gate**, and used for the purpose of applying metal to fill up any pipe or cavity resulting from the contraction of the metal in the casting; the top of the riser is open and serves to show whether enough metal has been poured into the mold. If the top surface of a casting is not enclosed in the mold, it is termed an **open sand mold**. If a number of molds are filled simultaneously from one central mold (**group casting**), the latter, into which the metal is poured directly, is known as a **git mold** (Eng.).

Coring.—Holes or deep recesses in castings are formed by inserting cylinders or pieces, usually made of hard baked sand or clay, called **cores**, after the pattern has been removed from the mold. A **cod** (Eng.) is a core of green sand. On the pattern are slight projections forming holes or **core prints** in the walls of the mold into which the cores are set. The cores are prevented from shifting their position (**floating**) by metallic pieces, called **chaplets or studs**, which are fastened against them in the sand. For small sizes special nails with flat heads, called **chaplet nails, molders' nails, or core nails**, are used, which are sometimes supported by a block of wood (**chaplet block**) previously driven into the sand. Particularly for heavy cores a piece of iron, called an **anchor bolt**, may be set inside the core and run through the core print to the outside of the mold to which it is fastened. Where more than one core is used, the main one is called the **body core**, the others the **branch cores**. Where the core is of larger diameter in the middle than at the ends, it is termed a **chambered core, belly (bellied) core, or roach belly core**. With cores of large diameter an iron bar (**core bar**) is put through the middle to stiffen them. A plate used to support a number of such bars in the same core is called a **core plate**. When the bars must be very large they are made hollow with perforations for venting, and are termed **core barrels**. To prevent the interior or very large castings cooling so much more slowly than the exterior, a pipe is sometimes inserted through which a stream of water flows; this arrangement is known as a **water core**. When considerable pressure and washing action from the metal must be resisted, the cores may be cut out of solid carbon (**carbon core**). In making cast-iron pipes the core barrel is usually wound with **hay rope or hay band** underneath the sand covering, which chars away and

so gives room for the contraction of the pipe. Cores are usually prepared in wooden molds (**core boxes**), after which they are dried. The sand, etc., of which they are composed is held together by a **core binder** or **core gum** consisting of potato starch, flour, etc., mixed with a little water. If a core is made in two or more separate sections these are fastened (**pasted**) together with **clay water** (water thickened with clay), etc. A metal box in which cores are dried is called a **sagger**, **saggar**, or **seggar**.

If portions of the sand in a mold are poorly supported, nails or brads (**sprigs**: Eng.) may be thrust through the solid part, and this operation would be termed **sprigging** or **nauling** (Eng.). The runners are sometimes called **sprues**, but this term is generally restricted to the metal which solidifies in them and which must be broken off the casting and remelted. To prevent the thick and the thin portions of irregular-shaped castings from tearing apart during cooling due to the thin portions solidifying first and contracting, while the heavier portions are still molten or mushy, they are connected or tied together by bent bars or brackets (**dogs**) set in the molds before pouring.

Where it is desired to hasten the cooling of certain parts of a casting, (*a*) to make the rate of contraction uniform throughout, or (*b*) with cast iron, to make the surface hard by retaining most of the carbon in the combined condition, pieces of iron (**chills**) are inserted in the mold flush with the surface. In the case of cast-iron car wheels, where it is desired to have the tread hard, a device known as a **contracting chill** is employed; this is arranged with metal segments mounted on an iron ring, the segments expanding inward from the heat from the casting, and remaining in contact with it as it cools and contracts. An iron mold for ingots might be termed a **chill mold**, but this name is usually restricted to a mold used for cast iron, and not for steel. **Plate molding**, used principally for small castings, consists in first casting a metallic pattern on a metal plate to insure ease and accuracy of handling. The pattern may be divided between two plates, provided with the necessary gates, etc. A plate may also be used having a hole exactly fitting the pattern, through which the pattern is withdrawn after ramming, the pattern projecting a little way above the plate (**stripping plate**). **Reversed molds** or **ramming blocks** are plaster or metal molds used in some classes of repetition molding work. The actual casting molds are made from these blocks direct, instead of from a pattern, and the advantage of their employment is that a very large number of molds can be made precisely alike without the labor of forming the parting surfaces and runners and risers at every molding (Horner). **Multiple molding** is where a number of molds are piled one on top of the other and connected with a common runner by which they are filled.

Loam Molding or **Sweep Molding**.—This method is used for producing objects having surfaces of rotation, *i.e.*, symmetrical circular sections. Objects such as large gears, round bottomed pots or kettles, blast furnace bells, etc., can be molded very quickly and economically by this method. Loam (a sand rich in

clay) or green sand is employed. The mold or case is first built up with bricks. These are held together and given a first coating with **roughing loam** or **black loam**, of cheap quality and strong binding properties. A finer grade is then used. A templet or arm called a **sweep** is fastened to and turned around a bar as an axis, which is set in the center of the brickwork. The lower edge or surface of the sweep has the shape which it is desired to impart to the mold, which it imparts as it is turned around. The drag and the cope are similarly formed, except the former is concave while the latter is convex, with a space left between the two (when put together) corresponding to the thickness desired in the casting. With gear wheels, the space between the teeth is cored out by hand or by a machine. The sweep is also called a **strickle** (Eng.), and the method of molding, **strickling**, **striking up**, or **sweeping up**.

The **cire perdu process** (**lost wax process**, **waste wax process**) is generally used for small bronze work of an artistic nature. A rough sand pattern of the object is first made, which is as much smaller than the object as the thickness desired for the metal in the casting, and is then coated with wax to the desired size, and the details finished by the artist. The whole is placed in sand in the same manner as an ordinary pattern, and is heated so the wax will melt and run out. The sand core remaining is held in place by wires run through it, and the space thus left is filled with metal.

Machine Molding.—In many cases where a number of castings are to be made from the same pattern it has been found advantageous to employ a machine which quickens the operation of molding, and also does away with much of the skill and labor required when it is done by hand as already described. The machine may be a **squeezer**, in which a **squeezer board**, operated by a lever, presses the sand around the pattern in the flask, or the pressing may be done by compressed air (**pneumatic molding machine**). The removal of the pattern may still be done by hand, or better, by a special type of machine which forces it either up or down through a stripping plate. In the **vibrator machine** the pattern is removed by vibrating it very rapidly an extremely small amount back and forth, so the sand in the mold is not disturbed appreciably, and no stripping plate is necessary. In the **jar machine** which is coming into extensive use, the flat platform or **platen** forming the top of the machine is raised from 2 to 5", and allowed to drop at intervals of 1 to 5 seconds, depending upon the size of the machine and of the flask to be rammed. The flask with the pattern in place, and filled with loose sand, is placed on the machine, and this jarring properly rams the mold.

Floor sand is that already used and emptied from dry sand flasks and swept up from the floor. A screen used for sifting sand by shaking, operated by machine or by hand, is termed a **riddle**.

Following are sample analyses of clay, sand, and loam:

	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	Loss
German clay....	78.39	1.23	13.83	0.80	0.81	4.74
White clay.....	68.90	0.60	21.20	0.25	0.90	7.50
Black clay.....	61.76	3.20	24.40	0.40	0.92	8.60
Green sand.....	86.64	3.13	6.99	0.43	....	2.81
Dunbar sand...	98.46	0.44	0.67	....	0.07	0.36
Coxey sand.....	96.05	0.40	2.80	....	....	0.75
Loam.....	76.06	3.64	11.66	0.28	1.42	6.20

Mold Gases (Howe).—Those evolved from molten and solidifying iron at atmospheric pressure.

Molders' Nail.—See page 299.

Molders' Rule.—See page 296.

Molding Box.—See page 297.

Mole.—See page 83.

Molecular Ease.—The condition in which the molecules in a body are allowed to take their normal or natural position.

Molecular Friction.—See page 268.

Molecular Heat.—See page 201.

Molecular Inertia.—See page 264.

Molecular Motion.—See page 199.

Molecule.—See page 81.

Moler.—See page 396.

Molten.—See pages 267 and 269.

Molten Metal.—Pig iron in the molten or fluid condition.

Molybdenum.—Mo; at. wt., 96; sp. gr., 8.6. It is never found uncombined. The pure metal is white and is merely a chemical curiosity. It is obtained as an alloy with iron called ferro-molybdenum (see page 353), and is used to a certain extent in the manufacture of special steels (see page 450). This name was formerly a synonym for plumbago.

Molybdenum Hardenite.—See page 275.

Molybdenum Steels.—See page 450.

Monad.—See page 86.

Monatomic.—See page 87.

Monell Process.—See page 316.

Monkey.—(1) In a blast furnace: see page 32; (2) in the manufacture of steel, the rods, called respectively **long** and **short-tailed monkeys**, placed in the cinder pit, and forming a frame to hold the slag together and allow it to be taken out with a crane; (3) a dolly; (4) a tup.

Monnot Process.—See page 372.

Monobasic.—See page 87.

Monocellular Structure.—See page 126.

Monoclinic System.—Of crystallization: see page 120.

Monoclinohedral System.—Of crystallization: see page 120.

Monodimetric System.—Of crystallization: see page 120.

Monometric System.—Of crystallization: see page 120.

Monomorphic.—See page 121.

Monosomatic.—See page 292.

Monosymmetric System.—Of crystallization: see page 120.

Monotrimetric System.—Of crystallization: see page 120.

- Monovalent.**—See page 86.
- Monovariant System.**—See page 327.
- Monotropic Transformation.**—See page 327.
- Mop.**—See page 115.
- Morf Process.**—See page 373.
- Morgan Mill.**—See pages 412 and 416.
- Morphology.**—See page 121.
- Morphometry.**—See page 121.
- Morse Optical Pyrometer; Thermogage.**—See page 207.
- Mother Liquor.**—See page 266.
- Mother Metal.**—See pages 56 and 266.
- Mother-of-Pearlyte (obs.).**—An old name suggested by Howe for the constitution of iron from which pearlite is formed on further cooling.
- Motherless Pigs.**—See page 342.
- Motion Plane.**—See pages 123 and 282.
- Mottle.**—See page 433.
- Mottled Iron; Pig.**—See pages 342 and 346.
- Mould, etc.**—Mold, etc.
- Mound.**—See page 181.
- Mouth.**—The top or aperture of a blast furnace, Bessemer converter, etc.
- Movable Bottom, Holley.**—See page 17.
- Moving Load; Concentrated Load.**—See page 468.
- Muck Bar.**—See page 377.
- Muck Mill; Train.**—See page 413.
- Muffle; Muffle Furnace.**—See page 183.
- Multicellular Structure.**—See page 126.
- Multiple Casting.**—See page 61.
- Multiple Drawing.**—See page 508.
- Multiple Isomorphism.**—See page 121.
- Multiple Molding.**—See page 300.
- Multiple Proportions.**—Law of: see page 85.
- Multiple Teeming; Pouring.**—See page 61.
- Multiple Twinning.**—See page 124.
- Mundic.**—See page 245.
- Munton Process.**—See page 60.
- Murdock Converter.**—See page 24.
- Muriatic Acid.**—Commercial hydrochloric acid.
- Mushet (D.) Process.**—(1) Direct process: see page 144; (2) for deoxidizing by manganese additions: see page 393.
- Mushet (R.) Process.**—Of desiccation: see page 30.
- Mushet Steel.**—See page 445.
- Mushy.**—See page 55.
- Mushy Stage.**—See page 268.
- Mushy Structure.**—See page 125.
- Muzzle.**—The nozzle or end of a tuyere.
- Myne (obs.).**—Mine (Eng.) or ore.

N

- N.**—(1) Chemical symbol for nitrogen, *q.v.*; (2) normal, of a solution: see page 83.
- Na.**—Chemical symbol for sodium (Latin, *natrium*), *q.v.*
- Nb.**—Chemical symbol for niobium (usually called columbium): see page 84.
- Nd.**—Chemical symbol for neodymium: see page 84.
- Ne.**—Chemical symbol for neon: see page 84.
- Ni.**—Chemical symbol for nickel, *q.v.*
- Nt.**—Chemical symbol for niton: see page 84.
- No. 2 Iron; No. 3 Iron.**—See page 378.
- N. M. T. A.**—National Metal Trades Association.
- Nailing.**—See page 300.
- Narrow Twin.**—See page 125.
- Nascent.**—See page 87.
- Nasmyth Process.**—See page 380.
- Nathusius Furnace.**—See page 162.
- Native Bloomery; Forge Process.**—See page 144.
- Natural Condition; State.**—Of metal, simply cooled after the last mechanical (ordinary) treatment.
- Natural Corrosion.**—See page 108.
- Natural Gas.**—A highly combustible gas occurring in pockets or caverns in the earth. In districts near which it occurs it is largely used for metallurgical purposes on account of its high calorific power and low sulphur. It consists almost entirely of marsh gas (methane) and hydrogen, the following being a representative analysis by volume:
- | | |
|-------------------------|-----|
| Hydrogen..... | 20% |
| Methane..... | 70 |
| Other hydrocarbons..... | 6 |
| Carbon dioxide..... | 1 |
| Nitrogen..... | 3 |
- Natural Hardness.**—See Hardness.
- Natural Steel.**—(1) Old name for “steel” made direct from ore; (2) tool steel: see page 446.
- Nature.**—Come to nature: see page 376.
- Nature Prints.**—See page 288.
- Nau Process.**—(1) Casting process: see page 61; (2) purification process: see page 387.
- Nealing (obs.).**—Annealing.
- Neck.**—Of a roll: see page 403.
- Necking.**—Of a test piece: see page 336.
- Needle Fracture.**—See page 178.
- Needle-shaped Crystal.**—See page 126.
- Negative Crystal.**—See page 127.
- Negative Hardening; Quenching.**—See page 231.
- Negative Segregation.**—See page 56.
- Nerve Structure.**—See page 125.

- Nesh** (Eng.).—Tender or brittle, as of tin plates.
- Nested**.—Of crucibles: see page 112.
- Net Structure**.—See page 126.
- Net Ton**.—See Ton.
- Network Size; Structure**.—See page 126.
- Neuberg Process**.—See page 63.
- Neumann Bands; Lamellæ; Lines; Structure**.—See pages 127 and 292.
- Neutral**.—(1) Of oxidized materials, neither acid nor basic; (2) of a flame, neither oxidizing nor reducing; (3) of wrought iron, neither red-short nor cold-short (rare).
- Neutral Axis**.—See page 337.
- Neutral Coke**.—See page 97.
- Neutral Lining**.—See Lining.
- Neutral Moment**.—In solidifying: see page 54.
- Neutral Refractories**.—See page 398.
- Neutral Siemens Process**.—See page 310.
- Neutral Surface**.—See page 337.
- Neutralizing**.—Of phosphorus: see page 385.
- Neville Process**.—See page 144.
- New Tool Steel**.—See page 446.
- Newland's Law of Octaves**.—See page 85.
- Newton's Law of Cooling; Radiation**.—See page 200.
- Newton Process**.—(1) Cementation process: see page 73; (2) crucible process: see page 118; (3) direct process: see page 144.
- Nichrome**.—The trade name for an alloy containing approximately nickel 60%, chromium 14%, with the remainder chiefly iron. It is largely used for parts exposed to high temperatures owing to its comparative freedom from oxidation and change of form.
- Nick Bend Test**.—See page 476.
- Nick and Break Test**.—For rails; see page 483.
- Nickel**.—(1) Influence on corrosion: see page 366; (2) commercial nickel: see page 353.
- Nickel**.—Ni; at. wt., 58.5; melt. pt., 1435° C. (2615° F.); sp. gr., 8.6 to 8.93. It is not found in the free state, but usually combined with sulphur or oxygen. It is a lustrous white metal with a slight yellow tinge when compared with silver. It is hard, strong, ductile, and malleable. It is obtained in the metallic condition (nearly pure) or as an alloy with iron, called ferro-nickel (see page 353), and is used in the manufacture of nickel steel (see page 450).
- Nickel-Chrome Steels**.—See page 451.
- Nickel-Ferrite**.—See page 272.
- Nickel Plating**.—See page 371.
- Nickel Steel**.—See page 450.
- Nickel Steel Armor Plate**.—See page 8.
- Nipper**.—See page 508.
- Nitric Acid**.—For etching: see page 287.
- Nitro-Cyanide of Titanium**.—See Salamander.
- Nitrogen**.—N; at. wt., 14; melt. pt., -213° C. (-351° F.); boil. pt., -195.5° C. (-319.9° F.); sp. gr., 0.973 (air = 1); 1 liter weighs 1.250 grams. It is a colorless, odorless, and tasteless gas, and its

principal occurrence is in air, of which it constitutes about four-fifths by volume, mechanically mixed with oxygen. It combines directly with very few of the elements, and separates readily from many of its compounds, often with explosive violence. It is found in iron, apparently forming a feeble compound, which tends to make the metal brittle; it is removed by the action of titanium or vanadium.

Nobbin (rare).—A bloom of puddled iron worked under the hammer.

Nobbing.—See Forging.

Nobili's Thermopile.—See page 207.

Noble Furnace.—See page 162.

Noble Metal.—See page 84.

Noble Metal Couple.—See page 209.

Nodulizing.—See page 45.

Non-acicular Martensite.—See page 276.

Non-anodic Passivity; Polarization.—See page 364.

Non-Bessemer Ore.—See page 243.

Non-caking Coal.—See Coal.

Non-coking Coal.—See Coal.

Non-continuous Combustion.—See page 202.

Non-corro Steel.—See page 451.

Non-crystalline.—See page 119.

Non-crystalline Movement.—See page 281.

Non-eutectic Cementite.—See page 273.

Non-eutectoid Cementite.—See page 273.

Non-eutectoid Ferrite.—See page 272.

Non-ferrous Alloy.—See Alloy.

Non-ferrous Structure.—Differing from that of ordinary (plain carbon) ferrous metals; as of alloy steels or cast irons.

Non-homogeneous System.—See page 328.

Non-magnetic Steels.—See page 445.

Non-malleable.—Of metals, not capable of being worked to a useful degree.

Non-metal; Non-metallic.—See page 83.

Non-phosphoric Pig.—See page 344.

Non-refractory Clays.—See page 396.

Non-reversible.—Of alloys, processes and transformations: see pages 265 and 327.

Non-reversing Mill.—See page 408.

Non-variant System.—See page 327.

Non-Walloon Processes.—See page 75.

Noodle.—See page 17.

Nordman's Heterochrome Photometer.—See page 208.

Noric Iron.—An iron formerly manufactured in what are now Styria and Carinthia; it is mentioned by various classical writers.

Normal.—(1) Of material which has been finished in the usual manner in contradistinction to that which has received special treatment; (2) in connection with the phase rule: see page 326; (3) perpendicular; at right angles; (4) of illumination, for microscopic work; vertical; (5) regular or standard; (6) average or mean, as normal temperature.

- Normal Carbide.**—See page 272.
Normal Pearlite.—See page 273.
Normal Scale.—Of temperatures: see page 205.
Normal Solution.—See page 83.
Normal Steel (rare).—Plain carbon steel.
Normal Stress.—See page 332.
Normal System.—See page 326.
Normal Thermometer.—See page 205.
Normalizing.—See page 232.
Norris Wear Test.—See page 480.
Northrup's Ratiometer.—See page 208.
Norton Process.—See page 65.
Nose.—(1) The top section of a Bessemer converter: see page 17; (2) the lip of a ladle; (3) the blunt end of a die or hammer; (4) an accumulation of chilled material around the inner end of a tuyere in a smelting shaft furnace, protecting and prolonging the tuyere (Raymond).
Nose Helve.—See Hammer.
Notch Gun.—For a blast furnace: see page 37.
Notch Toughness.—See page 482.
Nowel.—See page 297.
Nozzle.—See Ladle.
Nucleus.—Core; see page 67.
Number.—In wire drawing: see page 509.
Nut Coal.—See Coal.
Nyhammer Continuous High Bloomary.—See page 144.

O

- O.**—Chemical symbol for oxygen, *q. v.*
- Os.**—Chemical symbol for osmium: see page 84.
- O. D.**—Outside diameter.
- O. H.**—Open hearth.
- Oar (obs.).**—Ore.
- Obersteiner Process.**—See page 118.
- Objective.**—Of a microscope: see page 285.
- Oblique Fracture.**—See page 179.
- Oblique Illumination.**—See page 285.
- Oblique Stress.**—See page 332.
- Oblique System.**—Of crystallization: see page 120.
- Obstruction Theory.**—See page 341.
- Obstructive Elements.**—See page 276.
- Occlusion.**—The property possessed by certain metals, such as iron, platinum, and notably palladium, of absorbing large quantities of a gas when heated, and retaining it when cold (Newth); see also page 328.
- Ochre.**—See page 244.
- Octahedral Cleavage.**—See page 124.
- Octahedrite.**—See page 291.
- Octaves, Law of.**—See page 85.
- Odd-side Board.**—See page 297.
- Off.**—(1) To be through operating, or not operating; (2) to have the wrong composition, *e. g.*, to be off in carbon.
- Off the Boil.**—See page 314.
- Off Iron.**—Pig iron of a different grade from that intended to be made.
- Oil Cooling.**—See page 227.
- Oil Finish.**—See page 433.
- Oil Flaring.**—See page 231.
- Oil Furnace.**—See page 181.
- Oil Gas.**—This is obtained by the splitting up of a hydrocarbon oil at a high temperature, with or without the use of air or steam, into a permanent gas. It is used almost exclusively for lighting as its cost of production is too great for metallurgical purposes. **Water oil gas** (devised by Archer) is made as follows: "Steam superheated to about 1000° F. (550° C.) is made to pass through an injector and draw with it a quantity of oil which becomes mixed with the steam. The mixture is further heated to about 1300° F. (700° C.), when it receives an additional quantity of oil; and finally the mixture is heated to 2400° F. (1300° C.), whereby it is converted into permanent gas." **Pintsch gas**, among others, is made by dropping oil into a red-hot retort, somewhat on the principle of a "flash" boiler, which splits it up into a permanent gas. **Air gas** is the combustible mixture of air and hydrocarbons obtained when ordinary air is passed through the more volatile (liquid) constituents of petroleum. The

Amet-Ensign oil gas producer is used in California where the oil has an asphalt base, so it is generally used only under steam boilers. The oil is fed in from a weir box provided with an adjustable needle valve and runs down an adjacent inclined slide or plate, while the air comes up from below and passes under the lower edge. The products of combustion and distillation there formed pass up through a brick-lined combining tube and thence down to a water seal, after passing which they enter a rotary washer. Steam is to be used in the more recent forms (*Iron Age*, July 13, 1911).

Oil Gas Producer.—See Oil Gas.

Oil Hardening; Quenching; Tempering.—See pages 227 and 228.

Oil Toughening.—See page 232.

Oil of Vitriol.—Commercial sulphuric acid.

Oily Liquid.—See page 121.

Old European Process.—For malleable castings: see page 258.

Old High Bloomary.—See page 147.

Ologist Ore.—See page 244.

On.—To be operating.

On the Boil.—See page 314.

On Gas.—See page 34.

On Wind.—See page 34.

Onchnoid.—See page 290.

Oncosimeter.—See page 483.

One-blow Test.—See page 482.

Onion (Onion Skin) Type.—Of freezing: see page 55.

Onions Process.—See page 118.

Oölitic Hematite; Ore.—See page 244.

Oölitic Structure.—See page 125.

Open.—Of the charge in a blast furnace: see page 35.

Open Annealing.—See page 431.

Open Fire.—See page 75.

Open Fore-part.—See page 32.

Open Front.—See page 32.

Open Grained Iron; Pig.—Pig iron whose fracture shows large grains or crystals.

Open Hearth.—See pages 75 and 182.

Open Hearth Basic Pig.—See page 343.

Open Hearth Furnace.—See pages 183 and 310.

Open Hearth Process.—A process for the production of steel by the oxidation and removal of the impurities contained in a bath of metallic iron lying on the hearth of a regenerative furnace (see page 183), the product being tapped in a fluid condition. The charge may consist of (a) pig iron (either solid or molten); (b) pig iron and scrap; or (c) scrap and carbon (coal or coke). There are two modifications, depending upon the nature of the lining of the furnace:

1. **Acid open hearth process**, with removal of silicon, manganese, and carbon.

2. **Basic open hearth process**, with removal of silicon, manganese, and carbon, as in the acid process, and in addition most of the phosphorus and often some of the sulphur.

The original method (acid) of C. W. Siemens was to melt pig iron alone, and oxidize the impurities with ore (**Siemens process, pig and ore process**), while the Brothers Martin added scrap without ore to molten pig iron until the bath had the right composition, there being only slight oxidation from the gases (**Siemens-Martin process, Martin-Siemens process, Martin process, pig and scrap process**), consequently the former was an oxidation process while the latter was principally a dilution process. These various names have, however, lost their significance and are used interchangeably, the terms pig and ore or pig and scrap being employed where it is necessary to distinguish between them. Ordinarily a combination method employing pig, scrap, and ore is practised. In this country the name **open hearth process** is used on account of the type of furnace. The name **neutral Siemens process** has been applied where only pig and scrap (without any ore) are used. The terms **ordinary** or **straight open hearth process** are employed to distinguish regular practice from special methods or modifications as described below.

Open Hearth Furnace.—This is a regenerative reverberatory furnace, the name being derived from the fact that the hearth is open or exposed to the action of the flame. It should more properly be termed a **Siemens furnace** or **Siemens regenerative**

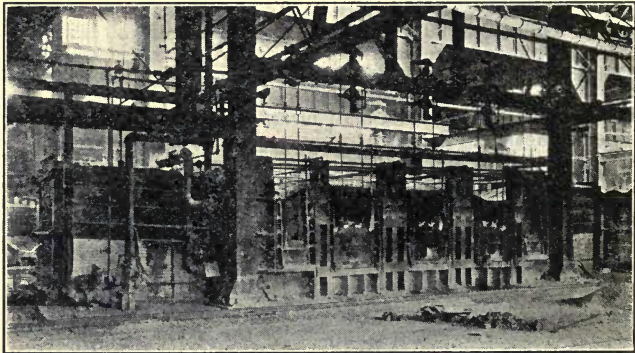


FIG. 44.—60-ton open hearth furnace.

furnace; the term **Martin furnace** (used on the Continent) is incorrect as the Martins had nothing to do with the design of the furnace—only with the process. The furnace comprises a **hearth** or **sole** which contains the charge, covered with an arched roof of bricks; **ports** or passages at each end, the air and gas for combustion entering at one end and leaving at the other; **regenerators (regenerative chambers)** at each end, connected with the ports by vertical flues (**uptakes**), and leading to the chimney or stack; at the bottom of the uptakes are

small chambers or receptacles (**cinder pockets, slag pockets, or dirt pockets**), easily cleaned, for the purpose of catching any particles of cinder or dirt carried over, so as to protect the checkers. The **hearth** consists usually of metal plates lined with silica bricks, on top of which is the lining proper, consisting (*a*) for acid practice, of silica bricks covered with fine sand; (*b*) for basic practice, of magnesite bricks covered with crushed dolomite, sometimes mixed with a little pitch or tar. The roof and walls above where the slag of the charge comes (**slag line**) are built of silica (rarely magnesite) bricks, and below this of silica (acid) or magnesite (basic) bricks, depending upon the process. Sometimes chrome (neutral) bricks are inserted

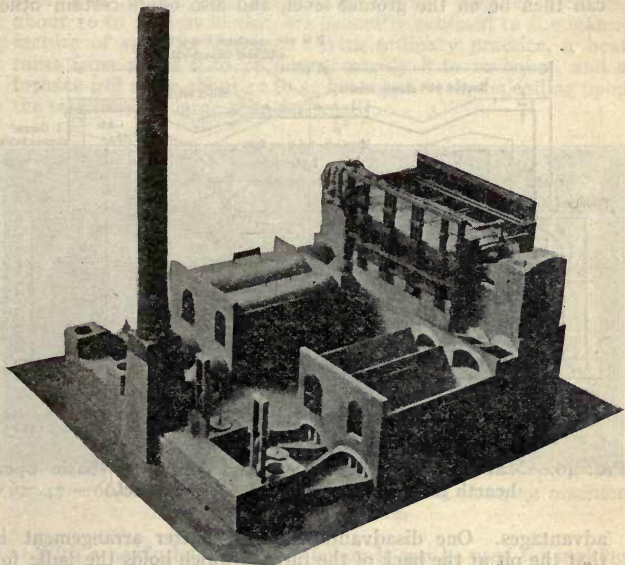


FIG. 45.—Model of a 50-ton open hearth furnace.

between silica and magnesite bricks. The hearth is provided at the back with a **tap hole** which, in the case of stationary furnaces, must be stopped up carefully with refractory material; with a tilting furnace, except, when tapping, it is above the level of the bath, and so need not be closed up tightly. The hearth is usually rectangular in shape, rarely round or oval. The **regenerators** are the distinctive feature of the furnace and consist of fire-brick flues nearly filled with bricks set on edge and arranged so as to leave a great number of small passages, known as **checkers** or **checker work**, which abstract most of the heat from the outgoing waste gases and return it later to the incoming (cold) gases

for combustion. If producer gas is used, both the air and gas are preheated in separate regenerators, uniting and burning only when they enter the furnace; with natural gas or petroleum, only the air is preheated.

Furnaces may be built either on a permanent foundation (**stationary or fixed furnace**), or so arranged that the part comprising the hearth may be tipped (**tilting, tipping, or rolling furnace**). The first type of furnace had **vertical regenerators** (*i.e.*, the greatest dimension was vertical), which necessitated having the hearth and the charging floor considerably elevated above the ground level; the present practice is to make the regenerators **horizontal**, as this lowers the charging floor which can then be on the ground level, and also offers certain other

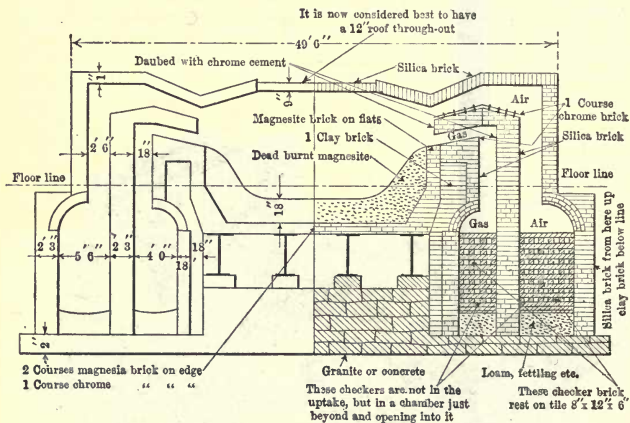


FIG. 46.—Materials of construction and lining for basic open hearth furnace. (Stoughton, *Met. of Steel.*)

advantages. One disadvantage of this latter arrangement is that the pit at the back of the furnace which holds the ladle for the steel, and the slag which runs over (**cinder pit, slag pit, or ladle pit**) must be correspondingly deep, and therefore difficult to clean on account of the heat. To overcome this difficulty, the ground at the back of the furnace may be dug away, making the cinder pit very shallow. This type of construction, is called a **double level furnace**; the old style, a **single level furnace**.

In the first furnaces the hearth was supported on the regenerator arches which were weakened by the high temperature to which they were exposed; also any charge breaking through the bottom would choke them up. This is avoided by the use of **horizontal regenerators** which are not underneath the hearth; it was also avoided in a special type of furnace, called the **Batho furnace**, in which the vertical regenerators were inclosed in an

iron sheathing, being set to one side and independent of the furnace. This furnace had a round (sometimes an oval or elliptical) hearth, and the roof was set in an iron frame so arranged that it could be lifted off to permit of charging scrap too large to pass through the regular charging doors, originally intended to facilitate repairs and relining. Such a furnace is termed a **removable top furnace** (sometimes a **round top furnace**), a few of which are still employed.

In this country furnaces used in connection with the manufacture of ingots generally have a capacity per charge of about 50 to 100 tons; for some special processes, up to 200 tons or over, and in this case are usually tilting. Smaller furnaces, about 10 to 20 tons in size, are generally confined to the manufacture of steel for castings. With ordinary practice, a heat takes from about 6 to 12 hours, usually 8 to 10 hours, and a furnace will make about 12 to 22 heats per week, depending upon the size (less for large than for small).

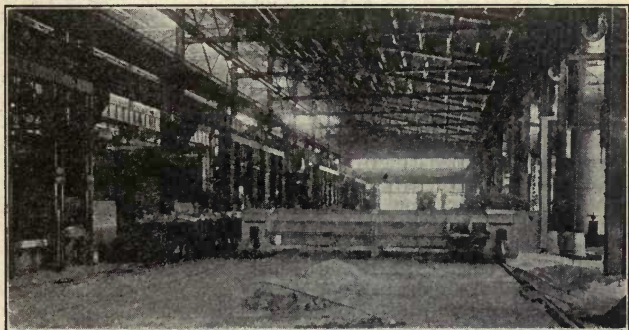


FIG. 47.—60-ton open hearth furnace, showing charging machine and charging boxes.

With a newly built furnace, before it can be used for making steel, the first operation is **making bottom**, *i.e.*, putting in the lining. Gas is burned to warm up the hearth and the checkers until the full working temperature is reached. With proper construction a sufficiently high temperature to fuse the roof can be attained. The refractory lining is then put on in thin layers, each of which is sintered in place before the next is put on. With an acid furnace a certain amount of old slag is then thrown in, melted, and tapped out. This is called a **wash heat** or **wash out heat** and is for the purpose of making the bottom dense and firm. The furnaces were originally charged by hand, the materials being laid on a **peel** (a bar flattened out at one end like a spade) which was rested on the sill of one of the doors as a fulcrum, and so pushed in (**peel charging**); but with modern large furnaces, both on account of the time required

and the arduousness of the labor, this is done by a machine (**charging machine**). The stock is loaded into boxes (**charging boxes**) which are picked up by the machine and dumped in the furnace by revolving the peel of the machine which engages with them at one end.

Acid Open Hearth Process.—Ordinarily the charge is composed of pig and scrap, the scrap as a rule constituting the greater part. The materials must contain less phosphorus (0.06%) than is to appear in the finished steel (see page 343). In some cases the scrap is charged first, with the pig on top, in others this order is reversed, the object being to prevent scorification of the lining by the iron oxide formed during melting. The first stage consists in melting the materials down, during which much of the silicon, manganese, and carbon are oxidized. When completely melted, the bath should contain about 0.60% of carbon if low-carbon steel is to be made, or over 1% for high-carbon steel for springs, etc. To determine this, a sample is taken out in a spoon and poured into a small mold, the test ingot resulting being chilled in water and broken, its fracture giving the desired information. Frequently with high-carbon steel a quick chemical determination is also made. If the heat **melts high**, *i.e.*, if the carbon is still too high, ore in small amounts can be fed in (**oreing** or **oreing down**) to effect the oxidation, without danger of corroding the lining, as this is now protected by the metallic bath and the slag already formed; if the heat **melts low**, with the danger of the bath not getting hot enough by the time the carbon is nearly all gone, pig is thrown in to supply the deficiency in carbon, and this is termed **pigging**, **pigging back**, or **pigging up**. The period after melting, when the carbon is being oxidized, is sometimes called the **boil**, and the charge is said to be **on the boil**; if nearly all the carbon has been oxidized, it is **off the boil**. To assist in oxidizing the carbon, the bath may be stirred (**shaken down**) with an iron rod. In some cases steel may be obtained with a higher percentage of silicon than usual, due to a reaction or **sand boil** (Eng.) whereby silicon is reduced from the bottom or banks of the furnace.

A certain amount of heat is generated by the oxidation of the impurities, but the greater part is obtained from the combustion of the gas. Contact of the iron with the hot gases is principally brought about by the evolution of the carbon monoxide gas formed by the oxidation of the carbon in the metallic bath, which causes it to bubble and seethe; consequently it is necessary to have a certain amount of carbon in the bath, as otherwise it will be too cold to tap. The temperature of the bath is determined partly by the eye and partly from the effect on a low-carbon iron bar in about ten seconds. If the bar is melted off sharply the bath is sufficiently hot, while if it tapers to a point it is too cold. The direction of the air and the gas for combustion is reversed at regular intervals: about 20 minutes at the beginning and 15 minutes or less toward the end of the heat.

Just before tapping, a small amount of ferro-manganese is usually thrown into the furnace to **hold the heat**, *i.e.*, to prevent

any further removal of carbon, and also to effect a partial de-oxidation of the bath. There are two methods for obtaining the right carbon content: (a) by removing practically all the carbon and then recarburizing; (b) by tapping when the carbon has been reduced to the right percentage (**catching the carbon on the way down**). In either case manganese (and sometimes silicon) must be added (generally in the ladle) to remove the remaining oxide in the metal. When the bath is in the right condition as regards both composition and temperature, it is run out of the furnace (**tapped**) by knocking out the material in the tapping hole, if a stationary furnace, or, if a tilting furnace, by lowering the tapping hole so the metal will flow out. It is caught in a ladle, and poured into molds. Recarburization (*q.v.*) is usually performed in the ladle, but may also be done in the furnace before tapping. Instead of tapping into a ladle, from which the molds are filled, the steel may be run into a **fore hearth**, a small chamber or tank attached to the furnace, and provided with holes in the bottom for filling the molds: its object is to prevent chilling of the metal. Occasionally, after tapping, some of the steel sticks around the tapping hole, and is sometimes termed a **dog collar**. A **chestnut** is a lump of steel sticking in the tapping hole.

Basic Open Hearth Process.—As in the acid process, the charge usually consists of pig iron (preferably molten) and scrap (with ore and limestone in addition), but the materials are not restricted as regards the phosphorus content; the sulphur, however, should be low, as its elimination is very uncertain, and at most slight; the silicon should also be low, to avoid the use of an excessive amount of lime. Since the lining is basic, ore can be charged initially without the danger of injuring it. The actual elimination of the phosphorus is performed by the lime, usually added as limestone, but occasionally burned beforehand. With these differences the basic process closely resembles the acid as regards melting and the preparation of the bath. The proportion of pig is generally larger, and whenever practicable it is charged in the molten condition, as a material saving in time and cost of handling results.

Under a superintendent a **foreman** has charge of a number of furnaces and is responsible for the composition and the condition of the steel produced. The individual furnaces are operated by a **melter** or **first helper**, an **assistant melter** or **second helper**, and a **cinder pitman**, the last named cleaning out the cinder pit, and assisting the others in **fettling** the furnace, *i.e.*, repairing the lining. There is also the gang necessary to load the stock, prepare the ladles, pour the heats, etc.

Special open hearth processes are modifications of ordinary practice designed to decrease cost, increase output, or make use of material of troublesome composition (*e.g.*, high phosphorus or high silicon). The most important are the following:

Bertrand-Thiel process: This was designed especially for the use of pig when the phosphorus is too high (about 1 to 2%) to be treated in ordinary open hearth practice on account of the

bulky slag required, but too low for the basic Bessemer process. It consists in charging pig, either alone or mixed with scrap, together with ore and lime, in one basic furnace (**primary furnace, finer, or refiner**) in which nearly all the phosphorus and silicon and only a small part of the carbon are removed, the resulting, partly purified metal, without any of the slag, being then transferred to another basic furnace (**secondary furnace or finisher**) in which scrap, or ore, or both, together with some lime (occasionally also a little pig) have previously been heated, when a very rapid reaction takes place between the iron oxide formed and the remaining impurities in the metal, which are quickly reduced to below the required limits. The further details are the same as in regular practice. The time required is about two to four hours in each furnace.

Monell process: This is a modification of the pig and ore process which, however, may also employ scrap. It is ordinarily carried out in a fixed basic furnace, but a tilting furnace will also serve. It consists in heating limestone and ore or some form of iron oxide, the latter amounting to about 20 to 25% of the weight of the pig, until it becomes pasty, when the pig, in a molten condition, is run in, and a violent reaction takes place. A large amount of slag is formed which is run out of a special notch into an auxiliary cinder pit (**hunch pit**), if a fixed furnace is used, or out of the tapping hole, in the case of a tilting furnace, by tilting it slightly. This slag contains about 90% of the phosphorus and most of the silicon originally in the pig, about 2% of carbon being still left in the bath. The heat is then worked down and handled as in regular practice taking about the same total time as an ordinary pig and scrap heat.

Talbot process or Talbot continuous process: This is a pig and ore process although scrap is occasionally added. It depends upon the rapid oxidation of the impurities contained in pig iron by a liquid, highly ferruginous slag, and is carried out in a basic open hearth furnace, generally of the tilting type. The essential feature of the process is always keeping a certain amount of metal in the furnace (*a*) to dilute the impurities contained in the additions of pig iron, and (*b*) to supply the heat necessary to keep the slag very fluid. A tilting furnace of 200 tons capacity or over is ordinarily employed, and from about one-quarter to one-third of the finished steel is tapped out at one time. This having been done, additions of ore or iron oxide and lime are made, and after they are properly melted and incorporated in the slag, molten pig iron is run in and a violent reaction takes place, most of the phosphorus and silicon being eliminated in a few minutes, a large part of the slag running out of the furnace. The bath is then adjusted as in ordinary practice, a part tapped, and the cycle of operations repeated. A furnace is emptied completely only at the end of the week or for repairs. The name **Talbot furnace** is applied to an open hearth furnace in which this process is conducted, but is really incorrect as the process does not require any special type. A heat can be made in about three to four

hours. This process is sometimes run in conjunction with the duplex process (see below).

Surzycki process: This is the Talbot process carried out in a stationary open hearth furnace, with tapping holes at different heights for permitting the removal of the slag and portions of the metal.

Campbell processes: These are two modifications of the open hearth process. The first is simply a pig and ore process with molten metal, and employing a tilting furnace of the Campbell type. The foamy slag produced early in the process is prevented from running out of the doors by properly tilting the furnace. Any excess is allowed to run out through a slag notch between the end of the furnace and the port which is prevented from chilling by the flame constantly passing over it. After the foaming has subsided the furnace is restored to its normal position and the heat finished as usual. In the second modification the heat is commenced in a basic furnace, run at a low temperature at which most of the phosphorus and silicon, and some of the carbon, manganese, and sulphur, are removed. The charge is then transferred to an acid furnace, and finished as usual, care being taken to prevent any of the basic slag from running in with the metal. The initial charge may be constituted in various ways. The object is to obtain any benefits supposed to accrue to acid steel.

Duplex process: This was designed for the use of ordinary materials, but more especially for the use of pig iron high in phosphorus and silicon. It consists in first blowing the molten pig iron in an acid Bessemer converter to remove the silicon and varying proportions of the carbon, the blown metal being transferred to, and finished in, a basic open hearth furnace (frequently tilting) according to regular practice. The blowing takes about ten to fifteen minutes and the finishing in the open hearth furnace from two to eight hours, depending upon the size of the furnace and certain other conditions.

The following processes are of only general interest:

Berard process: Two furnaces were used, joined together, and heated by gas. In one hearth air was blown into the bath through tubes dipping beneath the surface and, after being sufficiently refined, the charge was transferred to the other hearth and finished.

Biederman and Harvey's modification consisted in returning a part of the waste gases through the producer (*a*) to make use of their sensible heat and (*b*) to obtain a gas containing less nitrogen than when air alone is employed.

In **Bouiniard's process** a jet of air was used to stir up the metal in much the same way as adopted by Ponsard.

In the **Daelen-Pszczolka process** hot air, under low pressure, is blown on the surface of the bath.

Dyer's process consists in melting scrap with carbonaceous material instead of with pig iron.

M. Ehrenwerth and J. Prochaska's process consisted in employing briquettes of ore, charcoal or coke, and pig iron which were to be charged in place of scrap. The ore and char-

coal were either placed in a mold, and molten pig iron run in, or else were made into bricks around which the pig iron was cast.

P. Eyerman's process consists (a) in employing blast furnace gas which is passed over heated carbon to convert the carbon dioxide into carbon monoxide, and (b) in directing a jet of air upon the bath.

Galy-Cazalet's process was an old method for refining pig and making steel by injecting steam through the molten metal contained in a cylindrical furnace, provided with several tuyeres, or in an ordinary reverberatory furnace. It was not a success, as the cooling effect of the steam was too great.

P. C. Gilchrist's process consists in melting pig and lime in a basic furnace, the amount of lime being less than ordinarily required. At the same time a charge is blown in a basic Bessemer converter with an excess of lime, and this molten scrap together with the slag is added to the now molten charge in the open hearth furnace, and the heat finished as usual.

W. B. Hughes' process was essentially a modification of the Monell, and consisted in adding a suitable slag of iron ore and lime in a molten condition after preparing it in a separate furnace.

In **Krupp's process** a furnace on the same principle as a Ponsard furnace was used. It had a revolving hearth slightly inclined to the horizontal and with tuyeres at one part. When these were at the lowest point they blew air through the bath, but at the highest point they were above the bath and the air was stopped.

In the **Lencauchez process** the charge of pig or pig and scrap is held molten at a low temperature to effect separation of the manganese sulphide, after which the temperature is slightly raised (but not to the point where the carbon is attacked), and air is blown on the surface to effect the oxidation of the phosphorus and silicon; ore or scale may also be used for this purpose. The charge may be finished in the same or in another furnace.

In the **Lindenthal process** pig iron is melted in a cupola and run down through a closed conduit into a receiver. During its passage jets of air are blown on it to oxidize the silicon and phosphorus. From the tank furnace the metal (without any slag) is run into a basic open hearth furnace and finished as usual.

Niven McConnell's process was to desiliconize the pig iron in an acid converter, at the same time reducing the carbon to about 1%. This metal was then transferred to a heated mixer from which portions were taken periodically and finished in a basic open hearth furnace as usual.

Parry and Llewellyn's process: Pig and ore, etc., are charged in alternate layers and are heated just sufficiently to melt the slag which is allowed to run off; the temperature is then raised to melt the metal. The operation may be carried out in a furnace with one or two hearths.

The **Ponsard process** consists in using a special furnace known as a **Ponsard furnace** or **Fornoconvertisseur** having a movable hearth and heated with gas. It is provided with

tuyeres so that air can be blown through the metal during the earlier stages, and then, by partially revolving the hearth, the tuyeres are disconnected from the bath, and the process carried on in the same way as in an ordinary open hearth furnace. Another method was to use a hollow, water-cooled poker through which air was blown into the bath to stir it up.

In the **Schwartz process** a large proportion of the charge is steel scrap which is melted in a cupola and run into a bath of pig iron in a special type of furnace; it was claimed to be very rapid.

J. W. Thomas' process was devised for the manufacture of steel direct from titaniferous ores. After crushing they were mixed with coal, coke, or charcoal, 2% of lime, and 1% of salt, and were molded into briquettes which were added to a bath of pig iron in an open hearth furnace, and the heat finished as usual. The ore added in this way amounted to about 40% of the weight of pig iron.

The **Twynam process** consists in adding a certain quantity of briquettes, composed of iron ore and carbon, to the bath of a basic open hearth furnace; it was claimed that the reduction of the iron was very complete, but the process was used only experimentally.

Württemberg's process was designed to hasten operations by blowing air into the bath after the charge had melted down. Air under a pressure of 7 to 8 pounds was introduced through 1" tuyeres; protected by clay, which were dipped into the bath. It was found, however, that the lining of the furnace was destroyed to such an extent that the gain in the actual process was more than lost by the time required for repairs.

Wuth's process: The charge in an open hearth furnace was composed of alternate layers of bar iron (wrought iron) and graphite and was treated in the ordinary manner, spiegel or ferro-manganese being added at the end of the heat.

Open Hearth Processes, Special.—See page 315.

Open Hearth Steel.—Steel made by the open hearth process (see above) either acid or basic.

Open Iron.—See page 343.

Open Order En Echelon.—See page 283.

Open Pass.—See page 405.

Open Pit.—See page 57.

Open Sand Castings.—See page 57.

Open Sand Mold.—See page 299.

Open Sea.—In the freezing of alloys: see page 54.

Open Spray Tuyere.—See page 31.

Open Steel.—See page 55.

Open Top.—Of a blast furnace: see page 34.

Open Top Mold.—See page 299.

Open Tuyere.—See page 32.

Opposition Method.—See page 209.

Optical Analysis.—See page 284.

Optical Pyrometer.—See page 207.

Optimum (rare).—Best; *e.g.*, optimum temperature means the best or most favorable for a given reaction or condition.

Orange Heat.—See page 210.

Ordinary Annealing.—See page 231.

Ordinary English Pig Irons.—See page 349.

Ordinary Ferro-Silicon.—See page 354.

Ordinary Iron.—Sometimes applied to cast iron castings to distinguish them from malleable castings.

Ordinary Line of Deformation.—See page 126.

Ordinary Open Hearth Process.—See page 310.

Ordinary Solder.—See page 505.

Ordinary Steel.—See page 443.

Ordinary Tool Steel.—See page 445.

Ordinate.—See Curve.

Ore.—A natural mineral substance consisting of (a) one or more (usually) metallic elements, generally in the combined state, and (b) non-metallic elements as impurities or diluents, called the **gangue**. It is understood that there shall be a sufficient proportion of at least one of the metals to permit of its commercial (profitable) extraction. Thus, a clay containing, say, 6% of iron would not be considered as an ore of iron, as the iron could not be recovered profitably.

Beneficiation or **benefaction** is the general term applied to the preliminary treatment of an ore, having for its object either the enrichment of its metallic contents or the removal of injurious constituents, either by bodily removal or their change into something less harmful. By **roasting** or **calcination** (*q.v.*) moisture and volatile substances are driven off, and carbonaceous or combustible matter is burned out. It is carried out, usually with the admixture of solid fuel, in open piles, kilns, and sometimes in cupolas or small shaft furnaces, an excess of air being necessary. The removal of a considerable part of the earthy matter or gangue may be effected by **washing** in a **washer** or **jig**, by taking advantage of the differences in the respective specific gravities. The material is crushed and separated into lots, consisting of pieces of nearly equal size, by suitable screens (**sizing**), and is put in a jig or washer, the bottom of which has water pulsating through it. The material is fed in at the top, and the quicksand condition allows the constituents to separate according to their specific gravities (**sorting**), and they are then drawn off through separate holes. Only pieces of the same size are treated together. The earliest type of **shaft washer** consisted of a log 16 to 30 feet long fitted with blades revolving in an inclined trough, into which the ore is dumped and streams of water added. As the log revolves, the blades cut the clay lumps and force the sand, gravel and the ore up the incline of the trough to a discharge opening, the water carrying away the clay. This was sometimes called a **buddle**. It was improved by using two parallel logs in one trough, and, later, iron shafts replaced the logs. In **cone washers** there are a series of perforated iron staves secured to spiders, forming a cylinder with a conical end, which is revolved by gearing, into which the ore is fed with a stream of water. The staves have on their inner faces a series of blades or cutters which break up the clay lumps, the water carrying this

off, and the fine ore passes into a revolving screen which saves all the ore above a determined size (Birkinbine). **Cobbing** (Eng.) is a term used for hand picking. **Magnetic concentration** or **separation** consists in the removal of nearly all the iron oxide, in the form of the magnetic oxide (Fe_3O_4) by the aid of powerful magnets. If it does not already exist in that condition a preliminary roasting may be necessary for its formation. This treatment may be either for the purpose of enriching an ore of iron or of removing iron when its presence is undesirable. The finely crushed material may be brought into contact with magnets so the magnetic particles are removed on traveling belts or revolving drums; another method is to deflect these particles when falling in a stream past the magnet. Agglomerating fine particles into coherent masses is dealt with under Briquette.

- Ore Bloom.**—See page 135.
Ore Bridge.—See page 32.
Ore Burden.—See page 34.
Ore Distributing Devices.—See page 32.
Ore Metal.—See page 350.
Ore of Steel.—See page 245.
Oreing; Oreing Down.—See page 314.
Organic; Chemistry.—See page 82.
Orient; Orientation.—See page 119.
Oriented Lustre.—See page 127.
Origin.—In plotting curves: See Curve.
Orthobasic.—See pages 122 and 350.
Orthorhombic System.—Of crystallization: see page 120.
Orthosymmetric System.—Of crystallization: see page 120.
Orthotomous.—See page 124.
Orthotypous.—See page 124.
Orton Cones.—See page 209.
Osborne Process.—See page 380.
Osmond and Cartaud's Method.—Of etching: see page 288.
Osmond and Cartaud's Theory.—Of slip bands: see page 283.
Osmond Method.—Of quenching: see page 229.
Osmond's Reagents.—For etching: see pages 287 and 288.
Osmond's Theory.—(1) Of the allotropy of iron: see page 264;
 (2) of hardening: see page 279.
Osmondite.—See page 277.
Osmonditic Martensite.—See page 276.
Osmose; Osmotic Pressure.—See Solution.
Osmund; Osmund Furnace; Process.—See page 144.
Ostlund Process.—See page 380.
Ostracoid.—See page 290.
Otto Process.—See page 144.
-ous.—Chemical suffix: see page 88.
Out of Wind.—Not twisted or alternately bent; a requirement in some rail specifications.
Output.—The production of a mill, plant, or company for a certain period.
Outside Gage.—See page 186.
Outsides; Outside Sheet.—See page 431.

- Oval Groove; Pass.**—See page 405.
- Oven.**—See page 181.
- Over Iron.**—Surplus of (pig) iron melted for filling molds.
- Overblow.**—See page 20.
- Overburdened.**—Of a blast furnace: see page 34.
- Overcarburization.**—See page 68.
- Overhang.**—Of a tuyere: see page 31.
- Overheating.**—See page 226.
- Overheating Zone.**—See page 226.
- Overstrain.**—See pages 216 and 334.
- Overstrained Ferrite.**—See page 216.
- Overstraining.**—In hardening: see page 279.
- Overwork.**—See page 99.
- Oxidated (rare).**—Oxidized.
- Oxidation.**—See page 88.
- Oxide.**—(1) The combination of another element with oxygen; (2) oxide of iron or rust; (3) dross; (4) sometimes used for "scale," e.g., black oxide.
- Oxide Bottom.**—See Lining.
- Oxide Coating.**—See page 362.
- Oxide Film Theory.**—Of passivity: see page 364.
- Oxide of Iron.**—See page 396.
- Oxide Ore.**—See page 243.
- Oxide Pearlite.**—See page 274.
- Oxide Skin Theory; Oxide Theory.**—Of passivity: see page 364.
- Oxone.**—A trade name for fused sodium peroxide.
- Oxyacetylene Cutting; Welding.**—See page 503.
- Oxygen.**—O; at. wt., 16; melt. pt. -223°C. (-369°F.); boil. pt., -182.5°C. (-296.5°F.); sp. gr., 1.1056 (air = 1); 1 liter weighs 1.429 grams. It is a colorless, odorless, and tasteless gas, forming one-fifth of the air by volume, and is found in combination with various elements; it combines with all the elements except fluorine. Iron oxide dissolved in iron makes the metal both red-short and cold-short; in combination with manganese this effect is not so noticeable, as the compound appears to be only mechanically held. Ledebur states that iron containing combined oxygen up to 0.10% can be worked, but that above this the metal is bad; the maximum content is about 0.25 to 0.30%. Uncombined oxygen is sometimes found in blowholes or pockets.
- Oxygen Charge Theory.**—Of passivity: see page 364.
- Oxygen Film Theory; Oxygen Theory.**—Of passivity: see page 364.
- Oxygenated.**—Oxidized or impregnated with oxygen or oxide; burnt.
- Oxygenated Steel.**—See page 226.
- Oxyhydrogen Cutting; Welding.**—See page 503.
- Oxygenite Process.**—A trade name for oxyacetylene welding: see page 503.

P

- P.**—(1) Chemical symbol for phosphorus, *q.v.*; (2) pressure.
- Pb.**—Chemical symbol for lead (Latin, *plumbum*), *q.v.*
- Pd.**—Chemical symbol for palladium: see page 84.
- Pr.**—Chemical symbol for praseodymium: see page 84.
- Pt.**—Chemical symbol for platinum: see page 84.
- P. D.**—Pitch diameter; used in estimating the size of rolling mills; the distance between the center points of pinions and gears.
- P. & M. S.**—Planished and machine straightened (of tires, etc.).
- P. & O. Process.**—Pig and ore: see page 310.
- P. & S. Process.**—Pig and scrap: see page 310.
- Paal Steel Process.**—See page 78.
- Pack.**—See page 430.
- Packard Motor Company Process.**—See page 225.
- Paddle.**—A flat tool employed by puddlers in preparing the lining.
- Paddling Door.**—See Mixer.
- Paint.**—See page 365.
- Pair; Pair Furnace.**—See page 430.
- Pallasite.**—See page 292.
- Pallisades (obs.).**—Old name for bars.
- Pallets (Eng.).**—Or bits; the cast iron tools with chilled faces, used in forging, which come in contact with the object to form it.
- Pan (obs.).**—Ladle.
- Pane.**—Also spelled **pean**, **peen**, **pein**, or **pene**; it is the striking face or the smaller and narrower end of a hammer head. It is termed a **ball pane** when it is spherical in form: a **cross pane** when in the form of a narrow, round-edged ridge placed at right angles to the axis of the shaft; a **straight pane** when a ridge of the same character runs longitudinally (Horner).
- Paper Chill.**—See page 350.
- Parallel Growth.**—See page 121.
- Paramorph.**—See page 122.
- Paris Gage.**—See page 188.
- Parker Process.**—See page 369.
- Parkes Process.**—See page 62.
- Parrot Coal.**—See Coal.
- Parry and Llewellyn Process.**—See page 318.
- Parry Process.**—See page 387.
- Part Chill Roll.**—See page 403.
- Part Ingot.**—Butt ingot: see page 47.
- Partial Cementation.**—See page 67.
- Partial Fracture.**—See page 179.
- Partially Fusible Cements.**—See page 69.
- Parting.**—See page 123.
- Parting Plane.**—See page 123.
- Parting Sand.**—See page 298.
- Pass.**—See page 405.
- Pass Over Mill.**—See page 408.

- Passage (obs.).—Tuyere.
 Passivated Iron.—See page 364.
 Passive Break.—In connection with passivity: see page 364.
 Passive Iron.—See page 364.
 Passive Resistance.—See page 269.
 Passive State.—See page 364.
 Passivified Iron; Passivity.—See page 364.
 Pasting.—See page 300.
 Patch.—See page 432.
 Patents.—In coating sheets: see page 432.
 Patent Blacking.—See page 298.
 Patent Steel; Patented Steel.—A steel heat treated so as to contain a large proportion of sorbite; the same as sorbitic steel.
 Patented Wire.—See page 509.
 Patience.—See page 333.
 Pattern.—See page 296.
 Pattern Maker's Rule.—See page 296.
 Paweck Process.—See page 371.
 Paxson-Deemer Converter.—See page 24.
 Pea Coal.—See Coal.
 Pea Coke.—See page 97.
 Pean.—See Pane.
 Pearlite.—See page 273.
 Pearlite-Cementite.—See page 273.
 Pearlite-Ferrite.—See page 272.
 Pearlite Point.—See page 273.
 Pearlite Range.—See page 271.
 Pearlitic Cementite.—See page 273.
 Pearlitic Ferrite.—See page 272.
 Pearlitic Range.—See page 273.
 Pearlitic Special Steels.—See page 445.
 Pearloid.—See page 213.
 Pearly Constituent.—See page 273.
 Pearlyte.—See page 273.
 Peat.—A dark brown fuel resulting from the decay of small plants and mosses, occurring in bogs or swamps. It contains up to 80% of water, and must accordingly be dried before using. It is practically never employed in metallurgy. An average sample, after drying, shows:

Carbon	56.0%
Hydrogen	5.5
Oxygen	29.5
Nitrogen	1.5
Ash	7.5

- Peat Charcoal; Coke.—Produced by the destructive distillation of peat; it is not of metallurgical importance.
 Peckham Process.—See page 387.
 Peel; Peel Bar.—(1) A long iron bar, flattened out at one end like a spade, used for charging or withdrawing material from a furnace by hand; (2) in charging machines, the arm which engages with

- the charging boxes to dump their contents in the furnace; (3) the hoe-like plate on the end of a rabble.
- Peel Charging.**—See page 313.
- Peen; Pein.**—See Pane.
- Peening Test.**—See page 482.
- Pelilot Method.**—See Iron.
- Pellin Hardness-testing Machine.**—See page 478.
- Peltier Effect.**—See page 209.
- Peltoid.**—See page 290.
- Pene.**—See Pane.
- Penetration.**—Of carbon: see page 67.
- Penetration Twin.**—See page 124.
- Pentad; Pentavalent.**—See page 86.
- Pepper Blister.**—See Blister.
- Per-.**—Chemical prefix; see page 88.
- Percarbide.**—See page 278.
- Percussion Test.**—See page 481.
- Percussive Electric Welding.**—See page 504.
- Perfect Cleavage.**—See page 124.
- Perfect Elasticity.**—See page 330.
- Perfect Gas.**—See Gas.
- Period of Elasticity.**—See page 334.
- Periodic Law.**—See page 85.
- Perlite.**—See page 273.
- Permanent Distortion.**—See page 334.
- Permanent Mold.**—See page 296.
- Permanent Set.**—See pages 334 and 470.
- Permanent Stretch.**—See page 336.
- Permissible Working Stress.**—See page 468.
- Peroxide Theory.**—Of passivity: see page 364.
- Perpetual (obs.).**—Of the action of furnaces, processes, etc., continuous.
- Perret Method.**—Of quenching: see page 229.
- Perrins Process.**—See page 490.
- Perturbation.**—See Curve.
- Peter Process.**—See page 387.
- Petroleum.**—A heavy yellowish or dark-colored oil of natural origin. It has a high calorific power, and may contain a little sulphur which is usually higher in the Russian than in the American product. It is used to a certain extent for heating, in which case it is injected into the furnace in the form of spray. Its composition is approximately:
- | | |
|---------------|-------|
| Carbon | 85.0% |
| Hydrogen..... | 13.5 |
| Oxygen..... | 1.5 |
- Petroleum Furnace.**—A furnace in which petroleum is used for fuel. It is usually sprayed in (atomized) with a jet of air or steam.
- Pettitt Process.**—See page 22.
- Pewter.**—Of rails which are soft and are battered in service.
- Phantom.**—See page 289.
- Phase; Phase Doctrine; Field.**—See Phase Rule.

Phase Rule (Gibbs).—Or **phase doctrine** (Roozeboom); a rule for finding the number of phases that can exist in a system containing a certain number of components, and having a certain number of degrees of freedom. It connects together the number of components, degrees of freedom, and possible phases in equilibrium (Gibbs). A **system** is a body composed of two or more components or phases. Bancroft defines **phase** as "a mass chemically and physically homogeneous or a mass of uniform concentration, the number of phases in a system being the number of different homogeneous masses, or the number of different concentrations;" and **components** as "the substances of independently variable concentration in the phase or system under consideration." Howe says: "The components are the entities in play, the entities of which we are studying the reciprocal behavior; the phases are the states, physical and chemical, in which these components exist and into which they pass." A careful distinction must be made between the terms component and constituent: the **constituents** of a system are the chemical elements or compounds present, or capable of being present, as such; a constituent may occur in more than one phase, or more than one constituent may unite to form a single phase. For example, the constituent water may exist at the same time both as ice and as water; the constituents calcium oxide and carbon dioxide (each of which may be a component) can unite to form the single component calcium carbonate. To avoid confusion in the use of the term "phase" which has this specific meaning, Turner has suggested that **stage** be applied to indicate different conditions or structures as in the case of pearlite.

In regard to the applications and limitations of the phase rule, Howe says (*Metallography*, 231): "It is a most remarkable and valuable generalization; its conceptions help greatly toward getting a broad outlook on metallography; but its misconception has brought out a flood of obscuring writings. It tells us about the constitution toward which alloys tend, that which they reach when equilibrium is complete, when all tendencies have asserted themselves and have been compiled with completely. But it tells us nothing directly about the intermediate stages through which those alloys pass in their attempt to reach that equilibrium, nothing about alloys which are out of equilibrium. And whatever it may teach us indirectly about such **inequilibrium** (**incomplete equilibrium**) is so hedged about with the direct and indirect results of that inequilibrium that its application to any individual case is fraught with the greatest difficulty."

Equilibrium is the condition of a system with regard to the existing conditions. If the system is **normal**, *i.e.*, that which can exist under the given conditions, it is said to be in **stable equilibrium**, otherwise in **unstable equilibrium**. If a system is in unstable equilibrium, any change in the conditions tends to cause a **transformation** to take place, *i.e.*, a change to stable equilibrium. Where, with change of temperature a transformation (**thermal transformation**) should occur at a definite tempera-

ture (equilibrium or inversion temperature) but, owing to molecular inertia (lag, hysteresis, or internal friction), cannot do so instantaneously, a certain range of temperature may be traversed before the tendency is great enough to cause the transformation, after which the slightest disturbance will suffice. During this range of temperature (**metastable range**) the system is said to be **metastable** or **indifferent equilibrium**; beyond it (**labile range**), in **labile equilibrium**. In the case of steel in stable equilibrium above or below the transformation range, reference is sometimes made respectively to the **hot stable state** and the **cold stable state**. **Thermal equilibrium** is where the members of a system are at the same temperature. The case of the cooling of solutions which can be cooled without solidification below the normal freezing point is called **surfusion** or **undercooling**. **Equilibrium diagrams** are those which show the normal relations between concentrations (composition) and temperatures (and in some cases pressures); where metastable states are plotted they are called **metastable diagrams**. In an equilibrium diagram the different regions are termed **phase fields**. Where the transformation occurs at the same temperature either on heating or cooling, it is said to be **reversible**; if, due to lag, at different temperatures, an **irreversible** or **non-reversible transformation** or **process**. If the transformation can proceed only in one direction without any reverse change at all, it is then termed **monotropic**. Where the radiation from a body is counterbalanced by an equal evolution of heat, it is an **isothermal transformation**. A **polymorphic transformation** or **allotropic transformation** is where the change is from one form to another, as from gamma into alpha iron.

The phase rule may be written as an equation of equilibrium which has been deduced from thermodynamical considerations as

$$F = C + 2 - P$$

F = degree of freedom; C = number of components; P = number of phases. The **degree of freedom** (also termed **degree of liberty**, **degree of constitutive freedom**, and **degree of variability**) is whether the existing constitution of a system has such a degree of stability that it can survive a change of temperature or of concentration, or cannot (Howe).

An **invariant** or **non-variant system** is one which cannot survive any change in temperature, pressure, or concentration; a **monovariant system** is one which can survive a change in any one of these conditions, and a **divariant system** in one which can survive a change in one of the conditions if a conformable change is made in one of the others. "The degree of liberty of a non-variant system is 0, that of a monovariant system 1, and of a divariant system 2" (Howe). A system with n components can exist (a) if non-variant in $n + 2$ phases, (b) if monovariant in $n + 1$ phases, and (c) if divariant in n phases. A monovariant system is called a case of **complete heterogeneous equilibrium**, while a divariant system is known as a case of **incomplete heterogeneous equilibrium** (Bancroft). "If a

system is uniform throughout its whole extent, and possesses in every part identical physical properties and chemical composition, it is called **homogeneous**. Such is, for example, a solution of sodium chloride in water. An equilibrium occurring in such a homogeneous system (such as the equilibrium occurring in the formation of an ester in alcoholic solution) is called **homogeneous equilibrium**. If, however, the system consists of parts which have different physical properties, perhaps also different chemical properties, and which are marked off and separated from one another by bounding surfaces, the system is said to be **heterogeneous (non-homogeneous)**. Such a system is formed by ice, water, and vapor, in which the three portions, each in itself homogeneous, can be mechanically separated from one another. Where equilibrium exists between different, physically distinct parts it is known as heterogeneous equilibrium" (Findlay, *The Phase Rule*, 5). To **homogenize** is sometimes used to signify the obtaining of equilibrium for given conditions of temperature and concentration.

Le Chatelier's theorem states that "any change in the factors of equilibrium from outside is followed by a reverse change within the system."

Bancroft suggested that "it would be well to keep the term **adsorption** for effects which may prove to be due primarily to surface tension, and to treat **absorption** as the general term applying to liquid and solid solvents, while **occlusion** would refer only to the formation of solid solutions." With the object of explaining this **adsorption theory**, W. R. Whitney says (*Proc. Am. Electrochem. Soc.*, 1915, 187): "I cannot accurately differentiate between absorption and adsorption. We usually have adsorption in phenomena going on at a surface when something comes to it and clings there. But a sponge is made of a lot of interior surfaces, therefore a sponge would adsorb and not absorb. I think you will find the water is held on the surface in the pores. Glass surfaces adsorb from solutions; if you analyze the surface solution you will find the material in the solution has increased in concentration on the surface of the glass."

Phenocellular Structure.—See page 126.

Phenocryst.—See page 125.

Philosopher's Wool.—See Zinc.

Phosphate Ore.—See page 244.

Phosphide Phosphorus.—See Phosphorus.

Phospho-Ferrite.—See page 272.

Phospho-Manganese.—See page 353.

Phosphoretic.—Phosphorous; containing phosphorus.

Phosphoretic (Phosphoric) Cast Iron; Pig.—See page 346.

Phosphorous (adj.).—Containing phosphorus.

Phosphorus.—(1) In iron ore: see page 243; (2) influence on corrosion: see page 366.

Phosphorus.—P; at. wt., 31; melt. pt., 43.3° C. (78° F.); boil. pt., 269° C. (516° F.); sp. gr., yellow, 1.82, red, 2.25. It is never found in the free state, its most important occurrence being in combination with oxygen and various metallic ele-

ments, called phosphates. In its elemental condition it may occur in one of two allotropic forms: the ordinary variety which is a colorless or yellow wax-like poisonous solid, and another variety of reddish color, and non-poisonous, obtained by heating the ordinary variety to between 240° and 250° C. (464° and 482° F.) with exclusion of air; when heated to above 260° C. (500° F.) it passes back to the yellow variety. This latter is very inflammable and must be kept under water. It is the most undesirable impurity which occurs in steel, causing cold-shortness and, perhaps, to a slight extent, red-shortness. It is usually limited to 0.05% in basic, and 0.10% in acid steel, except for some special purpose. In cast iron it makes the molten metal more fluid. Baron Juptner suggests that in analogy to the different modifications of carbon it is possible to describe one form of phosphorus which, upon treatment of steel with dilute acids, escapes as PH_3 , and which causes cold-shortness, as **hardening phosphorus**, while the modification, insoluble in dilute acids, may be named **phosphide phosphorus**.

Phosphorus Additions.—See Recarburization.

Phosphorus Banding.—See page 289.

Phosphorus Reagent.—For detecting phosphorus on etching: see page 287.

Photogram; Photograph.—See page 284.

Photometer.—See page 208.

Photomicrograph; micrography; microscopy.—See page 284.

Physic; Physick; Physicking.—A term, usually restricted to the puddling and the crucible process, for an addition made with the object of assisting in the removal of the impurities, and the more rapid working of the heat; it may act chemically or simply as a flux. It may consist of a mixture of manganese dioxide with salt or a little ground charcoal, sal ammoniac, prussiate of potash, ground glass, fluorspar, etc.

Physical Analysis.—See page 284.

Physical Formulæ.—See page 337.

Physical Hardness.—See page 331.

Physical Metallurgy.—Suggested by Rosenhain for "that great branch of the knowledge of metals which has to a large extent grown up during the last fifty years—a branch which concerns itself with the nature, properties and behavior of metals and of alloys as such, as distinct from the far older branch of metallurgy which deals with the reduction of metals from their ores. Hitherto the term Metallurgy has indeed been almost entirely confined to this latter meaning, and those who have grown old in this idea are a little apt to resent an innovation which gives to the old term Metallurgy a wider and more general meaning than it formerly bore so as to include the newer knowledge of metals. This inevitable widening of the old term, however, demands a subdivision, so that the department of metallurgy which relates to the reduction of metals and their refining may well be termed **Process** or **Chemical Metallurgy**, leaving to the younger branch of the science the newer term **Physical Metallurgy**." (*Phys. Met.*, 1.)

Physical Properties.—(See also Testing.) Those properties ex-

hibited by a body which do not involve any change in its chemical composition. The general treatment of the subject in treatises and text books is usually under the title of **Strength of Materials** or **Properties of Materials** for which Ewing gives the following definition (Ency. Brit.): "That part of the theory of engineering which deals with the nature and effects of stresses in the parts of engineering structures. Its principal object is to determine the proper size and form of pieces which have to bear given loads, or, conversely, to determine the loads which can be safely applied to pieces whose dimensions and arrangement are already given. It also treats of the relation between the applied loads and the changes of form which they cause. The subject comprises experimental investigation of the properties of materials as to strength and elasticity, and a mathematical discussion of the stresses in ties, struts, beams, shafts and other elements of structures and machines." When a body possesses the same properties, no matter in what direction it is tested, it is said to be **isotropic**; when they differ in different directions, **anisotropic**, **aeolotropic** or **eolotropic**. Those here discussed are principally what are met with in testing (*q.v.*) materials.

The **strength** or **tenacity** of a body is its **resistance to rupture or breaking**, and may be of the following kinds:

1. **Tensile (tensional) strength** (sometimes referred to as **tensile strain**): resistance to being pulled apart.
2. **Compressive strength**: resistance to being crushed.
3. **Shearing strength**: resistance to being sheared or cut; the next two are also of this kind.
4. **Torsional strength**: resistance to torsion or being twisted.
5. **Bending, transverse or flexural strength**: resistance to flexure or bending.

A division may also be made into

6. **Static strength**: resistance to loads slowly and gradually applied.
7. **Dynamic strength**: resistance to loads suddenly applied (**shocks**) or repeated stresses.

Elasticity is the ability of a body to regain its original shape after having been distorted. This definition covers **perfect elasticity**; however as bodies seldom meet this condition entirely they are said in such case to possess **imperfect elasticity**. The distortion from which an **elastic** body can recover may be termed **elastic deformation** or **elastic strain** and the maximum stress under which this condition obtains is called the **elastic limit**, corresponding to the **elastic strength** or **elastic limit strength** for the material. In the *Quarterly Mathematical Journal* of April, 1855, Sir William Thompson (Lord Kelvin) discussed at some length the **thermo-elastic** properties of material, and showed mathematically that elastic matter when stressed absorbs heat, that is, its temperature as indicated by a thermometer is lowered; but when the stressing is carried beyond the elastic limit and the strain becomes permanent, the body gives out heat, that is, its temperature as indicated by a thermometer, rises (Capp). **Rigidity** or **stiffness** is the property by virtue of which bodies resist change of shape.

Resilience, or the work of resistance of materials, is frequently used in the same sense as elasticity. It connotes springiness and should properly be restricted to the amount of work absorbed when a body is stressed within its elastic limit and which can be recovered when the stress is removed; this is sometimes also termed **elastic resilience** which however seems redundant. Depending upon the nature of the stress there may be **tensile** or **compressive resilience**, **shearing**, **bending** or **flexural resilience**, and **torsional resilience**. The **modulus of resilience** is the work per unit volume in stressing up to the elastic limit and is equivalent to half the product of the elastic limit strength and the corresponding unit deformation.

The opposite of elasticity or resilience, when the slightest distortion or deformation (change of form) is permanent is called **plasticity**: no substance possesses either property absolutely. **Plastic** or **viscous** materials flow under a compressive load.

Hardness is resistance to indentation, or **abrasion** or **attrition** (wear from rubbing or crushing). **Abrasive hardness** is also known as **scratch hardness**. **Static hardness** is where the force acts relatively slowly as in the Brinell ball test (see Testing, page 477) or ordinary abrasion. **Dynamic hardness** is where the force acts suddenly as in the scleroscope test (see Testing, page 478); this term has also been suggested by Turner to cover resistance to the action of running water, to a sand blast, etc. A substance may be said to possess **chemical hardness** when this is due principally to its composition; **physical hardness** when due to its chemical and mechanical structure; and **mechanical hardness** when resulting from being worked, particularly cold, also known as **work hardness** and **strain hardness**.

Brittleness is the tendency to rupture under shock or loads suddenly applied; the opposite of this is **toughness**. Hardness and brittleness are not necessarily allied, as shown by manganese steel which is very hard and yet at the same time may be tougher than ordinary steel.

Malleability is the property which permits a metal to be hammered or pressed out into shape without cracking: **ductility** is practically a synonymous term but is applied more especially to that form of toughness which permits a metal to be drawn or drawn down. It was noted by A. LeChatelier that between 80 and 120° C. (175 and 250° F.) there was a **critical mechanical temperature** at which steel exhibited its minimum ductility. Ordinarily it is understood that any reference to the ductility of a body means when it is cold, otherwise the terms **hot ductility** and **cold ductility** (only in contradistinction) would be used. The term **cito-ductile** is sometimes applied to a body which can be stretched suddenly without rupture.

A force acting on a body is known as a **stress**: if it affects the entire body (e.g., gravity) it is termed a **body force** or **volume force**; if it acts only upon local portions (the pressure of one object against another) it is a **surface force** or **surface traction**. A force or stress may act either from outside a body (**external**

force) or from within (**internal force**). "The terms **axial forces** and **axial stresses** are used to include both tension and compression acting upon a bar, it being understood that the resultant of the applied forces acts along the axis of the bar. The axial force P is often called a **load**. It is always understood, unless otherwise stated, that the stresses due to an **axial load** or **concentric load** are uniformly distributed over the section area, and this is called the case of **simple axial stress**" (Merriman). Stresses (or strains) may be (a) **normal** or **direct** (**tensile** or **compressive**), (b) **shearing**, **flexural** or **tangential**, and (c) a component of the two or **oblique**. If the stress is in only one direction it is a **simple stress**; if in different directions a **compound stress**. "It may be shown that any state of stress which can possibly exist at any point of a body may be produced by the joint action of three simple pull or push stresses in three suitably chosen directions at right angles to each other. These three axes are called **principal stresses**, and their directions are called **axes of principal stress**. These axes have the important property that the intensity of stress along one of them is greater, and along another it is less, than in any other direction. These are called, respectively, the axes of **greatest** and **least principal stress**" (Ewing). As in the case of a liquid at rest, but where there are balanced stresses exerted upon it, such an effect is termed a **fluid stress**. Those directly produced by loadings may be called **primary stresses**; and further stresses, acting in conjunction with these, **secondary stresses** (Carpenter).

The term **pure stress** is employed where only one kind of stress exists. Where a plane is acted upon only by forces normal to it, this is sometimes called **pure normal stress**. Where a plane is acted upon only by forces parallel to it it is sometimes called **pure shearing stress**. Another use of the term **pure stress** is with respect to any and all planes that can be imagined drawn in the interior of a body. Where the forces acting upon the body have such values that there can be no shearing stresses within it, the case is called one of **pure internal normal stress**. The term **pure flexure** is used for a part of a beam where there are no vertical shears (Merriman). **True stresses** are those actually determined while those simply calculated are **apparent stresses**.

Owing to various conditions, such as irregular cooling, cold distortion, etc., an **unstressed body** is only theoretically possible, and consequently all bodies are more or less (internally) **self-stressed** or **self-strained**. A body with internal strains at a minimum is said by Pearson to be in a **state of ease**. Heyn calls outside stresses acting on such a body **additional stresses**. **Internal strains** may be set up by unequal expansion or contraction in different parts of a piece due to irregular heating or cooling or to transformations (**transformation strain**) of state (see Metallography, p. 264). In material cold drawn in the direction of its axis the outer layers are under tension and the inner layers are under compression, whereas in the case of cold-rolled and cold-hammered bars the reverse is true. In either case if the tensile stresses are excessive rupture may be caused (**spontaneous**

cracking—in the case of the cold-rolled or cold-hammered bars, **internal rupture, fracture, or defect**). If such strains are not excessive they may be removed by a suitable annealing (see Heat Treatment, p. 231). When a body is struck, **vibrations or waves** are set up in it, the effect depending on the frequency or number per second. In conducting experiments the stress originally present is known as the **initial stress**. The **range of stress** is the algebraic difference between the maximum and the minimum; the **mean stress** is half the algebraic sum.

The effect of a stress depends largely upon the manner in which it is applied. Thus when suddenly applied, as a blow (**sudden load, accelerated stress, impact or shock**), it has a considerably greater effect than a stress slowly and steadily applied (**static stress or load**). Again, if the stress is **repeated, i.e.**, applied a great number of times, each application being made before the material has been given time to recover from the preceding, it will eventually break, even though the stress is below the elastic limit as ordinarily understood. For practical purposes, if the stress is sufficiently small, and below what may be termed the **fatigue limit or endurance limit**, its repetition may be indefinitely continued. **Alternate stresses** are similar in effect, but are where the force acts first in one direction and then in the opposite. It will therefore be seen that stresses may vary from + to - (e.g., tensile to compressive) or from a higher to a lower value with the same sign (**stress difference or limiting stresses**). They are termed **dynamic stresses or loads** (producing corresponding **dynamic deformations or strains**) and are covered by **Wöhler's law**, which may be stated thus: Rupture of material may be caused by repeated **vibrations**, none of which attains the actual breaking limit; the difference of the limiting strains are sufficient for the rupture of the material. When a metal is subjected to a stress its component particles may become so disturbed and disarranged (see Plastic Deformation, under Metallography, p. 279), within the limits of elasticity be it understood, that after the removal of the stress, and it is left at rest, some time, and in certain cases considerable time, must elapse before the particles will have spontaneously readjusted themselves as they originally were. The term **fatigue or elastic break-down**, is meant to indicate such disturbance; the terms **refreshment, recovery, aging, or elastic after-working**, restoration of the metal to its original state; and the term **patience**, the time required for that restoration. If a body is subjected to a change of temperature and is acted upon by a force which tends to prevent the corresponding expansion or contraction, stresses are set up which may be termed **temperature stresses**.

Intensity of stress (unit stress) is the force exerted per unit of area; in English units, pounds or gross tons (England) per square inch, and in metric units, kilograms per square millimeter or per square centimeter.

Every stress, no matter how small, produces a corresponding **strain (tensile strain, compressive strain, etc.) or deformation** in the shape of the body acted upon, and which increases with the

stress. The stress and the corresponding strain are directly proportional up to a certain point, called the **elastic limit** (**limit of linear elasticity**, etc.), below which, by removing the stress, the corresponding strain disappears and the body returns to its original shape, or, in other words, is **elastic**. This fact constitutes **Hooke's law** or the **limit of proportionality**. After this period has passed, the strain increases more rapidly than the stress causing it, and if the stress be now removed, the body will partially, but not entirely, regain its original dimensions, as it has received a **permanent distortion** (**permanent set**, **overstrain**, **plastic strain**). **Gerstner's law** is that elastic deformations are proportional to the loads producing them both before and after permanent set. **Relative deformation** is the deformation per linear unit. The period before the elastic limit is reached is known as the **period of elasticity**. The point at which the elastic limit is exceeded is called the **yield point** or **breaking-down point**. If a material has been **overstrained** (a permanent set produced) and is immediately reloaded it will be found to have no true elastic limit (although its yield point will be about the same), also its ductility is lowered. If it is allowed to **recover** by resting (**aging**) several days or weeks, or is heated for a few minutes at the temperature of boiling water, a true elastic limit will be found, but higher than in the original material, and also the ductility will be increased (**spontaneous annealing**). If, instead of again testing in tension, it is tested in compression, the elastic limit will be lower than in the original material, but not necessarily to the extent that the tensile elastic limit and yield point have been raised. This is known as the **effect of hardening**, or the **hardening effect of permanent set**. **Vical's experiment** proved that heavily loaded material is likely to yield ultimately under loads that are sustained for short periods without apparent injury. **Emory's process** for increasing the elastic limit of material (particularly structural material such as eye bars) consisted in cold straining the material tensily slightly above its elastic limit or yield point; the load was then removed and the material annealed at a very low temperature, say not over 300 or 400° C. (570 or 750° F.). The effect of the cold straining was to destroy the true elasticity limit of the material which was restored to a higher point than before, by the annealing. The **modulus** (rarely **module**) or **coefficient of elasticity** or **Young's modulus** (first applied for extension only) is the ratio, within the limits of elasticity, of the stress to the corresponding strain, *e.g.*, the load in pounds per square inch divided by the deformation in fractions of an inch for each inch of gaged length of the specimen. It may be said to be the stress which would have to be applied to stretch the piece to double its original length assuming it to be perfectly elastic. This, of course, is impossible as the limit of elasticity of practically any material is passed when it has been deformed to about 0.001 of its length. For steel in tension or compression it varies from about 26,000,000 to 31,000,000 pounds per square inch, the more usual limits being between 28,000,000 and 30,000,000 pounds per square inch. The corresponding values

in the metric system (kilograms per square millimeter), wide limits, 1828 to 2179; usual limits, 1969 to 2109. The values for a material in tension (modulus of longitudinal extension or extensibility) are generally slightly higher than those for compression (modulus of compression or compressibility or bulk modulus). The modulus of elasticity "may also be called modulus of stiffness since it is a direct measure of the rigidity of a body (modulus of rigidity) or an inverse measure of its flexibility; a modulus of flexibility would be the reciprocal of the modulus of elasticity, but Prof. A. B. W. Kennedy has taken for such a modulus of specific extension the stretch in thousandths of an inch on a length of 10 inches under a stress of 1000 pounds per square inch. Its reciprocal multiplied by 10,000,000 is the modulus of elasticity" (Johnson). The shearing modulus of elasticity (modulus of elasticity for shear; modulus of shear) is the ratio of the shearing stress to the corresponding angular strain,

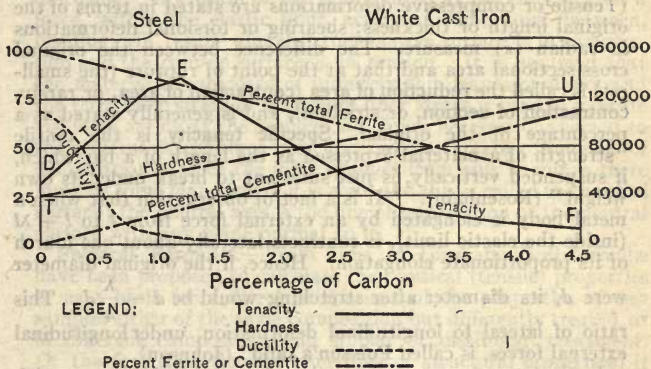


FIG. 48.—Physical properties and assumed microscopic constitution of the pearlite series, graphiteseless steel slowly cooled, and white cast iron. (Howe, "Iron, Steel and Other Alloys.")

and is two-fifths of the modulus for extension. "The volumetric modulus of elasticity of a solid body for an equal stress in all directions is two-thirds of Young's modulus which applies only to direct stress in one plane and its accompanying deformation" (Johnson). For compression it is termed the modulus of cubic compressibility.

If the stress be increased sufficiently, the body will eventually be broken or else distorted to such an extent that the force can no longer act, and in the former case this maximum stress (maximum load) applied is known as the ultimate strength of the body (sometimes referred to as the ultimate stress). The elastic ratio is the ratio between the elastic limit and the ultimate strength, the former figure being divided by the latter, it is sometimes expressed as a percentage.

The maximum tensile stress (**tensile strength**) does not necessarily correspond with the **breaking load** (**breaking or tearing stress**) at the moment of rupture, although this distinction is not always made, on account of the reduced cross-section. Here as the material is stretched longitudinally, it is obvious that it must contract with respect to its cross-section. This contraction, however, even in the case of a body having originally the same cross-section throughout, is not uniform, but at some portion an action called **necking** or **bottling** occurs, *i.e.*, the contraction is much more pronounced and rupture will occur there. The amount of **permanent stretch** upon rupture is called the **elongation** (**extension or stretch**) and is usually expressed as a percentage of the original length, *e.g.*, 25% in 8 inches. This percentage is a function of the relation of length to cross-section (see Testing, page 473) and therefore, in reporting it, the dimensions of the specimen in question should always be given. (Tensile or compressive deformations are stated in terms of the original length or thickness; shearing or torsional deformations in radian (π) measure. The difference between the original cross-sectional area and that at the point of rupture (the smallest) is called the **reduction of area** (**contraction of area**, or rarely, **contraction of section**, or **striction**), and is generally stated as a percentage of the original. **Specific tenacity** is the tensile "strength of a material expressed as the length of a bar which, if suspended vertically, is just sufficient to break under its own weight" (Rosenhain). "It is a fact of observation that when a metal body is elongated by an external force from l to $l + \lambda l$ (inside the elastic limit), it contracts laterally about one-fourth of its proportionate elongation. Hence, if the original diameter were d , its diameter after stretching would be $d - \frac{\lambda}{4} d$. This ratio of lateral to longitudinal deformation, under longitudinal external forces, is called **Poisson's ratio**" (Johnson).

In the case of **compression** "there is no such thing as an ultimate strength of a plastic body. There is, however, a definite apparent elastic limit, the same as in tension. Beyond this the material simply spreads" (Johnson). This is, therefore, the **elastic compressive strength** or **compressive strength**. "The term **bearing compression** is in common use for the sidewise compression brought upon a rivet by the tension in the plate. Rivets are more apt to fail by shearing than by bearing compression" (Merriman). The ductility is indicated by the **shortening** or **ultimate shortening** (upon rupture) which however is rarely determined, for obvious reasons, particularly in the case of very ductile bodies.

"When a beam is laid upon supports its weight and the weight of its load are borne by the supports which exert **reactions** upward against the beam. The **vertical shear** for any section of a beam is a measure of the tendency to shearing along that section . . . being greatest near the supports . . . The usual method of failure of beams is by **cross-breaking** or **transverse rupture**. This is caused by the external forces producing rota-

tion around some point in the section of failure (plane of shear). **Resisting shear** is the name given to the algebraic sum of the internal vertical stresses in any section, and **vertical shear** is the name for the algebraic sum of the external vertical forces on the left of the section. **Resisting moment** is the name given to the algebraic sum of the moments of the internal horizontal stresses with reference to a point in the section, and **bending moment** is the name for the algebraic sum of the moments of the external forces on either side of the section with reference to the same point" (Merriman, *Mechanics of Materials*, 93-98). **Simple shear** is where there are only two principal opposite forces of equal value. **Single shear** (in the case of rivets, for example) is where the object is supported at only one end; in the case of **double shear** both ends are supported. **Flexural rigidity** is used in the same sense as flexural or shearing strength, the resistance offered to **flexural stress**. **Transverse strain or deformation** is also termed **detrusion**. If a beam or bar is supported at the ends against a force, within the elastic limit, acting at some point between, bending will result whereby the concave surface is in compression and the convex surface is in tension. It is assumed that the material is composed of infinitely thin leaves or **fibers** and the term **fiber stress** or **maximum fiber stress** is used to indicate the force acting at the surfaces which are necessarily affected to the greatest extent since they undergo the greatest amount of deformation. Since the force changes from plus to minus there must be some plane where it is zero, and this is called the **neutral surface**; the **neutral axis** is the line of intersection of the neutral surface with any plane normal to it.

Physical Formulæ.—From time to time empirical formulæ have been proposed to calculate the physical (tensile) properties or as a basis for a direct comparison of the properties of two samples either of the same composition but differently treated, or of different composition and similar or dissimilar treatment. Of the first class (**tensile properties** or **structural properties**) it may be said they are based on the assumption that the properties are **additive**, *i.e.*, proportional to the composition or a summation of the properties of the individual components. This, unfortunately for the purpose, is usually far from being the case, and in addition there are so many other factors entering into the problem, such as size, mechanical and thermal treatment, that to determine accurately their bearing would generally be much more difficult, and even the real result would be left in considerable doubt, than to make a direct test.

Tensile Formulæ.—These in turn may be divided into: (a) **chemical formulæ**, based on ultimate chemical composition; (b) **structural formulæ**, based on microscopic or proximate chemical analysis. Sauveur distinguishes between **proximate structural composition**, *e.g.*, ferrite and pearlite, or cementite and pearlite, and **ultimate structural composition**, *e.g.*, the total ferrite and cementite both free and contained in pearlite.

(1) **Chemical Formulæ.**—**Bauschinger's** formula for tensile strength of Bessemer steel:

$$T. S. = 43.64 (1 + C^2)$$

T. S. in kilograms per square millimeter; C = carbon %.

H. H. Campbell's formulæ for tensile strength:

(a) for acid steel, carbon by combustion:

$$T. S. = 40,000 + 1000 C + 1000 P + x Mn + R$$

(b) for basic steel, carbon by combustion:

$$T. S. = 41,500 + 770 C + 1000 P + y Mn + R$$

The strength is in pounds per square inch. C, P, and Mn are the values of these elements given in hundredths of a percent. The coefficients x and y are given in tables (see *Manufacture and Properties of Iron and Steel*, 391). R is a variable to allow for heat treatment which must be specially determined. See modified formulæ below as proposed by Merriman.

Cunningham's formula for tensile strength for acid and basic open hearth steels, based on his values for pure iron, carbon, and phosphorus, may be stated as follows:

$$T. S. = 40,000 + 100,000 C + 100,000 P$$

T.S. in pounds per square inch; values for C and P in percent.

Deshayes' formulæ:

(a) Tensile strength:

$$T. S. = 30.09 + 18.05 C + 36.11 C^2$$

T. S. in kilograms per square millimeter; C = percentage of carbon.

(b) Elongation:

$$\begin{aligned} E_{20} &= 42 - 56 C \\ E_{10} &= 35 - 30 C \end{aligned}$$

E_{20} and E_{10} are percentage of elongation in lengths of 20 and 10 centimeters (approximately 8" and 4") respectively; C = percentage of carbon.

Howe's formulæ for elongation, percent in 3 inches:

(a) for steel under 0.50% carbon:

$$E = 33 - 60 (C^2 + 0.1)$$

(b) for steel between 0.50 and 1.00% carbon:

$$E = 12 - 11.9 \sqrt[3]{C - 0.5}$$

Merriman's formulæ for tensile strength:

(a) Deduced from Campbell's formulæ:

Acid steel: $T. S. = 40,000 + 68,000 C + 100,000 P + 80,000 CM$;

Basic steel: $T. S. = 38,800 + 65,000 C + 100,000 P + 9000 M + 40,000 CM$.

T. S. in pounds per square inch; values for C, P, and M (Mn) are in percent (not in hundredths of a percent as in Campbell's original formulæ).

(b) Approximate values for open hearth steel unannealed:

Acid steel: 45,000 + 108,000 C

Basic steel: 45,000 + 90,000 C

Salom's formula for tensile strength (average values):

$$T. S. = 31.74 + 70.53 C$$

T. S. in kilograms per square millimeter; C = percentage of carbon.

Sauveur's formulæ (*Metallorgaphy*, p. 138 et seq.):

(a) Tensile strength:

(i) Hypo-eutectoid steels (carbon not over 0.834%)

$$T. S. = 50,000 + 90,000 C$$

(ii) Hyper-eutectoid steels (carbon over 0.834%)

$$T. S. = 142,000 - 20,600 C$$

(b) Elongation, percent in 2", for hypo-eutectoid steels:

$$E = 40 - 36 C$$

Thurston's formula for tensile strength (minimum values):

Unannealed steel: T. S. = 42.32 + 49.37 C

Annealed steel: T. S. = 35.27 + 42.32 C

T. S. in kilograms per square millimeter; carbon in percent.

Webster's formula for tensile strength, based on his values for pure iron, carbon, phosphorus and sulphur, may be stated as follows:

$$T. S. = 34,750 + 80,000 C + m P + 50,000 S$$

T. S. in pounds per square inch; C, P, and S in percent; m a variable, depending on the carbon content, from 80,000 to 150,000. A former value assigned for pure iron was 38,000.

Weyrauch's formula for tensile strength (minimum values):

$$T. S. = 44.17 (1 + C)$$

T. S. in kilograms per square millimeter; C = percentage of carbon.

(2) **Structural Formulæ.**—Sauveur's formulæ: These are based on the assumption that the tensile strength in pounds per square inch is for ferrite 50,000, for pearlite 125,000, and for cementite 5000; the percentage of elongation in 2" for ferrite 40, and for pearlite 10 (no estimate for cementite):

(a) Tensile strength:

(i) Hypo-eutectoid steels:

$$\begin{aligned} T. S. &= 500 F + 1250 P \\ &= 50,000 + 750 P \end{aligned}$$

(ii) Hyper-eutectoid steels:

$$\begin{aligned} T. S. &= 1250 P + 50 C m \\ &= 5000 + 1200 P \end{aligned}$$

(b) Elongation, percent in 2", for hypo-eutectoid steels:

$$E = 0.4 F + 0.1 P \\ = 40 - 0.3 P$$

F, P, and Cm = respective percentages of ferrite, pearlite, and cementite.

Quality Formulæ.—These are for the purpose of comparing the properties of a specimen with a standard, or of two or more specimens with each other to decide their relative merits. To illustrate why this is sometimes desirable, a piece of steel may be likened to a photographic plate. The plate is capable of producing a beautiful result provided it is suitably prepared, properly exposed and carefully developed; a mistake in any one of these processes will result in a defective negative. In the same way, the steel if of suitable composition has latent possibilities which can only be brought out to their fullest extent by the greatest attention to every detail in its handling and treatment. Examples of how this works out will be given below. The figure used for the comparison is termed the **figure of merit, merit number or quality figure**. The formulæ are based on the well-known fact that, under the same general conditions, as the strength increases the ductility decreases, and *vice versa*; and while the assumption that they are inversely proportional is only approximately true, and for limited ranges, the deductions which may be drawn from it are sufficiently accurate for most purposes. The specimen showing the largest quality figure must possess the highest combination of strength and ductility and therefore be in the highest state of development, at least from an abstract viewpoint. There must, however, always be considered the purpose for which the material is intended. Thus, a sample with very high strength and comparatively low ductility might have a higher quality figure than another sample with much lower strength but higher ductility. For cold bending or flanging, the second would be the more suitable. Where the determinations are accurately made, the value for the elastic limit best represents the strength; with turned specimens the reduction of area is a more accurate measure of the ductility than the elongation which is more likely to be affected by the point of rupture and the shape of the specimen.

De Marre formula: (see Armor Plate, page 8).

British or English formula:

$$M = T + E$$

M = figure of merit; T = tensile strength in gross tons per square inch; E = elongation, percent, for specimens of identical or similar shape.

McKenna's formula:

$$M = T (E + 20)$$

M = figure of merit; T = tensile strength in pounds per square inch; E = elongation, percent, for specimens of identical or similar shape.

Tiemann's formula:

$$Q = S \times D$$

Q = quality figure; S = strength, either tensile strength, but preferably elastic limit in any unit; D = ductility, either elongation, but preferably reduction of area, percent, for identical or similar specimens. As examples of the last formula, taking the elastic limit as S and the reduction of area as D:

No.	Treatment	Tensile Strength	Elastic Limit	Elongation, %	Reduction of area, %	Quality Figure $\frac{Q}{(E.L. \times Red.)}$
1	Untreated	80,000	40,000	23	40	1,600,000
2	Untreated	85,000	42,000	21	36	1,512,000
3	Annealed	80,000	39,000	25	43	1,677,000
4	Quenched and Tempered (a)	90,000	55,000	26	55	3,025,000
5	Quenched and Tempered (b)	100,000	60,000	23	50	3,000,000

Nos. 1 and 2 are taken as samples of slightly different composition but having had the same treatment; Nos. 3 to 5, samples of the same composition but having had treatment as shown.

Obstruction Theory (Howe, *Metallography*, 389).—"The usual explanation of the increase of the tensile strength and elastic limit with the carbon content is, briefly, that the stronger pearlite stiffens the mass by impeding the flow of the weaker ferrite; and, going a step further, that the reason why pearlite, though made up of about 6 parts of ferrite to 1 of cementite, is yet so much stronger than pure ferrite, is that this pearlitic cementite thus stiffens the pearlitic ferrite. The pearlite in one case and the pearlitic cementite in the other, is said to "hold up" the ferrite. After discussing the "obstruction principle" I call attention to the **ferrite-refinement principle**, that the effects of increasing carbon contents may be due in considerable part to the accompanying changes in the grain size of the ferrite." See also Conduction (under Heat), page 200; Density, page 132; Expansion (under Heat), page 204.

Physical Solution.—See page 107.

Physical Test.—See page 467.

Physically Developed.—A term sometimes applied to material whose properties have been increased by cold working (e.g., cold twisted bars) as opposed to heat treating.

Physically Dissolved.—See page 107.

Physico-metallurgical (adj.).—Relating to physical metallurgy, *q.v.*

Piano Wire Gage.—See page 187.

Pickling.—The treatment of iron or steel with dilute acids for the purpose of obtaining a clean surface by removing the scale (oxide). When the action is completed the piece is washed in water (swilled) to free it from the adhering acid, and is sometimes

dipped into milk of lime (**liming**) to eliminate the last traces. The pickling fluid, when so exhausted that it can no longer be used profitably, is known as **spent acid** or **waste liquor**. In **Reed's pickling process** a solution of dilute sulphuric acid is used and the object to be pickled is made the cathode, the anode being a piece of lead. Pickling is of special application in the manufacture of sheets and tin plate (page 431), tubes (page 491), and wire (page 507).

Pickling Bath.—See page 507.

Picric Acid.—See page 287.

Piece.—The particular piece of metal under consideration, usually in connection with rolling or forging: see page 407.

Pielsticker and Müller Process.—See page 65.

Piercing.—Producing a hole in a body by forcing a pointed instrument through it, the displaced material being forced into the wall (distinction from punching).

Pietzke Process.—See page 380.

Pizeoglyps.—See page 293.

Piezometer.—See page 476.

Pig.—(1) See Pig Iron; (2) in the open hearth process: see page 314.

Pig Back.—See page 314.

Pig Bed.—See page 36.

Pig Boiling.—See page 374.

Pig Breaker.—A machine for breaking off the pigs from the sow or runner in the case of sand-cast pig iron.

Pig Casting Machine.—See Pig Machine.

Pig Face.—See page 68.

Pig Iron.—Sometimes called **pig metal**: (1) the name given to cast iron which is cast at the blast furnace into shapes known as **pigs** for convenience in handling and transporting after cooling; (2) also applied as a general term to the product of the blast furnace (either solid or molten) before treatment in some refining process, or casting into finished products. The name **pig** is derived from the old method of casting when the molten metal was led to the depressions or molds in the sand floor of the pig beds; the iron in the molds proper, being connected to that in the runner or feeder, bore a supposed resemblance to a litter of sucking pigs, the runner being called the **sow** (**sow metal**). This method produces what is known as **sand cast pig**. To avoid the sand which always adheres, the iron is frequently cast in metal molds or **chills**, and is then known as **chill cast pig**, or if a pig machine is used, **machine cast pig**, or rarely, from the fact that they are cast individually without a central connecting runner, **motherless pigs**.

The color of the fracture of pig iron depends upon the condition of the carbon; if it is all combined (the silicon being low) the fracture is **white** (not silvery); if all is in the form of graphite it is **gray** or **graphitic** (rarely called **black**); while if only a small part is in the graphitic form, giving rise to alternate white and gray spots, the iron is said to be **mottled**. Johnson has called attention to **spotted iron** which is gray on the outside and has white spots near the center; this he explains as due to silicon

below 0.8%, together with sufficiently rapid cooling, the portion freezing last at the center being composed of the eutectic segregate (*Met. & Chem. Eng.*, Nov. 1, 1916). If the silicon is high the fracture is silvery (not white). Close pig (close grained pig; close iron) has a very fine grained fracture; open iron has a coarse fracture or grain. Blazed pig, glazed pig, or glazy pig (Eng.) is a grade which is brittle from high silicon. Cinder iron or pig (Eng.) is smelted from a mixture containing some puddle cinder or refinery cinder; according to T. Turner, a grade with about 2½% carbon, 1½% manganese, and considerable phosphorus is common in South Staffordshire. Dry Iron (Eng.) is low in silicon, while rich iron (Eng.) or hot iron is high in silicon and usually low in sulphur. In foundry work iron which is fluid, partly from its temperature and partly from its composition, is called hot iron; the opposite is cold or dull iron or metal. Pig iron suitable for making pots or similar objects is sometimes called pot metal. Gun metal may signify either a kind of bronze, or steel or cast iron suitable for making cannon. In the last case (gun iron) requirements have been given as tensile strength 33,000 to 35,000 pounds per square inch, with transverse strength of 4000 pounds on an arbitration bar 1¼" in diameter, with 12" between supports. Pig steel (Richards, *Eng. Soc. W. Pa.*, March 19, 1912) is the name for the metal made directly from iron ore in an electric pig iron furnace, which is really crude steel with 2.2% or less carbon, a very small amount of silicon and manganese, low in sulphur and phosphorus.

Pig iron is classified according to (a) the method of manufacture (see Blast Furnace); (b) the purpose for which it is intended; and (c) its composition. It was formerly graded by breaking the pig and examining the fracture, but this method has been largely superseded by chemical analysis. The terms pig and iron are often used as abbreviations for pig iron, the latter where the context indicates clearly what is meant.

A. Method of manufacture:

1. **Coke pig:** smelted with coke, and always with hot blast.
2. **Charcoal pig:** smelted with charcoal:
 - (a) Hot blast.
 - (b) Cold blast.
3. **Anthracite pig:** smelted with anthracite coal mixed with coke, and with hot blast.

B. Purpose for which intended:

4. **Bessemer pig:** for the Bessemer process:
 - (a) Acid (in this country the only kind); hematite pig (Eng.); also used for the acid open hearth process.
 - (b) Basic (foreign); Thomas pig; Thomas-Gilchrist pig (Eng.).
5. **Basic pig (basic open hearth pig)** for the basic process (U. S.), and for the basic Bessemer process (foreign).

6. **Malleable pig**, or malleable, for malleable cast-iron castings.
 7. **Foundry pig**, for foundry work.
 8. **Forge pig**: an inferior grade used for puddling and for some classes of foundry work.
- C. **Chemical composition**:
9. **Silicon pig or high silicon pig**.
 10. **Low phosphorus pig**.
 11. **Special low phosphorus pig**.
 12. **Ferro-alloys and special cast irons** (e.g., ferro-manganese): see below.

The classification on the next page has been arranged by Eliot A. Kebler based on the Government's scale of prices (to July 1, 1918). The previous classification furnished by Mr. Kebler has been retained also for purposes of reference:

(The following details have been taken largely from an article by Eliot A. Kebler, of which the foreign classification was supplied by W. W. Hearne, in the *Iron Trade Review*, June 25, 1908, entitled "Grading Pig Iron, Ferro-Alloys and Coke." This has been somewhat rearranged and several additions made.)

In this country pig iron is usually sold per ton of 2240 pounds (rarely 2268 pounds), and always in England; in Germany and France per metric ton of 1000 kilograms.

Bessemer pig iron:

Standard Bessemer (U. S.), used in making acid Bessemer and acid open hearth steel. The standard specification is:

Silicon	1 to 2.00%
Phosphorus, not over	0.01
Sulphur, not over	0.05

In the central section (Mahoning and Shenango Valleys and Pittsburg) it is sold per ton, 2268 pounds, if sand cast, or 2240 pounds, if chill cast, except for special purposes where the sand iron is broken, in which case it may be sold per ton, 2240 pounds, and a charge of 25c. may be added for breaking. In the East and West (Chicago) it is always sold per ton of 2240 pounds.

Hematite, also spelled (Eng.) *hæmatite* (for acid Bessemer process):

Silicon, about	2.50%
Sulphur, about	0.035
Phosphorus, usually	0.035
seldom running over	0.06

West Coast hematite has manganese under 0.50%; **East Coast hematite**, over 0.75%. **Bessemer pig** in Europe generally should not contain more than 0.05% phosphorus. It is often used as a synonym for hematite pig, but while the latter term covers all the grades from No. 1 to white, the term Bessemer pig is applied only to Nos. 1, 2, and 3 (Ridsdale). This grade of pig is also referred to as **non-phosphoric**.

OFFICIAL PIG IRON PRICES AND CLASSIFICATION

October 1, 1918 through December 31, 1918

BIRMINGHAM Basis—\$34.00 ton, 2240 Pounds. + Add to Base. — Deduct from Base Rivers—also St. Louis, Mo., but not including furnaces bordering on the Ohio River. **PITTSBURGH Basis**—Eastern Districts, i. e.: east of the Allegheny Mountains and north of the Potomac River. **F. O. B. Cars FURNACE**—All charcoal and all Low Phosphorus iron and all districts not included above.

FOUNDRY IRON (All Sulphur under 0.05)

Silicon	Manganese, %				For higher manganese add \$1.00 for each 0.50% of manganese.
	Under 1.00	1.00-1.50	1.50-2.00	2.00-2.50	
1.00-1.75	-\$0.50	+\$0.00	+\$1.00	+\$2.00	
1.75-2.25	Base	0.50	1.50	2.50	
2.25-2.75	1.25	1.75	2.75	3.75	
2.75-3.25	3.00	3.50	4.50	5.50	
3.25-3.75	3.00	3.50	4.50	5.50	
3.75-4.25	3.00	3.50	4.50	5.50	
4.25-4.75	3.00	3.50	4.50	5.50	
4.75-5.25	3.00	3.50	4.50	5.50	
5.25-6.00	3.00	3.50	4.50	5.50	

SILVERY

6.00	+\$10.00				
7.00	11.00				
8.00	13.50				
9.00	15.50				
10.00	18.00				
BESSEMER FERROSILICON					
10.00	+\$23.00				
11.00	26.30				
12.00	29.60				

Max. P	LOW PHOSPHORUS. Silicon not over 2.00. Sulphur not over 0.04.			Copper over 0.50
	Copper 0.04 Max.	Copper 0.25 Max.	Copper 0.50 Max.	
0.030	+\$23.00	+\$22.00	+\$21.00	+\$20.00
0.035	21.50	20.50	19.50	18.50
0.040	20.00	19.00	18.00	17.00
0.045	17.50	16.50	15.75	15.00
0.050	15.00	14.25	13.50	13.00
0.055	12.50	12.00	11.50	11.00
0.060	10.00	9.50	9.25	9.00
0.065	6.50	6.50	6.50	6.50
0.070	5.50	5.50	5.50	5.50
0.075	5.00	5.00	5.00	5.00
0.100	1.20	1.20	1.20	1.20

Add \$1.75 for each 1% addition of Silicon.

Add \$3.00 for each additional unit of Silicon.

FORGE.....	—\$1.00
MILL.....	— 1.00
MALLEABLE Silicon.	2.25 max. + 0.50
“	2.25-2.75 + 1.25
“	2.75-3.00. + 3.00
BASIC.....	1.00-3.00 + 1.00
BESSEMER..	3.00-3.50 + 3.20
“	3.50-4.00 + 4.20
“	4.00-4.50 + 5.20
“	4.50-5.00 + 6.20

CHARCOAL

Southern or Warm Blast.....	+\$17.00
Sil 2.00 max. P. 0.40-0.60.	
Add \$1.00 for each 0.50 additional Silicon.	
Cold Blast.....	+\$47.00
Muirkirk.....	+ 37.00
Northern Semi-cold Blast.....	+ 37.00
Lake Superior for Sil. 1.25 max.	+ 2.50

Compiled by ELIOT A. KEBLER.

Thomas-Gilchrist or Thomas pig iron (for the basic Bessemer process) is usually about:

Silicon	0.50%
Phosphorus	2.50
Manganese	2.50
Sulphur, up to	0.20

In England and on the Continent **basic pig** (phosphoric or phosphoretic pig) is regarded as containing 1.5 to 3% phosphorus, 0.10% or less sulphur, 1.5 to 2.5% manganese, and less than 1% silicon (Ridsdale).

Malleable Bessemer or malleable iron (also called **coke malleable** or **malleable coke iron**), used for the manufacture of malleable cast-iron castings: the usual specification is:

Phosphorus, not over.....	0.20%
Sulphur, not over.....	0.05
Silicon, as specified.....	0.75 to 2.00

If sand cast, pigs are usually broken, and both sand cast and chill cast are sold per ton of 2240 pounds, except from a few furnaces in the Central District which still sell some broken and unbroken pigs per ton of 2268 pounds.

Low phosphorus pig (U. S.), sometimes called **special low phos** (for making steel extra low in phosphorus): the usual specification is:

Silicon	1 to 2.00%
Phosphorus, not over	0.035
Sulphur, not over.....	0.035

Higher silicon is desired when for use in baby Bessemer converters.

Washed metal (see page 383) is pig iron from which most of the silicon and phosphorus have been removed (for special low phosphorus steel: open hearth and crucible process); it is sold by analysis, the four analyses recognized (U. S.) being:

1. Phosphorus, not over	0.010%
Sulphur, not over	0.015
2. Phosphorus, not over	0.015
Sulphur, not over	0.020
3. Phosphorus, not over	0.020
Sulphur, not over	0.025
4. Phosphorus, not over	0.025
Sulphur, not over	0.030

It is cast on an iron plate, and comes in irregular pieces about 8" square; sold per ton of 2240 pounds.

Basic pig; basic iron (U. S.), for the basic open hearth process; the specifications are:

Silicon, under	1.00
Sulphur, under	0.05

The phosphorus is not specified but is usually under 0.50%,

except with some Southern irons, when it may go as high as 1.00%. It is sold per ton of 2240 pounds. In Europe or England there is practically no open hearth basic pig made; at Middleboro, Bell Bros. are making a grade which analyzes:

Silicon	0.75 to 1.50%
Phosphorus	1.00 to 1.75
Sulphur, up to	0.20

American foundry iron: graded by fracture (this method is being rapidly superseded by analysis grading):

No. 1 Foundry: Fracture contains crystals.

No. 2 Foundry: This is considered the standard and contains medium-size crystals, say $\frac{1}{8}$ " square, with no spot larger than 1" in diameter without crystals, although the pig can be close for $\frac{1}{4}$ " along the edges.

No. 3 Foundry: Contains small crystals; fracture close.

East of Altoona, Pa., and throughout all of New York these grades are **No. 1 X**, **No. 2 X**, **No. 2 Plain**, and **No. 3 Foundry**. No. 1 is the highest in price, the usual differential being 50 cents a ton.

Forge has a gray fracture with practically no crystals.

Mottled shows small white spots giving the fracture a mottled appearance; most of the carbon is in the combined state.

White shows a white fracture as practically all the carbon is in the combined state. These last two grades are usually high in sulphur and low in silicon.

In the South (U. S.) iron which has a silvery fracture is graded as follows:

Silvery iron or silvery gray iron is sometimes divided into:

No. 1 Silvery, usually about 5% of silicon.

No. 2 Silvery, usually about 4% of silicon.

No. 1 Soft: Solid same price as No. 1 Foundry.

No. 2 Soft: Solid same price as No. 2 Foundry.

No. 4 Foundry: Price is between that of No. 3 Foundry and Gray Forge.

Foundry iron containing 6 to 12% of silicon is called **high silicon softener** or **softener**, or is designated by the content, e.g., "8% silicon," etc.

Foundry pigs cast in sand are always broken, and the product of all furnaces outside of a few in the Central District is sold per ton of 2240 pounds. These few still sell per ton of 2268 pounds, the extra 28 pounds being added to cover sand adhering to the pig. Forge, mottled, and white irons may be broken or unbroken and are sold per ton of 2240 pounds, with the exception of some Central District irons which are sold per ton of 2268 pounds. No. 2 Foundry and No. 2 X Foundry are the standards, and No. 2 Soft sells at the same price. No. 1 Foundry or No. 1 Soft sells usually for 50 cents a ton higher, depending upon the silicon content. The other grades decrease 25 to 50 cents a grade. **Scotch** indicates a more fluid iron, usually higher in phosphorus and silicon than the ordinary furnace run: the higher the silicon the higher the price. In selling by

analysis the tendency is to do away with numbers and merely give the limits in silicon and sulphur.

American Foundry and Forge Iron Graded by Analysis: A committee appointed by the blast furnace interests has made the following classification by analysis, and the tendency is to sell iron by analysis instead of by fracture. All pig iron cast in chills is sold by analysis, per ton of 2240 pounds.

SOUTHERN POINTS

	Silicon, %	Sulphur, %
No. 1 Foundry	2.75 to 3.25	0.05 and under
No. 2 Foundry	2.25 to 2.75	0.05 and under
No. 3 Foundry	1.75 to 2.25	0.06 and under
No. 4 Foundry	1.25 to 2.00	0.065 and under
Gray Forge	1.25 to 1.75	0.07 and up
No. 1 Soft	3.00 and over	0.05 and under
No. 2 Soft	2.50 to 3.25	0.05 and under

EASTERN POINTS

	Silicon, %	Sulphur, %
No. 1 X	2.75 and up	0.03 and under
No. 2 X Foundry	2.25 to 2.75	0.045 and under
No. 2 Plain	1.75 to 2.25	0.05 and under
No. 3 Foundry	1.25 to 1.75	0.065 and under
No. 2 Mill	1.25 and under	0.065 and under
Gray Forge	1.50 and under	0.065 and up

NOTE.—If sulphur is in excess of maximum, the iron is graded as lower grade, regardless of silicon.

CENTRAL WEST AND LAKE POINTS

	Silicon, %	Sulphur, %
No. 1 Foundry	2.25 to 2.75	0.05 and under
No. 2 Foundry	1.75 to 2.25	0.05 and under
No. 3 Foundry	1.75 and under	0.05 and under
Gray Forge .....	.....	0.05 and over

BUFFALO DISTRICT

	Silicon, %	Sulphur, %
Scotch.....	3.00 and over	0.05 and under
No. 1 X.....	2.50 to 3.00	0.05 and under
No. 2 X.....	2.00 to 2.50	0.05 and under
No. 2 Plain.....	1.50 to 2.00	0.05 and under
No. 3 Foundry.....	1.50 (under)	0.05 and under
Gray Forge.....	.....	0.05 (over)

CHICAGO POINTS

	Silicon, %	Sulphur, %
No. 1 Foundry.....	2.25 to 2.50	0.02 to 0.05
No. 2 Foundry.....	1.75 to 2.25	0.02 to 0.05
No. 3 Foundry.....	1.35 to 1.75	0.06 and under
Scotch.....	2.50 to 3.00	0.05 and under
Silvery.....	3.00 to 3.50	0.05 and under
Gray Forge.....	.....	0.06 and over

Sampling.—The American Society for Testing Materials recommended the following method of sampling which has been adopted by the American Foundrymen's Association. In all contracts where pig iron is sold by chemical analysis each carload or its equivalent shall be considered as a unit. At least one pig shall be selected at random from each four tons of every carload, and so as fairly to represent it. Drillings shall be taken so as fairly to represent the fracture surface of each pig and the sample analyzed shall consist of an equal quantity of drillings from each pig, well mixed and ground before analysis. In case of disagreement between buyer and seller, an independent analyst, to be mutually agreed upon, shall be engaged to sample and analyze the iron. In this event each pig shall be taken to represent every two tons. The cost of this sampling and analysis shall be borne by the buyer if the shipment is proved up to specification, and by the seller if otherwise.

English Foundry Iron.—This is graded by fracture, and no analysis is guaranteed. The rules for standard foundry pig iron issued by the London Metal Exchange are as follows, and it will be noted that, instead of grading by silicon content, as in this country, sulphur seems to be the governing element:

	Silicon, %	Phosphorus, %	Sulphur, %
No. 1.....	2½ to 3½	1.00	0.04
No. 2.....	2½ to 3½	1.25	0.05
No. 3.....	1 not over 3½	1.65	0.08
No. 4.....	1 not over 3	1.75	0.10

The ordinary English pig irons can be divided into two groups, with

Manganese, under 0.75%, and
Manganese, say, 0.75 to 1.10%.

The brand and grade chiefly imported into this country is **Middlesboro No. 3**; analysis unguaranteed, but usually

Phosphorus.....	1.40 to 1.50%
Manganese.....	0.40 to 0.75
Silicon, usually high, say.....	2.50
Sulphur.....	0.02 to 0.05

No. 1 has practically the same composition except that the sulphur is extremely low.

All mine pig, mine pig, or ore metal (Eng.) is made from ore without any admixture of scale or cinder; its composition is about as follows:

Phosphorus.....	0.20 to 0.70%
Sulphur.....	0.06 to 0.20
Manganese, under.....	0.75

Scotch iron is also sold by fracture, a typical analysis of No. 3 being:

Phosphorus.....	0.60 to 1.15%
Manganese.....	1.10 to 1.80
Sulphur, about.....	0.03
Silicon, about.....	2.00 to 2.50

American Charcoal Irons.—These irons are divided into two classes:

- (a) **Cold blast**, which is made in small furnaces with a capacity of about 4 to 8 tons a day, blown with unheated air, and
- (b) **Warm blast**, in which the blast is preheated to from 500° to 900° F. (260° to 480° C.).

Cold blast charcoal iron (used principally for making chilled rolls), outside of the Lake Superior region, is graded as follows:

No. 1, highest silicon, lowest sulphur iron, with a fracture like that of a No. 3 coke iron.

No. 2 has a fracture like that of a Forge, and will chill $\frac{1}{8}$ " deep when cast against an iron plate. Casting such an iron on an iron plate to determine the depth of chill is called the **chill test**. What is termed a **paper chill** is where a line of white no thicker than a piece of paper is visible around the edge of the pig (Johnson).

No. 3 shows $\frac{1}{4}$ " chill.

No. 4 a $\frac{3}{8}$ " to $\frac{3}{4}$ " chill.

No. 5 a $\frac{3}{4}$ " to $1\frac{1}{2}$ " chill, the face of the pig being strongly mottled.

No. 6 is white, practically all of the carbon being in the combined state.

Warm blast or hot blast charcoal iron (used principally for car-wheel work, for strengthening general machinery castings, and for making rolls), outside of the Lake Superior region, is graded as follows:

No. 1, highest silicon, lowest sulphur iron, with a fracture like that of No. 2 coke iron.

No. 2 has a fracture like that of a No. 3 coke iron.

No. 3 has a fracture similar to that of Forge.

No. 4 will show a chill about $\frac{1}{4}$ " deep if cast against an iron plate.

No. 5, a chill about $\frac{1}{4}$ " to $\frac{3}{4}$ ".

No. 6, a chill of about $\frac{3}{4}$ " to $1\frac{1}{2}$ ", and is mottled when cast in sand.

No. 7 has a white fracture; the carbon is practically all combined.

Lake Superior charcoal irons are graded, not by fracture, but by analysis, the following classification being most generally used:

	SILICON, %			Chill
	Average	Min.	Max.	
A Scotch.....	2.50	2.38	2.62	
B Scotch.....	2.25	2.13	2.37	
C Scotch.....	2.00	1.88	2.12	
Low 1.....	1.75	1.63	1.87	
High 1.....	1.50	1.38	1.62	
Low 2.....	1.25	1.13	1.37	
High 2.....	1.00	0.88	1.12	
Low 3.....	0.75	0.63	0.87	Trace to 1/4"
High 3.....	0.56	0.50	0.62	1/4" to 5/8"
Low 4.....	0.44	0.38	0.50	5/8" to 1"
High 4.....	0.32	0.25	0.38	1" to 1 1/2"
Low 5.....	0.20	0.15	0.25	Low mottled
High 5.....	0.10	0.05	0.15	White mottled
No. 6.....	0.00	0.00	0.05	White
Phosphorus.....			0.15 to 0.22%	
Manganese.....			0.30 to 0.70	
Sulphur.....			trace to 0.018	

Ferro-alloys, ferro-products, special cast irons, or alloy cast irons.—These are alloys or metallic compounds of iron with a considerable amount of some special element or elements (**alloy elements**), such as manganese, chromium, etc., and contain, as a rule, an equal or greater amount of carbon than ordinary pig iron, this last differentiating them from special steels (*q.v.*), although the dividing line is not always sharply drawn. Howe suggests (*E. & M. J.*, 1911) as definitions for ferro-alloy: "An alloy of iron with so large a proportion of some element other than carbon that it is not usefully malleable at any temperature." or "Iron so rich in some element other than carbon that it is used as a vehicle for introducing that element in the manufacture of iron or steel." Tiemann has suggested that ordinary pig iron, as the initial member of the ferro-alloy series, corresponding to ferro-manganese, etc., be designated as **ferro-carbon**. Owing to the fact that many of the ferro-alloys have been in use for only a comparatively short time, fixed standards have not, in many cases, been accepted. One company designates its material by showing the number of units of carbon by "X," and the kind of alloy by its chemical symbol; thus: a ferro-chrome containing 9.70% of carbon would be designated "9XC_r." All foreign ferro-alloys are sold to the American consumers f.o.b. cars American seaboard, based on existing duties, United States Custom House weights at seaboard to govern settlement, and certificate of foreign chemist of repute to be conclusive as to quality.

Ferro-aluminum is sold containing 10% aluminum. Metallic

aluminum comes in two grades: No. 1 being guaranteed over 99%, and No. 2, over 90% pure aluminum, with no impurities rendering it unsuitable for alloying with iron or steel. Each grade is sold by the pound.

Ferro-chrome, ferro-chromium, or chromeisen runs 60 to 68% of chromium. It is graded per unit of chromium and per unit of carbon, the price increasing with the chromium, and decreasing with the increase in carbon, the percentage of these elements being guaranteed. If low in carbon it is sometimes called **mild ferro-chrome**. It is sold per ton of 2240 pounds. A typical analysis, guaranteed only as above, is as follows:

	Mild, %	Ordinary, %
Chromium.....	64.80	66.00
Iron.....	33.43	21.91
Carbon.....	1.21	9.90
Silicon.....	0.29	1.40
Phosphorus.....	0.027	0.07
Sulphur.....	0.02	0.22
Manganese.....	0.09	0.20
Copper.....	0.12	....
Aluminum.....	....	....

Ferro-chrome is manufactured in an electric furnace which may be of several types, such as a Héroult or a Girod furnace as used for making steel. The charge consists of chromite and anthracite coal mixed in proportions based on theoretical calculations. In one operation direct from ore, ferro-chrome with as low as 5% carbon can be made economically; and it is possible to produce it with as little as 2%. The refining of high grade ferro-chrome is carried on in an arc furnace, where the alloy is subjected to prolonged heating with a slag of chromite, lime and flourspar. In this way the carbon can be reduced from 10 to 0.25% but more usually about 0.50%. The content of chrome remains about the same, and the silicon may be reduced to about 0.2% (Keeney, *Am. Electroch. Soc.*, XXIV).

Ferro-manganese contains over 30%, usually over 60%, manganese. **Standard ferro-manganese** is guaranteed only to average 80% or over of manganese. The English grade runs lower in phosphorus than that from the Continent. It is sold per ton of 2240 pounds. A typical analysis, manganese only guaranteed, is:

	English, %	American, %
Manganese.....	80.50	80.20
Iron, by difference..	11.50	12.18
Silicon.....	1.65	0.66
Phosphorus.....	0.23	0.16
Sulphur.....	....	trace
Carbon.....	6.78	6.80

Ferro-molybdenum is sold per pound of pure molybdenum contained, regardless of the percentage of other constituents. Thus, if a pound of 80% ferro-molybdenum is purchased, 1¼ pounds of alloy will be received. A typical analysis, molybdenum only guaranteed, is:

Molybdenum.....	79.5%
Iron.....	17.55
Carbon.....	3.24
Phosphorus.....	0.028
Sulphur.....	0.021

It is generally manufactured in the electric furnace from raw sulphide ore (molybdenite); also by reduction of the roasted sulphide with carbon in a crucible or the electric furnace (Keeney).

Ferro-nickel is made with 25, 35, 50, or 75% of nickel as specified. The percentage of the other constituents, exclusive of the iron, is approximately:

Carbon.....	0.85%
Silicon.....	0.25
Sulphur.....	0.15
Phosphorus.....	0.025

Nickel, metallic nickel, or ingot nickel, as ordinarily used in the manufacture of nickel steel, is guaranteed over 99% nickel, and is sold by the pound.

Ferro-phosphorus contains over 10% of phosphorus. It is sold per ton of 2240 pounds. The foreign is guaranteed 22 to 24%. A typical analysis of the foreign product, phosphorus only being guaranteed, is:

Phosphorus.....	21.40%
Iron.....	75.03
Manganese.....	0.70
Silicon.....	1.63
Carbon.....	1.17

The domestic is guaranteed:

Phosphorus.....	18 to 22.00%
Sulphur, under.....	0.05
Manganese, under.....	0.50

Phospho-manganese is essentially a ferro-manganese containing a high percentage of phosphorus. It is sold per ton of 2240 pounds. A typical analysis shows approximately:

Manganese.....	65.00%
Phosphorus.....	25.00
Iron.....	7.00
Carbon.....	2.00
Silicon.....	1.00

Ferro-silicon, siliconeisen, or high silicon pig is used in the manufacture of steel to increase the silicon. It is usually called **Bessemer ferro-silicon** (sometimes **ordinary ferro-silicon**) as the American is guaranteed not over 0.10% of phosphorus, and not over 0.05% of sulphur, and the foreign, while not guaranteed, is approximately the same. The silicon is 10 to 20%, usually 12%, the price increasing about \$1.00 a ton per unit. It is sold per ton of 2240 pounds. A typical analysis shows:

Silicon.....	12.74%
Phosphorus.....	0.095
Manganese.....	0.87
Sulphur.....	0.02

Ferro-silicon higher than this is produced in the electric furnace, and ordinarily contains over 40% of silicon, and is known as **special ferro-silicon** or **special high silicon iron**. It is guaranteed 50% silicon, with a variation in price of \$1.75 per unit either way. The other constituents are not guaranteed. A typical analysis shows:

Silicon.....	49.90%
Manganese.....	0.016
Carbon.....	0.55
Phosphorus.....	0.075
Sulphur.....	0.018

There is also a grade guaranteed to average 75% of silicon, with a variation in price of \$2.50 per unit either way.

Silico-spiegel is a product of the blast furnace. It contains 17 to 22% of manganese and 6 to 12% of silicon. It is sold per ton of 2240 pounds. The standard is guaranteed:

Manganese.....	18 to 20%
Silicon.....	9 to 11, average 10%

A typical analysis, nothing but manganese and silicon guaranteed, shows:

Manganese.....	20.32%
Iron, by difference.....	68.02
Silicon.....	10.33
Carbon.....	1.26
Phosphorus.....	0.07
Sulphur.....	.....

Silico-ferro-manganese or **silico-manganese** is the name usually applied when higher in manganese: Manganese about 60 to 80%, silicon, 20 to 25%, and varying percentages of carbon, iron, and aluminum. There are three silicides of manganese recognized: SiMn , Si_2Mn_3 , and Si_2Mn .

Silicon-calcium-aluminum has been tried as a deoxidizer; it is reported to consist of approximately:

Silicon.....	47 to 57%
Calcium.....	15 to 25
Aluminum.....	2.5 to 6.5

Ferro-sodium is obtained by dissolving metallic sodium in molten pig iron in a crucible. It is sold per pound, and usually contains 25% of sodium, free from lime or excess of carbon.

Spiegel, spiegeleisen, mirror iron, or specular pig iron, is a product of the blast furnace. It contains 10 to 30% of manganese. It is sold per ton of 2240 pounds, and the standard is guaranteed:

Manganese.....	18 to 22%, average, 20%
Phosphorus, not over.....	0.10

The silicon limits are sometimes specified. A typical analysis, guaranteed only as above, shows:

Manganese.....	20.50%
Iron.....	73.61
Silicon.....	0.76
Carbon.....	5.18
Sulphur.....	0.002
Phosphorus.....	0.055

Ferro-titanium is produced in the blast furnace or, for higher grades, in the electric furnace. The lower alloy contains 10 to 12%, is guaranteed only for titanium, and is sold per pound of alloy. A typical analysis shows:

Titanium.....	11.21%
Iron, by difference.....	87.68
Carbon.....	0.67
Silicon.....	0.37
Phosphorus.....	0.04
Sulphur.....	0.03

If higher in titanium, it is sold per pound of pure titanium contained, regardless of the percentage of other constituents, the titanium alone being specified. A typical analysis shows:

Titanium.....	51.30%
Iron.....	44.18
Carbon.....	2.82
Manganese.....	0.08
Arsenic.....	1.12
Sulphur.....	0.047
Phosphorus.....	0.021
Aluminum.....	0.41

Ferro-tungsten is sold per pound of tungsten contained, the price increasing with the increase in tungsten, and decreasing with the increase in carbon. Typical analyses, the tungsten and carbon only being guaranteed, show:

Tungsten.....	85.47%	61.20%
Iron.....	13.90	33.02
Carbon.....	0.30	2.97
Silicon.....	0.13	0.47
Manganese.....	0.09	1.88
Aluminum.....	0.00	0.31
Phosphorus.....	0.019	0.03
Sulphur.....	0.025	0.03

It is manufactured from ores in three ways: (1) by direct reduction by carbon in a crucible; (2) by reduction in an electric furnace by some reducing agent other than carbon; (3) by direct reduction by carbon in an electric furnace (Keeney).

Ferro-vanadium is sold per pound per unit of vanadium contained, *i.e.*, if the alloy contains 20% of vanadium, and the selling price is 5c. per unit, it would cost \$1.00 per pound, of alloy. A typical analysis, vanadium alone being guaranteed, shows:

Vanadium.....	36.00%
Manganese.....	0.60
Iron.....	61.00
Carbon.....	0.40
Silicon.....	0.90
Aluminum.....	0.80

It may be produced by the thermit process; by reduction of the oxide with carbon; or by reduction of vanadate of iron with carbon in a crucible. In Europe some is made by the reduction of the oxide, sulphide, or vanadate of iron with carbon in an electric furnace (Keeney).

Pig Iron, Sampling of.—See page 349.

Pig Machine.—An appliance for the continuous casting of pig iron in iron molds. The types at present in use consist of one or more endless strings or **strands** of molds mounted on vertically revolving drums. The metal is run into the molds from a ladle at one end, and is rapidly cooled with water as the molds advance, so that the pigs are cold enough to be dumped into a car or other receptacle when they reach the other end. In another type, formerly used, the molds were mounted on a large horizontally revolving table.

Pig Metal.—See page 342.

Pig and Ore Process.—(1) Crucible process: see page 113; (2) open hearth process: see page 310.

Pig and Scrap Process.—(1) Crucible process: see page 113; (2) open hearth process: see page 310.

Pig Steel.—See page 343.

Pig Up.—See pages 314 and 393.

Pig Washing Processes.—See page 383.

Pigging.—In open hearth practice: see page 314.

Pigment.—See page 365.

Pile.—(1) A type of furnace: see page 181; (2) in connection with puddling, etc.: see page 377.

Pilger Rolls.—See page 490.

Pill Heat.—See page 257.

Pillaring.—See page 35.

Pin (Eng.).—Housing screw: see page 403.

Pin Bottom.—See page 17.

Pin Hole.—See page 113.

Pinacoidal Cleavage.—See page 124.

Pinch Bar.—A crowbar; also a special form for moving cars by prying the wheels.

- Pinch Phenomenon.**—In electricity: see page 158.
- Pinch Roll.**—See page 415.
- Pinched Sheet ; Pincher.**—See page 430.
- Pine Tree Crystal.**—See page 122.
- Pinhead Blister.**—See Blister.
- Pinion ; Pinion Housings.**—See page 407.
- Pink Method.**—See page 61.
- Pinny (Eng.).**—A term used to describe metal which contains enclosed particles of metal harder than the rest.
- Pintsch Gas.**—See Oil Gas.
- Pipe ; Piping.**—(1) A defect in castings: see page 53; (2) tubes: see page 489.
- Pipe Metal.**—An alloy of lead and tin used for making organ pipes.
- Pipe Ore.**—See page 244.
- Pipe Stove.**—See page 34.
- Piping Steel.**—See page 55.
- Pisolithic Ore.**—See page 244.
- Pistol.**—For metal spraying: see page 373.
- Pistol-Pipe Stove.**—See page 34.
- Pit.**—A depression in the surface of material caused (a) by subcutaneous blowholes from which the skin has been burned away, and (b) from scale or dirt rolled or forged in, and which has subsequently dropped out. Where the skin from a blowhole has not entirely burned away but is not welded to the rest of the metal and may be removed by hammering the piece, it is called a **scab, shell** or **spill** (Eng.), and the material is said to be **scabby, shelly** or **spilly**. When this occurs in the tread of car wheels (usually cast iron), *i.e.*, when particles of the metal drop out leaving a hole resembling a carbuncle, it is known as **shelling** or **shelling out**; the flaking out of material in steel wheels is sometimes similarly designated but more commonly as **spalling** or sometimes **scaling**. A defect sometimes occurs in cast iron wheels which have become worn through the chill, and have fine cracks presenting an appearance somewhat like that of a comb, hence such wheels would be called **comby**. (2) An excavation to receive cinder, or in which molds are placed.
- Pit Annealing.**—See page 58.
- Pit Casting.**—See page 57.
- Pit Coal.**—See Coal.
- Pit Heating Furnace.**—See page 184.
- Pit Hole.**—See Pit.
- Pit Sample.**—See page 82.
- Pit Scrap.**—The steel which has run into the cinder pit under the ladle when a heat is tapped.
- Pitch.**—(1) The height of the top of an arch above the points from which it springs; (2) the distance between two consecutive threads of a screw measured on a line parallel to the axis, or, in other words, the amount the screw would be raised by one complete revolution; (3) a thick, sticky, black substance obtained from the sap of pine trees, or by the distillation of coal.
- Pitch Diameter ; Line.**—The center line of a rolling mill; a line parallel with the axis.

- Pitting.**—See Pit; also page 106.
- Plain Annealed Wire.**—See page 508.
- Plain Drawn Wire.**—See page 508.
- Plain Roll.**—See page 404.
- Plaited Structure.**—See page 126.
- Plane.**—(1) Of shear: see page 337; (2) of symmetry: see page 123; (3) of weakness: see page 123.
- Planished Sheet.**—See page 431.
- Planishing Rolls.**—See page 415.
- Plastic.**—See page 331.
- Plastic Compression.**—See page 63.
- Plastic Deformation.**—See pages 279 and 281.
- Plastic Elongation.**—See page 472.
- Plastic Material.**—See page 331.
- Plastic Origin.**—Produced in a plastic condition.
- Plastic Static Deformation.**—See page 281.
- Plastic Strain.**—See page 334.
- Plastic Sulphur.**—See Sulphur.
- Plasticity.**—See page 331.
- Plate.**—A flat piece of metal produced by rolling (rarely by hammering), usually over No. 12 gage or $\frac{1}{8}$ " thick; if thinner than this it is generally called a **sheet**, except in the case of tin plate. Plates for safes, armor plate, etc., are sometimes made by welding together several plates of wrought iron or soft steel and high carbon or alloy steel, alternately, which, according to the number employed, are called **three-ply**, **five-ply**, etc. See also page 430.
- Plate Iron; Metal.**—See page 383.
- Plate Mill.**—See page 413.
- Plate Molding.**—See page 300.
- Plated Bars.**—See page 71.
- Platen.**—See page 301.
- Platines (obs.).**—An old name given to the material rolled into sheet iron thinner than boiler plate.
- Plating.**—Metallic coating for protection: see page 370.
- Plating Forge; Hammer.**—See Hammer.
- Platinite.**—See page 451.
- Platinum Resistance Pyrometer.**—See page 208.
- Platinum Steels.**—See page 453.
- Platt Process.**—See page 369.
- Plessite.**—See page 291.
- Plow Steel Wire.**—See page 509.
- Plug.**—Of a converter: see page 17.
- Plumbago Blacking.**—See page 298.
- Plumbago Crucible.**—See page 111.
- Plus Gage.**—See page 186.
- Ply.**—See Plate.
- Pneumatic Molding Machine.**—See page 301.
- Pneumatic Process (obs.).**—Bessemer process: see page 15.
- Poisoning (rare).**—Of metal, when some substance (usually introduced in the process of manufacture) injures the quality.
- Poikilitic Structure.**—See page 125.
- Poisson's Ratio.**—See page 336.

- Poling.**—Stirring molten metal, either in a furnace or in a ladle, with a pole of green wood, the heat distilling off the volatile products which stir up the metal and, together with the charcoal formed, help to reduce any oxides present.
- Polish-Attack ; Polish-Etching.**—See page 288.
- Polishing.**—See page 285.
- Polyatomic.**—See page 87.
- Polybasic.**—See page 87.
- Polycellular Structure.**—See page 126.
- Polycentric Structure.**—See page 126.
- Polyhedral Steel.**—See page 443.
- Polymerism.**—See page 85.
- Polymorphic Transformation.**—See page 327.
- Polymorphism ; -ous.**—See page 121.
- Polysomatic.**—See page 292.
- Polysynthetic Twinning.**—See page 124.
- Pommarède Method.**—See Iron.
- Pond Sludge.**—See page 33.
- Ponsard Furnace ; Process.**—See page 144.
- Pontelec Method.**—See page 503.
- Pony Roughing Stand.**—See page 415.
- Pool (rare).**—The hearth of a reverberatory or other furnace.
- Poole Process.**—See page 73.
- Poor Lime.**—See Flux.
- Pop Mark (Eng.).**—See page 473.
- Porcelanic Fracture.**—See page 178.
- Porous.**—See page 55.
- Poryphyritic Structure.**—See page 125.
- Port.**—In a furnace (generally of the regenerative type), the openings through which the air and gas enter, and the products of combustion leave; the space over the hearth.
- Porter ; Porter Bar.**—A long bar for handling heavy pieces of metal, particularly for forging. It has a chuck at one end which fits over, or is welded to, one end of the piece, and a counterweight at the other end, and the whole is raised by a chain fastened at the proper point to balance.
- Porter Process.**—See page 371.
- Portevin's Method.**—For etching: see page 287.
- Posnikoff Process.**—See page 60.
- Post-Eutectic.**—See page 269.
- Post-Eutectoid.**—See page 271.
- Post-Genital Malleableness.**—Not malleable as produced, but made so subsequently.
- Post-Neutral Period.**—In solidification: see page 54.
- Pot.**—(1) A box used in annealing; (2) the box or chamber used in the cementation process; (3) a crucible; (4) a ladle (obs.).
- Pot Annealing.**—See page 232.
- Pot Furnace.**—Crucible Furnace.
- Pot Galvanizing.**—See pages 370 and 431.
- Pot Hole.**—See page 114.
- Pot House.**—See page 112.
- Pot Melting.**—See page 113.

- Pot Metal.**—See page 118.
- Pot Packer.**—See page 114.
- Potash.**—(1) The element potassium, *e.g.*, caustic potash (potassium hydrate), etc.; (2) potassium carbonate.
- Potash Hardening.**—See page 69.
- Potassa.**—Potash.
- Potassium.**—K.; at. wt., 39; melt. pt., 62.9° C. (145.2° F.); sp. gr., 0.86. It is always found in the combined state with oxygen, etc. As the oxide or the carbonate it finds a very limited application as a flux, but practically never in the metallurgy of iron or steel, except accidentally.
- Potential Brittleness.**—See Brittleness.
- Potential Recrystallization.**—See page 216.
- Potentiometer Method.**—For temperature measurements: see page 208.
- Pottering Down (Eng.).**—See page 114.
- Pottery Mine.**—See page 244.
- Pottkoff Process.**—See page 371.
- Pouillet's Color Scale.**—Of temperatures: see page 210.
- Pouillet Pyrometers.**—(1) Gas: see page 207; (2) pyrheliometer: see page 207.
- Pound Calorie.**—See page 200.
- Pound-Centigrade Heat Unit.**—See page 200.
- Pouring.**—See pages 53 and 57.
- Pouring Basin; Gate.**—See page 299.
- Pouring, Special Methods of.**—See page 59.
- Power.**—Of a microscope: see page 285.
- Power Gas.**—See Producer.
- Practical Proof Strain.**—See page 468.
- Precipitate; Precipitation.**—See page 88.
- Precipitation Process.**—Of C. W. Siemens: see page 146.
- Preliminary Slag.**—See Slag.
- Preliminary Test.**—See Furnace Test.
- Pre-Neutral Period.**—In solidification: see page 54.
- Preparation of Specimens.**—For metallographic examination: see page 285.
- Prepared Iron.**—See page 364.
- Preservative Coatings; Process.**—See page 362.
- Press.**—Or hydraulic press; a machine used for working metal, much in the same way (except for special purposes) as with a hammer, but as its effect penetrates throughout the piece, its action being comparatively slow so that opportunity is given for the metal to flow, it is available for larger pieces, and also, as a rule, gives a much better structure. It consists essentially of a hydraulic cylinder in which a plunger or ram moves vertically and which is forced down upon the piece of metal suitably supported on an anvil block as in the case of hammers. The action of the ram may be continuous (**continuous acting press**), *i.e.*, the squeeze may be of the same intensity throughout its duration, or it may be intermittent or pulsating (**intermittent acting press**), increasing and decreasing while the actual squeeze is taking place.

Press Hardening.—See page 229.

Presser.—That portion of a molding machine which imparts the necessary pressure to the molding sand (Horner).

Pressing.—See Forging.

Pressing-in Method.—For determining hardness: see page 477.

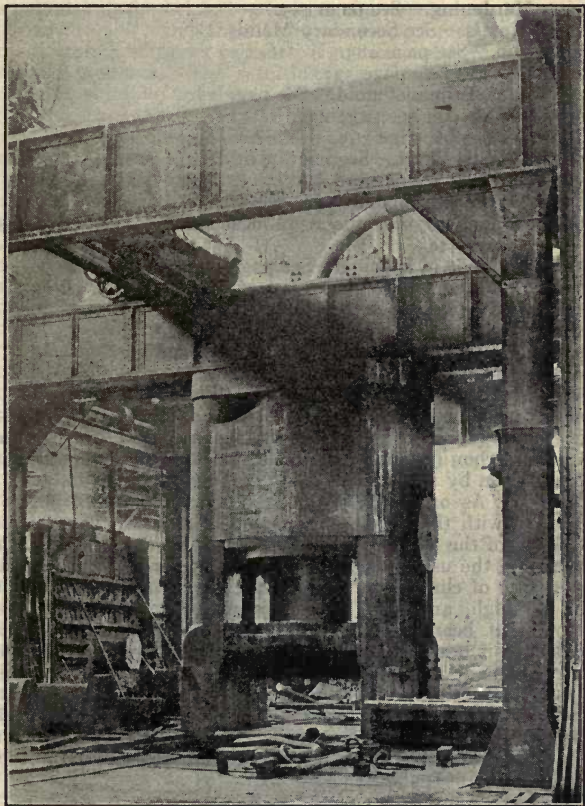


FIG. 49.—10,000 ton hydraulic press.

Pressure Hardening.—See page 229.

Prevost's Law.—See page 200.

Price and Nicholson Process.—See page 118.

Prick-punch Marks.—See page 473.

Pricking.—In wire drawing: see page 508.

- Primary Austenite.**—See page 274.
Primary Cementite.—See page 273.
Primary Crystals.—See page 121.
Primary Crystallization.—See page 120.
Primary Furnace.—See page 316.
Primary Gas.—See page 33.
Primary Hardening.—See page 447.
Primary Metals.—See Secondary Metals.
Primary Slip.—See page 283.
Primary Stress.—See page 332.
Primaustenal, Primaustenoid.—See page 275.
Primes.—Of sheets: see page 433.
Priming Coat.—See page 365.
Primitive Elastic Limit.—See page 471.
Prince Process.—See page 387.
Principal Stress.—See page 332.
Prinsep Method.—For temperature measurements: see page 209.
Print.—See page 285.
Printing Methods of Etching.—See page 288.
Prismatic Cleavage.—See page 124.
Prismatic Structure.—See page 125.
Prismatic Sulphur.—See Sulphur.
Prismatic System.—Of crystallization: see page 120.
Process Annealing.—See page 509.
Process Metallurgy.—See Physical Metallurgy.
Producer; Producer Gas.—Rarely called **generator gas**; this is a fuel gas produced by blowing air through a thick bed of incandescent carbon (generally coal), the theoretical reaction giving a composition by volume of 23% of carbon monoxide and 77% of nitrogen. As ordinarily made, a certain amount of steam is blown in with the air, the proportion being such that the temperature of the bed of fuel is not unduly lowered. The advantage from the use of steam consists in preventing the excessive formation of clinkers by keeping the temperature from becoming too high, and also by converting the extra specific heat into latent heat in the reaction between the steam and the carbon, this heat being recovered later when the gas is burned. The gas made with steam is sometimes called **mixed gas**, being a combination of straight producer gas and water gas, and the process, **mixed process**; it is also known as **semi-water gas**, **Dowson gas** (Eng.), or **power gas**. The composition by volume of a good grade of gas from a modern producer using bituminous coal and steam is about:

Carbon monoxide.....	26%
Hydrogen.....	13
Hydrocarbons.....	4
Carbon dioxide.....	4
Nitrogen.....	53

The apparatus in which the gas is made is called a **gas producer** or simply a **producer**, rarely a **gas generating furnace**

or generator. The first practical producer was designed by C. W. Siemens (from which came the name **Siemens gas**), and consisted of a brick chamber in which the fuel was supported on an inclined grate, and air alone was used. On account of the construction, the producer had to be shut down at frequent intervals in order to clean out the ashes. A modern producer consists essentially of a cylindrical, fire-brick, combustion chamber containing the bed of fuel through which the air and steam are forced, usually from the bottom, and under pressure; if suction is used, it is termed a **suction producer**. The resulting gas is taken off at the top through suitable openings. If the air and steam are forced through from the top to the bottom, it is called a **down-draft producer**. The fuel is fed in at the top through a hopper, and the ashes are cleaned out at the bottom as a rule through a water seal (**water seal producer**), the action practically always going on uninterruptedly (**continuous producer**), as it is not economical to take the producer out of service except when the gas is no longer needed.

- Products of Combustion.**—See page 202.
Product of Rolling Mills.—See page 411.
Pro-Eutectic.—See page 269.
Pro-Eutectic Austenite.—See page 275.
Pro-Eutectic Cementite.—See page 273.
Pro-Eutectic Ferrite.—See page 275.
Pro-Eutectoid.—See page 271.
Pro-Eutectoid Cementite.—See page 273.
Pro-Eutectoid Ferrite.—See page 272.
Profile (Eng.).—The section or shape of rolled iron or steel.
Progressive Fracture.—See page 179.
Progressive Freezing.—See pages 54 and 266.
Prony Brake.—See page 483.
Proof Load; Strain; Strength; Weight.—See page 468.
Proof Test.—See pages 467 and 482.
Properties of Crystals.—See page 121.
Properties of Materials.—See page 330.
Proportional Limit.—See page 334.
Proportionality.—(1) Law of: see page 473; (2) limit of: see page 334.
Protected Metal.—See Protection.
Protection.—In cementation: see page 70.
Protection.—The prevention of **corrosion** (*q.v.*) in iron or steel, which, however, is only relative, is effected by means of **protective coatings** or coverings which are either inert or very resistant to corrosion, such as tar or concrete, or are acted upon in preference to the iron, such as zinc, and are of three kinds: (a) those simply adhering to the surface of the object, composed of some extraneous substance, *e.g.*, paint; (b) those formed by the oxidation of the surface (**oxide coating**); and (c) those which may be a combination of the two preceding, or where a metal coating forms an alloy where it comes in contact with the object. Such coatings and the processes for producing them are designated **protective, preservative, or inoxidizing**. Articles which

have a protective oxide coating are sometimes termed **black iron objects**. In practically every case the surface of the iron must be carefully cleaned before any kind of coating is applied.

Passivity or Passive State.—If a piece of iron (also certain other metals) is immersed in concentrated nitric acid, strong solutions of chromic acid or potassium bichromate (**chromatic protection**), or exposure to certain other strongly oxidizing reagents, it is only slightly attacked; and if subsequently placed in acid or other solution which would ordinarily attack it vigorously, it still remains almost unaffected. The rate of solubility in dilute nitric acid is sometimes made a measure of the degree of passivity; where relatively large proportions of NO_2 are evolved has been termed the **passive break**, *i.e.*, the dividing line. Iron in this condition has been termed **passive**, **passivated**, **passivified**, **inactive**, **altered**, or **prepared**, and, as a contradistinction, when in its ordinary condition, **fresh iron**. This inactivity may be removed by scratching the surface or touching it with an active substance; also by making it the cathode with the passage of a sufficiently powerful current. The change from the active to the passive condition is not necessarily abrupt, but may be gradual, so that passivity may exist in varying degrees of **retardation**.

Anodic passivity or polarization is where the object forms the anode in an electrolyte; **non-anodic passivity or polarization**, where the object is not part of an electrolytic couple, also called, in contradistinction to the former, **chemical passivity**. **Faraday's oxide or oxygen theory** assumed the surface to be oxidized; this had to be abandoned when it was found that chromium could be rendered inactive without actual oxidation. This was modified in the **oxide skin or oxide film theory** on the assumption that the metal was protected by a thin covering of oxide. **Finkelstein's valency theory** assumed differences in valency of the metal. **LeBlanc's reaction-velocity theory** assumed the passage of the metal to be accompanied by a chemical change; if this was slow the metal was passive. **Fredenhagen's oxygen charge or oxygen film theory** was due to his finding that when an anode was polarized the potential rose gradually, which led him to believe this was due to a slow oxidation, an oxygen film forming over the surface of the electrode. He assumed that oxygen or oxide was present in the metal as a solid solution. **Foerster and Schmidt's hydrogen or catalysis theory**; that passivity was the normal state for pure iron, and that activity was due to the presence of some catalytic agent, particularly hydrogen. In the **peroxide or adsorption theory** it was assumed that iron ions were oxidized to a high oxide (perhaps FeO_3) which were then adsorbed by the surface of the metal. **Sackur's anion discharge theory** is similar to LeBlanc's and assumes that the velocity with which the metal is attacked depends on the accessibility of the discharged anion. **Reichinstein's constant sum theory** states: "The sum of the concentrations of all the constituents of the electrode volume is always constant. Electrode volume is simply an hypothesis of Reichinstein's to account for the possibility of the displacement of one substance by another. He found that the sum total of all

concentrations at this surface must be constant, and therefore talked about concentrations. If you substitute for concentration the idea of the extent to which a surface is covered with atoms, then, instead of the sum of the concentrations being constant, you say the total sum of the spaces on the surface is constant. You then get Reichstein's hypothesis in different language, so you can then talk about electrode volume as the electrode surface." (The above is largely based on *The Passive State* by Bennett and Burnham, *J. Am. Electrochem. Soc.*, XXIX, 1916).

Where corrosion is due to electrolysis, methods have been devised or suggested consisting in setting up a counter e.m.f. of greater intensity. This is the principle of the **Cumberland process** where the shell of the boiler forms the cathode, and the anodes are pieces of iron suspended in the water and insulated from the shell. A continuous current at a low voltage is employed and successful results are claimed; it is also said to be effective in removing scale and in preventing its formation. Pieces (protectors) of zinc, which is electro-positive to iron, connected with the shell, have also been tried, but such practice has received only a limited application.

Paint, from a commercial viewpoint, is a substance applied in liquid form to produce a protective coating. It is composed of (1) a solid substance in a fine state of division, known as the **pigment** or coloring matter, and the base or principal constituent (these may be the same), and (2) the **vehicle** or menstruum in which they are held in suspension. The pigment or base may be a metal or a chemical compound. Where the vehicle is linseed oil, a **drier** consisting of a salt of manganese or some other substance is often added to hasten the oxidation (hardening) of the oil. The **body** of a paint is its covering power, *i.e.*, the relative amount of surface a given quantity will cover thoroughly. When more than one coat is applied the first is called the **priming coat**; when applied to structural material shipped ready for erection it is termed a **shop coat** or **field coat**. A coating employed for pipes, known as **Angus Smith's solution**, originally consisted of coal tar, tallow, slaked lime, fine rosin, and coal naphtha; as used at present the mixture generally consists of coal tar and pitch oil in the proportion of about two to one, and it is heated nearly to the boiling point when the pipes, cleaned from scale and rust, are dipped in it. **Collodion** is occasionally employed for coating objects, but the film is thick, which is disadvantageous for certain purposes, and also is easily destroyed.

Lacquer is a varnish made by dissolving shellac in wood alcohol with the addition of other substances, particularly some pigment. **Japan** is similar to a varnish made by dissolving shellac in hot linseed oil to which a drier, such as litharge, is usually added. **Black Japan** or **Japan lacquer** is asphaltum dissolved in linseed oil and thinned with turpentine.

Caustic soda (NaOH) or caustic potash (KOH), in strong solutions, has a marked effect in preventing rust, and for this reason cleaned articles are frequently dipped in a concentrated

solution of one of these salts. So-called **boiler compounds** are sometimes used to neutralize free inorganic or organic acids which may be present, and for this purpose usually contain some powerful base such as sodium carbonate. One such compound contains sodium carbonate, tri-sodium phosphate, dextrine, and a substance with tannin. The use of lime direct is objectionable owing to the scale which is likely to result, and its employment is generally restricted to preliminary **purification** of water in large tanks, which also results in softening the water and so reducing scale for the removal of which, when formed, special compounds are advocated.

Influence on Corrosion of Certain Elements.—A few years ago the theory was advanced that, if iron could be manufactured approximately pure, that is, free from the usual metalloids and impurities, it would show extreme resistance to corrosion. Later work, however, indicates that several of the metalloids, within certain limits, are rather beneficial than harmful in their effects on the corrosion rate.

Carbon.—Under 0.20%, carbon has little influence on corrosion. From 0.20 to the eutectoid (0.85) percent, there is a gradual increase in the corrosion rate with additional carbon, and from the eutectoid percent up to approximately 1.25% the curve again drops.

Manganese.—A belief that manganese increases corrosion is still held by some metallurgists. Recent work, however, seems to prove that the real offender is sulphur (see Sulphur below), and not manganese, and that the latter, instead of increasing, slightly lowers the corrosion rate.

Sulphur.—The corrosion rate increases directly with the sulphur content, and corrosion is especially rapid in steels and irons approximately free from copper and carrying an abnormally high amount of sulphur.

Phosphorus.—Phosphorus has little or no influence on the corrosion rate. It has been noticed that, when a comparatively small amount of phosphorus is added to steel, the corrosion is slightly less, which is probably due to the deoxidizing effect of added phosphorus.

Silicon.—In the amounts normally present in open hearth and Bessemer steel, this element has no effect on corrosion. If as much as 0.10% or more, however, is added, the corrosion rate is increased.

Copper.—Copper has a remarkable influence in lowering the corrosion rate of steel or iron, even when present in very small quantities. It has the effect of neutralizing the influence of sulphur, and the rust film on the surface of the steel gradually becomes protective rather than accelerative as is the case with steels and irons comparatively free from copper.

Nickel.—The influence of nickel is similar to that of copper, except that probably more nickel than copper is required to produce a similar increased resistance.

Cobalt.—It is quite probable that cobalt in the lower ranges slightly decreases the corrosion rate. When cobalt is alloyed

with steel to the amount of approximately 12%, together with a little chromium, a product is obtained which is practically unacted upon by any corrosive agent.

Chromium.—Chromium tends to reduce corrosion especially in amounts over about 6%. What is known as **stainless steel** contains about 10 to 15%.

Oxide Coatings.—**Rust**, produced by slow oxidation and well known by its brownish, yellowish or reddish color, consists principally or wholly of ferric oxide (Fe_2O_3), hence readily parts with a portion of its oxygen to the metal beneath, absorbing a fresh supply from the surrounding atmosphere or other medium, thus setting up a catalytic cycle of which it is the agent. The oxide or scale which rapidly forms on iron objects when they are heated to high temperatures consists almost entirely of the magnetic oxide (Fe_3O_4); while it does not so readily part with oxygen, it is only slightly adherent when produced in this way and, being easily detached, offers little protection. Hence the necessity for special treatment to yield an adherent, non-corrosive coating (**rust proof coating**). One of the simplest methods is known as **blueing** which is effected by heating an object until the previously cleaned surface takes on a thin oxide film of that color. It is so thin that it is quickly worn off when handled, and accordingly its protection is relatively slight. **Barff's process** consists in passing superheated steam over the objects which are heated in a muffle to about 500°F . (260°C .); for more complete protection a temperature of 1200°F . (650°C .) is employed. Such objects are said to be **barffed**. "George Bower interested himself in this process and tried using air instead of steam (**Bower process**); he was not successful, however, until his eldest son, A. S. Bower, conceived the idea of using a producer gas rich in carbonic oxide to reduce the red oxide, as obtained by air treatment, either by barffing, or by subjecting the work to acid fumes. . . . The air treatment lasted 40 minutes and the gas treatment 20 minutes, these being repeated alternately four or eight times. Finally the Barff patents were purchased in order to secure a satisfactory first coating of red oxide in a practical manner. The combined process, known as the **Bower-Barff process**, consisted in heating the articles to be coated in a closed retort to a temperature of 1600°F . (871°C .); superheated steam was then injected, forming a coating of both magnetic oxide (Fe_3O_4) and red oxide (Fe_2O_3); this first operation lasted 20 minutes, and was followed by the injection, during 15 to 25 minutes, of carbonic oxide (CO) from a gas producer which reduced the Fe_2O_3 to Fe_3O_4 . These operations could be repeated alternately any number of times until a sufficient depth of oxide had been obtained" (Alfred Sang, *I. T. R.*, September 16, 1909).

The **Swan process** is a patented modification of the Bower-Barff process. The articles to be treated are first placed in a muffle furnace with the following substances, preferably as follows: Copper sulphate, 30 parts; sal ammoniac, 1 part; tannin, 2 parts; and glucose, 3 parts. They are heated to about 1050°

F. (620° C.), and superheated steam is injected for about 30 minutes. They are taken from the furnace, permitted to cool, and then submerged in paraffin oil heated to about 150° F. (65° C.). They are then dried in air and have a dead-black coating. Repeated treatments are not necessary unless a heavier coating is required. In **Bertrand's process** the iron to be coated is first carefully cleaned by immersion in dilute sulphuric acid (5%), and preferably brushed. It is then rubbed with grain or sand until quite clean, and immersed for four or five seconds in a bath consisting of 200 grams of acid tin salts, 600 grams of sulphate of copper, and 300 grams of sulphovinic acid in 100 liters of water. The work should then have a yellowish bronze color; it is washed in water containing $\frac{1}{2}\%$ of oxalic acid, dried and heated in an oven the atmosphere of which may be either oxidizing or reducing. The time required varies somewhat according to the temperature employed; but about 10 minutes is stated to give a fairly adherent coating of magnetic oxide which is capable of resisting atmospheric influences very perfectly (Turner). **Bontempi's process** consists in heating iron objects to approximately 1000° F. (540° C.) in a closed and preferably air-tight chamber, the iron having been previously treated according to the Bower-Barff process or not, as desired, when it is subjected to the gas or vapor of one or more non-corrodible substances. When the Bower-Barff process is omitted, the temperature need be only high enough to insure volatilization of the non-corrodible substance. **Browning** is used largely for gun barrels. The method in use at the Woolwich Arsenal (*Journ. I. & S. I.*, 1881) is as follows: The barrels, etc., are first scalded in a solution of soda for 20 minutes, and are then washed in clean water. The browning mixture is applied and they are exposed to a damp heat for about $1\frac{1}{2}$ hours, when they are scalded again and, when cool, the rust is scratched off. This process is repeated four times and then the barrels are cleaned off and oiled. The whole operation takes about 8 hours. The browning mixture consists of:

Spirits of wine.....	5 oz.
Spirits of niter.....	8 "
Tincture of steel (chloride of iron).....	8 "
Nitric acid.....	4 "
Sulphuric acid.....	3 "
Blue vitriol.....	4 "
Water.....	1 gal.

Sometimes browned steel is produced by simply rubbing the surface with a mixture of zinc chloride and olive oil. The **Buffington process**, used for parts of guns, etc., consists in suspending the objects for five minutes or more in pure molten niter, containing manganese dioxide, at a temperature where sawdust thrown on the surface will burn; the pieces are then hung for a few minutes over the pot and afterward placed in boiling water to remove any niter adhering to the surface; this method produces a fine bronze color. **Claudius' process**

consists in dipping the articles in a 5 to 6% solution of manganese nitrate and drying them slowly over a fire, the operation being repeated until a coating of the desired thickness is obtained; any loose powder is brushed off after each operation. In **Forbes' process** the articles are heated in a mixture of manganese dioxide or some similar substance mixed with a neutral material. In **Gesner's process** the articles are heated in gas-fired retorts for about 20 minutes at a temperature of 1000° to 1200° F. (540° to 650° C.), when superheated steam is introduced for about 35 minutes. After this a small quantity of naphtha is run in and the heating continued for 10 minutes; steam is again admitted for 15 minutes. The **De Wees Wood process** was earlier than, and practically identical with, the preceding and was applied to sheets. The **hydraesfer process** (patented by Bradley) is somewhat similar to the Bower-Barff process and requires but one furnace operation which lasts one hour or less; the color of the coating is a blue black. The process owes its name to the use of brass in connection with the partly decomposed steam which is injected into the retort. The metal to be coated is kept at a temperature of about 1100° F. (595° C.). **A. de Meritens' process** consists in placing the object in water at a temperature of 70° to 80° C. (160° to 175° F.) where it constitutes the anode of an electrolytic cell. An electric current, just strong enough to decompose the water, is used and the oxygen liberated forms a thin black layer of magnetic oxide which withstands rubbing and may be polished. No previous cleaning is necessary. If the current is too strong the oxide will not be adherent; it is also found advantageous to have hydrogen present in the iron by first passing the current, for a short time, in the opposite direction.

The **Parker rust proof process** consists in immersing the pieces to be treated in a bath containing about 2% of a mixture of phosphoric acid, manganese dioxide, etc., heated to about the boiling point. The pieces, previously cleaned, are allowed to remain in the bath a variable length of time, depending upon their composition, or until effervescence ceases. They are then removed and dipped in oil. The surface produced has the appearance of gun metal. **C. Platt's method**, intended for wire, consists in exposing it to the action of steam containing acid vapor which produces a fine brown coating in a few hours. It is then heated for an hour at a temperature of 100° to 125° C. (210° to 255° F.), dipped in oil, the superfluous oil removed in a centrifugal machine, and the wire again heated.

Spellerizing is a process, devised especially for treating the metal for steel tubes, consisting in first subjecting the skelp at the proper temperature to the action of rolls having regularly shaped projections on their working surfaces, and other rolls with smooth surfaces, the object being to knead and work the surface of the skelp (**roll-knobbling**) to produce a more adherent scale and one better adapted to resist corrosion, especially in the form of pitting. In **G. Weigelin's process** the objects are heated in a furnace so arranged that they may be exposed alternately

to reducing and oxidizing gases, whereby a film of magnetic oxide is produced.

Enameling is a method of producing a smooth, opaque, vitreous coating (glaze or enamel) on metals. The enamel is usually put on as a powder or solution of which silica is practically always a constituent; this is baked or fused. It may be applied in one coat, or sometimes a non-vitreous material, called the **base material**, is first applied and heated or **burned in** to make it adherent, after which the top coat or glaze is fused on. One method of producing a silicate coating on pipes is to cover the cores (in the mold) with a mixture of silicates of lime and magnesia which are fused when the molten metal comes in contact with them and become firmly attached to the surface. **Dode's inoxidizing process** consists in depositing successive layers of lead or silicate on iron and steel, and then gilding, platinizing, or bronzing them. The **Hydrogen Company's process** is used for soil pipes, and requires about two hours. The pipes are heated in retorts to the desired temperature, and steam is admitted for about one hour. Some hydrocarbon liquid is then injected with steam into the retort. The coating produced is claimed to unite with the iron and not form a mere paint. **Ward's inoxidizing process** is for producing a dull black coating on objects of cast iron or steel by dipping them in or painting them with a solution of some silicate. After dipping, the articles are heated in a furnace at a temperature which causes the silicate partially to fuse and to unite with the iron.

Metallic Coatings.—Various methods may be employed for applying the metal, such as dipping in a molten bath, depositing electrolytically, applying in a finely divided form, as a paint, by welding, and heating in contact with the powdered metal (**metallic cementation**). **Galvanizing** (rarely termed **zinc plating**) is a process for coating metal with a thin layer of zinc. It is so called from the fact that a galvanic couple is formed, of which the zinc is the more electro-positive, and hence, when exposed to corrosive action, is dissolved in preference to the iron, etc. Before the coating is applied, the surface of the object is cleaned from scale and dirt by pickling or some other means. According to the usual method, termed **pot galvanizing** or **hot galvanizing**, the object is dipped in molten zinc or **spelter** (commercial zinc) contained in an iron vessel or pot, at a temperature usually about 810° to 840° F. (430° to 450° C.). The surface of the molten zinc is largely protected from oxidation by a layer of ammonium chloride. In **Winiwarter's process**, intended more especially for sheets, the tank is kept nearly full of lead (to prevent the formation of hard zinc), on top of which is a layer of zinc about an inch thick containing 2 or 3% of tin to promote crystallization. Before coating, the sheets are cleaned by dipping in a dilute solution of chlorides of zinc and ammonium. In **Kuffler's process** superfluous zinc is removed from the surface of sheets by means of wire brushes. **Bedson's continuous process** is that very generally adopted for galvanizing wire (see page 509). **Reese's**

process is also a modification adapted for wire, in which the wire is galvanized in bundles without uncoiling, and then put immediately inside the drum of a centrifugal machine by means of which the excess of zinc is thrown to the periphery. **Porter's process** is devised for removing the excess of zinc from articles by placing them while still hot in a vibrating hopper, the surplus zinc collecting at the bottom, while the articles themselves are delivered before reaching the bottom. **Electro-galvanizing**, also called **cold galvanizing**, is where the object to be coated with zinc is attached (after cleaning) to the negative electrode (kathode) in an electrolytic bath, metallic zinc constituting the anode, and a soluble salt of zinc the electrolyte. In the **Cowper-Cowles process** the electrolyte is zinc sulphate, which is regenerated by circulating it through tanks containing zinc dust. In **S. Wagner's process** the zinc anode is covered with flannel saturated with a solution of zinc and is moved over the surface of the object. Electrolytic methods of galvanizing, which differ slightly in details from those described, have been devised by **Heathfield, H. Paweck, Pottkoff, Rawson, and Walker**. **Sherardizing** is a process of **dry galvanizing** invented by **Sherard Cowper-Cowles**. The articles, after cleaning, are placed in a retort, usually a revolving drum, with **zinc dust**, commonly called **blue powder**. This is the flue dust produced in the manufacture of zinc, and contains about 75 to 90% of pure zinc. A small amount of powdered charcoal is added to prevent oxidation of the zinc from the air inside the retort at the beginning of the operation, and the receptacle is closed and heated to a temperature about 200° F. (110° C.) below the melting point of zinc. The zinc appears to form a true alloy with the iron. This method is used principally for objects such as bolts and small castings, and does not appear to be applicable to sheets. After exposure, this coating assumes a grayish-blue appearance, which does not interfere with its resisting properties, called the **curing color**.

Coatings of tin, or a mixture of tin and lead, are used principally for thin plates or sheets, known respectively as **tin plates** and **terne plates**, which are described under **Sheets and Tin Plate**. **Nickel plating** and **copper plating** are usually done by electrolytic methods, the object to be coated forming the kathode, a piece of the metal for the coating, the anode, and a solution of some salt of the same metal, the electrolyte. In nickel plating, a preliminary coating of copper is often applied to make the nickel more adherent. Copper may also be deposited from solution by a purely chemical reaction with metallic iron whereby a corresponding amount of the iron goes into solution.

The electrolytic method is generally used where a relatively thin coating is desired on a finished object; frequently also as a preparation for nickel or other additional plating owing to the better adherence thus secured. This method may also be carried further to secure a thicker layer where the coated steel in the form of billets is subsequently rolled or worked down as in the production of small sections such as rods and wire. In this

second case the same object may be attained by a **welding process** by first depositing a relatively thin coating and then inserting the piece in a closely fitting tube of copper, the whole being subsequently heated to a moderate rolling temperature and squeezed into intimate contact, usually in a rolling mill. The product is referred to as **copper clad steel**. Of a similar nature is the **Monnot process**. Here the copper is cast around a piece of steel and the compound billet then rolled and drawn down, etc., or the heated billet may first be dipped in a bath of copper at a high temperature (to produce a copper-iron alloy film) and then into a second bath at a much lower temperature where the necessary thickness of coating is secured. By the electrolytic or welding methods the junction of the two metals depends only upon the very intimate contact, which is claimed to be better for use as electrical conductors than where the junction is formed by an actual alloy. The **Willis' process** is somewhat similar but varies in certain details. The term **coppered steel** is generally understood to refer to a copper coating, but is occasionally applied to steel containing, as one of its ingredients, a small percentage of that metal, the preferable term being, however, **copper steel** (see page 453). In this connection W. H. Walker suggested the term **ferro-brass** to illustrate the similarity of the reduced corrosion of copper steel to that of zinc to which copper has been added (forming brass).

Coatings of aluminum may be applied as in hot galvanizing, or as a paint the base of which is finely ground aluminum. A number of special methods have been devised. **Calorizing** is a process for the protection of metals against oxidation at high temperatures. The coating, called **insuluminum**, is claimed to prevent indefinitely oxidation below 1000° C. (1830° F.) and to increase the life greatly at higher temperatures. It consists in heating the pieces to be treated in a mixture of powdered aluminum, alumina, and about 1% of sal ammoniac in a gas-tight receptacle filled with a reducing or inert gas; the heating is slow and the time is usually two or three hours, depending upon conditions and the results to be obtained. Its principal application is for furnace parts, pyrometer tubes, combustion tubes, etc. (W. E. Ruder). The percentage of aluminum varies from about 5 to 50% by weight. For copper and brass objects the mixture is kept low in aluminum and the heating is carried out at about 700° to 800° C. (1290° to 1470° F.). For steel and iron objects, richer mixtures are employed and the temperature is increased to 900° to 950° C. (1650° to 1740° F.). These mixtures may be used repeatedly with the addition of the amount of aluminum and ammonium chloride necessary to make up the loss. The **Van Aller process** is very similar, the metallic objects to be coated being heated in revolving drums with mixtures containing finely divided aluminum. **Alumaloyd** is the trade name for sheets coated with aluminum by a special process. It is claimed that such sheets can be worked without cracking the coating, and that the surface is particularly adapted for painting where a high finish is desired.

The spraying of metals from the molten state is an old idea for producing powders, and the spraying of a liquid to produce a covering of paint, varnish or enamel is also well known. It has recently been adapted to produce uniform metallic deposits. In the Schoop process a metallic powder is driven at high velocity against the surface of the body to be coated, by means of gaseous jets expanded from considerable pressure. In earlier attempts the metal was melted in a pot, forced under high pressure through a fine nozzle, and sprayed on the surface with steam or gas. Morf devised a machine to combine pulverization and deposition. The essential parts of this machine or pistol are a combined melting and spraying jet and a feed mechanism. The metal to be used, in the form of a rod or wire, is fed to the melting flame which can be gas, acetylene, hydrogen, etc., in air or oxygen. For the best cohesion the surface must be thoroughly cleaned, preferably by a sand blast. Schoop's new method is based on the conception that the force with which the solid molecules are driven against the surface brings them into the liquid, or at least the malleable, state, resulting in perfect union and the consequent formation of a homogeneous body (Morcom, *J. Inst. Met.*, 1914, II). A modification introduced by C. F. Jenkins is based on the action of an electrical fuse which deposits and blows a shower of very minute metallic particles on the surface. The Lohmann or Lohmannizing process is used for coating iron and steel sheets with a protective alloy which is claimed to extend below the surface and to fill every pore or cavity. It appears to depend upon the use of what is called the Lohmann bath containing an "amalgamating" salt and, later, an immersion in a molten alloy. The metal is pickled and then dipped in this bath where a metallic salt is deposited, and the sheets are then dried and immersed in a molten alloy which is kept at a temperature of 950° to 1000° F. (510° to 540° C.). When the submerged objects have reached a temperature of about 500° F. (260° C.) the previously deposited salt is driven off and leaves the surface in a perfectly clean condition where it is replaced by the coating metal. An important feature of the process is the use of an alloy of zinc, lead and tin, the proportions of which are varied to suit requirements. Kalamein is the trade name for a coating of lead, tin and antimony applied in a manner similar to hot galvanizing. It is used especially for tubes and similar objects (said to be kalameined). It is of a silvery color, resembling the appearance of galvanized objects, but without spangles, and is not cracked or injured by bending or rough handling.

Miscellaneous methods.—A. Bucher recommends applying the following solution:

Distilled water.....	1¾ pints
Tartaric acid.....	50 grains
Stannous chloride.....	150 "
Mercuric chloride.....	30. "
Indigo solution.....	750 "

diluted with 100 times its volume of water. **A. M. Villon's process** consists in subjecting the object to the vapor of sulphur, which combines with the iron forming a **sulphide coating**.

Protective Coatings; Process.—See page 363.

Protector.—See page 365.

Proving.—See page 467.

Proximate Analysis.—See page 82.

Proximate Structural Composition.—See page 337.

Pseudocrystalline Structure.—See page 125.

Pseudosymmetry.—See page 125.

Pseudomorph; Pseudomorphic Crystal.—See page 122.

Puddle Ball.—See page 376.

Puddle (Puddled) Bar.—See page 377.

Puddle Cinder.—See page 377.

Puddle (Puddled) Iron.—Wrought iron made by the puddling process.

Puddle (Puddled) Steel.—Iron made by the puddling process which contains enough carbon to be hardened by quenching: see page 379.

Puddle Train.—See page 413.

Puddlers' Candles.—See page 376.

Puddlers' Mine (Eng.).—See page 376.

Puddling, Puddling Process.—This process has for its object the production of wrought or malleable iron (rarely steel) by oxidizing and removing most of the silicon, carbon, manganese, and phosphorus contained in pig iron, the operation being conducted on the hearth of a reverberatory furnace. The charge during the early stages is molten, but, owing to the temperature not being sufficiently high, the final product is in a pasty state, and for this reason is mechanically mixed with a certain proportion of slag, most (but never all) of which is removed during subsequent steps in its manufacture.

Until 1784 all wrought or malleable iron was made by some direct process (*q. v.*) or by similar means. In this year, however, Henry Cort patented the process of puddling (hence **Cort's process**) by which it is produced from pig iron in a reverberatory or air furnace, without the assistance of an air blast. The furnace at first was lined with sand, which combined with the iron which was oxidized, and caused a very heavy loss; there was little if any removal of phosphorus, and the operation was slow. This method is called **dry puddling** (on account of the relatively small amount of slag) to distinguish it from the later method (at present used exclusively) where the furnace is lined with some form of iron oxide, called **wet puddling** or simply **puddling**, and iron oxide is also charged to form a slag. Formerly **puddling** meant the practice employing refined pig, and **boiling** or **pig boiling**, where unrefined pig was used, but now this distinction is not generally observed, as the pig is seldom refined.

Puddling Furnace.—The hearth (sometimes called **basin** or **puddling basin**) is built of cast-iron plates carried on brick walls or on short iron pillars. It is usually about 5 or 6 feet

long, and 4 feet wide opposite the charging door. Resting upon and extending around the sides of the hearth is a box, or a double wall, of cast iron 8" or 10" high, through which water circulates. The iron bottom is also sometimes double and water-cooled. Air may be substituted for water as a cooling medium. The fuel is generally bituminous coal, although gas is occasionally used (see below under special furnaces). For coal the grate has an area of about 6 square feet, sometimes 10 or more. The grate bars are separately detachable to allow of cleaning any part of the fire, and also so they may be replaced when necessary. Between the grate and the hearth is a fire-brick wall (bridge wall) extending from side to side and rising sufficiently high to prevent any of the fuel from passing over on the hearth, or any metal or slag from falling on the fuel. The hearth at the other end, next the

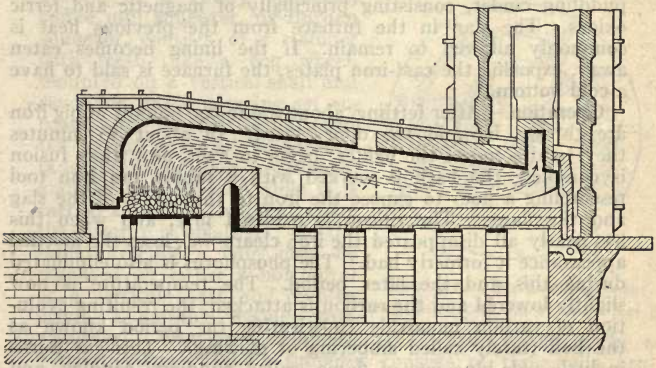


FIG. 50.—500-lb. puddling furnace.—(Stoughton, *Met. of I. and S.*)

chimney, terminates in a second bridge (**altar**) which prevents the overflow of the metal at that end. Beyond this the furnace flue inclines downward and terminates at the chimney flue. At the foot of this there may be an opening (**floss hole**) through which any cinder overflowing the altar may escape, and warmed by a fire to keep this cinder (**flue cinder**) molten. On the side of the furnace opposite the middle of the hearth is the working door. This is about 20" square and is closed by a slide lined with fire-brick which can be raised or lowered. A small opening (**rabbling hole**) at the bottom of the door large enough to admit a rabble permits the workman to stir the charge, protected from the heat, and also without admitting a large amount of cold air. The roof of the furnace is an arch about 2 feet high at the fireplace and sloping gradually until, at the chimney, it is less than a foot above the bottom of the flue.

The furnace just described is known as a **single furnace** and has a capacity of about 400 to 600 pounds and is the type generally employed. If two such furnaces are placed back to back with the separating wall omitted, it is called a **double furnace**, and can take a charge over twice as great as a single furnace. Two double furnaces placed side by side, with the separating wall omitted, constitute a **double-double furnace** or a **quadruple furnace**.

Lining and Fettling.—The bottom and sides of the hearth are covered with ore or slag rich in iron oxide, etc., which is set by heating to a high temperature. After the preceding charge has been drawn, the hearth is repaired (**fettled** or **fixed**) by throwing in up to, say, 200 pounds of ore, etc., slightly moistened. The material for this purpose is called **fettling** or sometimes (Eng.) **fix**, **mill fix**, or **puddlers' mine**. **Bull dog** (Eng.) is calcined tap cinder. **Best tap** (Eng.) is a specially prepared puddling cinder, consisting principally of magnetic and ferric oxides. The slag in the furnace from the previous heat is commonly allowed to remain. If the lining becomes eaten away, exposing the cast-iron plates, the furnace is said to have a **cold bottom**.

Operation.—After fettling, about 200 to 600 pounds of pig iron are thrown in, and the door closed. In about 20 minutes they (and some of the oxides) begin to melt, and when fusion is complete the bath is worked with a **rabble** (an iron tool resembling a hoe) to expose the iron to the action of the slag and the flame. The silicon is oxidized first, and when this has nearly all disappeared the iron **clears**, *i.e.*, loses the mottled appearance it formerly had. The phosphorus is also eliminated during this and the later period. The temperature is now slightly lowered and the carbon is attacked, the resulting evolution of carbon monoxide constituting the period known as the **boil** (rarely called **sibbering** or **stewing**). This gas burns in little pale-blue jets of flame, called **puddlers' candles**, and during its escape puffs up the cinder so that the level of the bath is raised (**high boil**). Corresponding to the loss of carbon the charge becomes more and more pasty, and the bath drops to its former level (**drop of the bath**), and about this time grains of nearly pure iron appear on the surface and the iron is said to have **come to nature** or to have been **brought to nature**; this condition is sometimes termed **drying**, and the iron is called **ready iron** or **young iron**. At this point the charge must be well worked up to insure proper welding together of the particles. When the action is complete the pasty mass is broken up with a bar into lumps called **balls** or **puddle balls** (the operation is termed **balling**) of about 100 to 200 pounds each, which are drawn successively with tongs and taken to be **squeezed**, an operation to expel most of the slag, and also to weld the grains of iron together. The total time of the charge is about 1 to 1 $\frac{3}{4}$ hours.

If, after charging, the pigs are not moved about, part of the iron may melt at too high a temperature (**hot melting**) and

stick to the bottom (**aproning**) in an insufficiently decarburized condition. If the removal of carbon is too rapid the grains of iron are coarse and form a compact mass difficult to work and ball (**gobbed heat**). **Rodney** (Eng.) is cold cinder sticking to a piece of old iron put into the furnace to help bring on the boil. A **cobble** is a ball which has been drawn too soon and must consequently be put back in the furnace.

In some cases part of the cinder may be removed just before the boil and is called **boilings**, the remainder, if removed at the end of the process, is known as **tappings** or **puddle** (**puddling**) **cinder**. A furnace is said to have a **dry bottom** when the slag is drawn off at intervals (this operation is termed **bleeding**); a **wet bottom** is where the slag is allowed to remain. The fluid, vitreous cinder on top of the bath is occasionally called **floss**.

Squeezing.—The machine for this operation is termed a **squeezer**, and may be of several types. The present form, known as a **rotary squeezer**, **coffee mill squeezer**, or **Burden squeezer**, consists of a cylinder with teeth, like a cog wheel, mounted on a vertical shaft and revolving inside a casing set eccentrically, the ball being inserted at the point where the distance between them is greatest, and the slag expelled while it is carried around to the point where the distance is smallest. On the same principle a cam may be mounted on either a horizontal or a vertical shaft and revolve inside a suitable casing (**cam squeezer**).

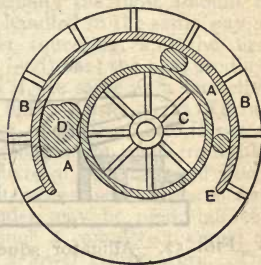


FIG. 51.—Burden squeezer.
—(Thurston, *Iron and Steel*.)

Winslow's squeezer has a cam revolving in a vertical plane. **Head's squeezer** consists of three rolls, provided with grooves and collars, arranged much like a set of plate bending rolls. In **Siemens' squeezer**, three horizontal rams opposed to each other, operated by hydraulic power or by steam, squeeze the ball on a turntable. The original type of machine, called an **alligator squeezer** or **crocodile squeezer**, consisted of an anvil block, upon which the ball was laid, and a vibrating toothed jaw which alternately pressed down upon the ball and rose to allow of changing its position. The use of hammers was still older, and the operation was termed **shingling** (rarely **nobbing**).

Piling.—After squeezing, the rough bloom is rolled into a flat bar known as **muck bar** or **puddle** (**puddled**) **bar**. This is cut up into short lengths (if broken, the operation is known as **cabbling**) and a number piled together, termed a **pile**, to be reheated in a furnace, called a **reheating furnace**, **balling furnace** (Eng.), or **mill furnace**, and rerolled, when more of the slag is expelled. Ordinarily the pieces of muck bar are all laid the same way, but occasionally the bars in alternate layers are placed

crosswise, and this arrangement is called **cross piling**. Instead of piles a rough box may be made up, the sides, bottom, and top consisting of pieces of muck bar, the interior of which is filled with miscellaneous small iron scrap; this is termed a **fagot** (**faggot**), or **box piling**, and the operation, **fagoting**; the iron so produced is sometimes called **fagoted iron**.

Product.—The material, in general, is called **puddled iron**, and after rerolling is known as **refined iron**, **refined bar**, **merchant bar**, **single rolled iron**, **single refined iron**, or **No. 2 iron**; if subjected to a second piling, heating, and rerolling, **double** (**doubly**) **refined iron**, **double rolled iron**, **No. 3 iron**, **best bar**, **wire iron**, or also **refined bar**. **Horseshoe iron** is a superior grade made by piling and rerolling old iron horseshoes. Two obsolete products are **stampings** and **lumps** which are (Percy) rough plates about 12" square, the former being about 1½" thick, and the latter 4" to 5" thick.

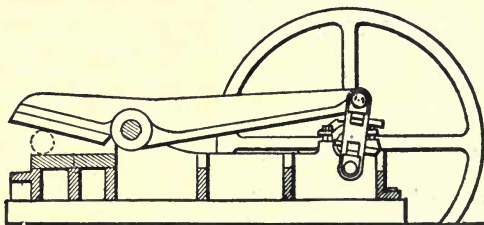
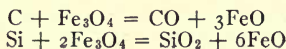


FIG. 52.—Alligator squeezer.—(Thurston, *Iron and Steel*.)

Theories of Puddling.—The oxidation of the impurities is due to the oxide of iron present, rather than to the direct action of the oxygen in the air. Siemens considered that magnetic oxide, Fe_3O_4 , was the active agent (**magnetic oxide theory**) which is generally accepted, while Snelus referred the action to ferric oxide, Fe_2O_3 (**ferric oxide theory**).

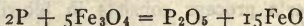
The action will probably be most readily understood by considering a piece of cast (pig) iron heated in contact with the air. A crust or shell of oxide is formed, and, upon removing this, the metallic iron which is left will be found to contain practically the same percentage of impurities as originally. This oxidizing action may be continued, and the metallic iron which remains will have the same composition even if the temperature is sufficient to cause the scale to melt, provided this is allowed to drain off. As soon, however, as the melted scale or slag remains in contact with the iron, particularly if the iron is molten, a new state of affairs is found to exist. The magnetic oxide, Fe_3O_4 , of which the scale is principally composed, readily parts with one atom of its oxygen which combines with the carbon, silicon, etc., of the iron, and is itself reduced to ferrous oxide, FeO , thus:



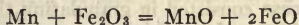
Most of the ferrous oxide is reoxidized by the air to magnetic oxide which again reacts with the impurities, and this cycle goes on indefinitely; a small portion, however, is reduced to metallic iron which is dissolved by the bath:



The phosphorus and manganese are similarly oxidized, thus:



also



Scrap Iron.—Instead of starting the process with pig iron, as described, scrap iron may be employed. This is generally of small size, called **busheling scrap** from the fact that it can be gathered up in a bushel basket, and is heated in a furnace (**busheling furnace** or **scrap furnace**) the same as a regular puddling furnace. The charge is usually the right amount to form one ball (**scrap ball**), which is handled in the same way as a puddle ball. The material, after squeezing, and the first rolling, is called **scrap bar** or **bushel (-ed) bar**; the final product, **busheled iron**. A **swarfing furnace** is the same as a busheling furnace, but the scrap used is much finer. Large pieces of scrap are heated and welded or rolled direct, or made up into fagots as described above. **Common iron** is wrought iron made from coke pig; finer grades are made from charcoal pig (**charcoal iron**).

Puddled (puddle) steel is made in very much the same way as puddled iron, and the same cinder may be used, but the process is arrested before there is such a complete removal of carbon, and must be conducted at a lower temperature. The product contains roughly up to about 0.5% of carbon (wrought iron, usually under 0.1%), but there is no sharply drawn line between the two: the steel must be capable of hardening.

The working of the charge is now practically always carried on by hand: mechanical devices have been tried from time to time, but have achieved only a temporary consideration. **Mechanical rabble, mechanical stirrer**, or rarely (Eng.) **iron man**, is a machine which works the charge in an ordinary (or special) type of furnace. The furnace, or simply the hearth, may be rotated in a vertical or a horizontal plane to effect the same thing: such a furnace is called a **rotary puddling furnace, rotator, mechanical puddler, puddling machine, or rotating puddling machine**. Modifications of these, as well as of ordinary furnaces, consist principally of the application of various mechanical devices which need not be mentioned.

Barnett's process consisted in applying a solution of salt to the lining of the furnace to improve it.

Beasley's process consists in using a mixture of powdered puddling cinder and blue billy, treated with hydrochloric acid, to which lime and salt are afterward added. This is painted on the surface of the lining, after fettling, and is claimed to remove a greater amount of phosphorus, and also to increase the output.

According to **W. W. Collins' process** pig iron was melted in the ordinary way with a large quantity of silicate of iron or other metallic oxide. The melted mass was allowed to remain quietly until the iron began to rise, when it was vigorously worked at a high temperature and balled. The product was to be melted in crucibles with the addition of the desired amount of carbon.

E. A. Cowper's process consists in blowing preheated air and combustible gas on the bath.

Hewitt's process consisted in granulating the pig and mixing it with oxide of iron, the melting and working being conducted as usual.

Hunt's process consisted in working metal, partly decarburized in a Bessemer converter, in a puddling furnace or a charcoal hearth.

In **Jones and Jones' process** partial purification of the pig was performed in the ordinary way, the final treatment and balling being conducted in a rotary furnace.

In **W. Middleton and P. Hayward's furnace** between the ordinary puddling furnace and the chimney is a retort, heated by the waste gases, in which the pig iron, before being introduced into the furnace, is melted and purified with a blast of air.

The **Pietzke process** employs a special furnace which is gas fired and is connected directly with a gas producer. It has two hearths which can be rotated jointly 180° . The charge is introduced into the hearth which is farthest from the fire, and the operation is completed by rotating it to the position nearest to the fire, two charges being worked at the same time.

In **Riepe's process** (for steel) about 280 pounds of pig were melted and cinder was added. It was then puddled with the addition of a little black oxide of manganese, common salt, and dry clay previously ground and mixed. When this had acted for a few minutes, 40 pounds of heated pig were put in, and boiling commenced. When grains began to form, they were worked under. He claimed that the most important part of the process was the regulation of the temperature during the final operation.

Sherman's process consisted in adding potassium iodide to the metal under treatment.

W. Spielfield, to prevent oxidation of puddled or raw steel, heated the lumps or balls in retorts or closed vessels.

Taylor's process was to cool the puddle balls, without squeezing, then crush them and separate the small refined particles from the coarse unrefined ones. The former were heated and balled; the latter retreated.

E. Bonehill used direct metal with mixers. **Guenyveau** suggested a steam and air jet; **Guest and Nasmyth**, a steam jet; **Trick, Davis, Daniel and Phillips** also suggested steam.

J. J. Osborne's process consisted in adding a physic composed of various proportions of salt, burnt lime, and hammer slag. **Ostlund** proposed, in the case of refractory Swedish pig, to refine in a revolving iron pot, lying in an inclined posi-

tion, and heated with carbonic oxide introduced through a blowpipe. In **Sterling's process** about half a per cent of tin was added to the charge, but this made the iron difficult to forge and weld.

Puddling Basin.—See page 374.

Puddling Cinder.—See page 377.

Puddling Furnace.—See page 374.

Puddling Machine.—See page 379.

Puddling Mine (Eng.).—Roasted hematite, suitable for use in puddling furnaces.

Puddling Operation ; Process.—See page 376.

Puddling Product.—See page 378.

Puddling, Theories of.—See page 378.

Puffed.—Of rolls: see page 430.

Pull Over Mill.—See page 408.

Puller Out.—See page 115.

Pulling.—Of castings: see page 56.

Pulling Test.—See page 469.

Pulpit.—An elevated platform commanding a view of the entire mill, where the various appliances are situated for controlling its operation.

Pulverize.—To reduce to powder or a fine state of division by crushing or grinding.

Punch.—A machine or tool for making holes in metal by forcing out a certain portion.

Punching.—Producing a hole in a body by driving a blunt-nosed instrument through it, the displaced material being almost entirely removed from and forced out at the farther side, only a very small proportion being forced into the wall (distinction from piercing); see also Cold Working and Forging.

Punching Test.—See page 477.

Punish.—To subject material to very severe or abusive treatment.

Pure.—Of materials, free from impurities or undesirable elements, or where these are so low they do not exert a harmful influence; degrees of chemical purity: see page 89.

Pure Cast Iron ; White Iron.—Pig iron nearly free from everything but carbon.

Pure Chemistry.—See page 81.

Pure Flexure.—See page 332.

Pure Stress ; Normal Stress ; Internal Normal Stress ; Shearing Stress.—See page 332.

Purification.—(1) Of metals: see Purification Processes, also page 56; (2) of water: see page 366.

Purification Processes.—Those which are concerned (a) principally with the removal from pig iron of silicon, phosphorus, and sulphur, the action being stopped when the carbon is attacked, the product being further treated in some other process; and (b) embracing certain details or modifications applied to ordinary processes for making iron or steel. From a practical standpoint the term is not considered to include the regular processes for the manufacture of wrought iron and steel, although from strictly theoretical considerations they would also be included.

Oxidation is the general means employed, the metal treated being nearly always in a molten condition. **Decarburization** (decarbonization), **desulphurization**, **dephosphorization**, and **desiliconization** are the technical terms used respectively for the removal of carbon, sulphur, phosphorus, and silicon. The general principle to be observed is that at a low temperature, with oxidizing conditions, and in the presence of a basic slag

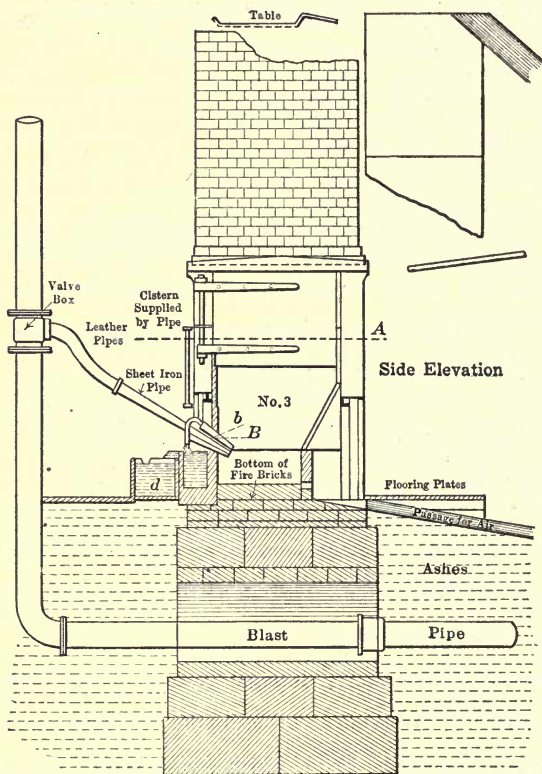


FIG. 53.—Melting finery.—(Stoughton, *Met. of I. & S.*)

(basic purifying processes), phosphorus and silicon are oxidized in preference to carbon. If the slag is not basic then the phosphorus will not be removed. Under oxidizing conditions the removal of sulphur is uncertain. Under strongly reducing conditions, and with a basic slag, as in the blast furnace,

the removal of sulphur is under fairly good control, the action being due to the formation of sulphides of calcium and manganese which pass into the slag.

The terms commonly employed for this special treatment are **fining**, **refining**, **hearth refining**, **refinery process**, or **refining process**, and the furnace employed is called a **finery**, **finery fire**, **refinery**, **refinery hearth**, **refining hearth**, **running-out fire**, and **run-out fire**. These embrace the earliest method employed which is still used to a limited extent. The apparatus consists of a hearth, generally rectangular, built up of naked, water-cooled, iron plates, blast being usually supplied by two tuyeres opposite to each other, and with a capacity of about $\frac{1}{2}$ to 2 tons of pig. The fuel is either coke or charcoal (**coke finery** or **refinery**; **charcoal finery** or **refinery**), and the pig is charged either molten or, more commonly, solid. The fuel is burned by the blast from the tuyeres, which also supplies the necessary oxygen for oxidizing the silicon, etc. If ore is added part of the phosphorus is removed. Each charge takes about two hours, less if the metal is initially molten. The product (**fine metal**, **finer's metal**, **refined metal**, **metal**, or **refined cast iron**) is tapped out on the iron plates of the floor (**plate metal**) or into iron molds. It has a white fracture (**white metal**) due to the absence of silicon. It is sometimes tapped directly into the furnace in which the final treatment is to take place and the furnace is then termed a **melting finery** or **refinery**. The loss of iron is about 5 to 20%, and the fuel required, about $\frac{1}{8}$ to $\frac{1}{5}$ of the weight of the metal charged. Parry tried to hasten the process by blowing a jet of air and superheated steam on the bath of pig in a refinery, which modification he called a **steam refinery**. A **melting down refinery** is one in which selected pig and scrap are employed, instead of pig alone. The product of **charcoal fineries** or **charcoal hearths** is frequently known as **charcoal hearth cast iron**, and the process is sometimes called **frischen process**, from the German, whence the name **German forge** sometimes applied. Where the process is carried further, and wrought iron is produced, will be found discussed under **Charcoal Hearth Processes**.

Pig washing processes are a modification of ordinary refining. They consist in treating molten pig iron with molten oxides (oxides of iron, occasionally mixed with oxides of manganese) in a reverberatory furnace. At the low temperature employed, and in the presence of the very basic slag, most of the silicon and the phosphorus are removed, the metal being tapped out before the carbon has been materially attacked. The elimination of the silicon and the phosphorus may amount to 90 or 95%. In **Bell's pig washing process** (**Bell's dephosphorizing process**) the molten pig is agitated with molten oxides of iron; **Krupp's pig washing process** (patented a couple of months later) is essentially the same, except that a certain proportion of oxide of manganese was used and the operation was usually carried out in a furnace with a revolving hearth (**Pernot furnace**). They are now generally referred to as the **Bell-Krupp pig washing process**, and the special addition of oxide of man-

ganese is dispensed with as unnecessary. The product is called **wash metal, washed metal, or washed pig.**

Slag processes are those in which molten slag is employed, and pig washing should properly be included. In the **Talbot slag process** a basic slag consisting of iron oxide and lime is first made in a regenerative furnace and is then poured into a vessel of suitable form (like a ladle) so it forms a deep column. The molten pig to be treated is poured on top of this column through which it sinks and, during its passage, a considerable quantity of silicon is removed, together with some of the carbon and phosphorus. The treated metal is then transferred to a basic open hearth furnace, and the purification completed in the usual way. The **Knoth slag process** was designed especially for use in connection with the basic open hearth process, to effect a preliminary purification. The molten slag from the previous heat is transferred to a ladle or other suitable receptacle, and lime and other basic materials are added to give it the proper composition. It is then returned to the regular furnace on top of the next charge of molten metal. **S. B. Sheldon's process** appears to be very similar to that devised by Knoth. The slag at the end of the refining operation is transferred to an auxiliary furnace where fresh basic material is added, the whole made fluid, and then put back into the original furnace for the next operation.

Following are brief descriptions of processes which have been suggested and tried from time to time with varying degrees of success.

Aubertin and Boblique's process had for its object dephosphorization by the action of alumina or fusible aluminates, in puddling or in some steel-making process, it being claimed that phosphate of alumina was more stable in the presence of silica than the phosphate of lime or magnesia.

Bacon and Thomas' process was designed for the removal of silicon from pig iron by melting it in a cupola with the addition of oxide of iron and limestone.

Wm. Baker's process consists in blowing air on the surface of molten pig as it flows from the blast furnace in a specially designed trough.

In **Ball and Wingham's process** molten pig iron, high in sulphur, was treated with potassium cyanide, sodium carbonate, and potassium carbonate, either singly or together, and in some reported analyses the elimination of sulphur varied from 83 to 100%.

Bell's refining process, the product of which was to be used in puddling, consisted in oxidizing the silicon in a Bessemer converter, carbonaceous matter being introduced with the blast, or spiegel added, if there was danger of removing too much of the carbon, so the phosphorus would not be properly eliminated in the puddling operation. The blown metal was to be used molten.

Brinell's process is a modification of the Ellershausen process (see below). An ingot mold is partly filled with molten pig iron, and when solidification is about to take place a quantity

of fine ore is thrown in until the mold is full. The ingots so produced are intended to be used in the open hearth process in place of ordinary pig iron.

Brown's process for "neutralizing" phosphorus by the addition of bichromate of potash is absurd.

Budd's process for removing silicon consisted of running the metal from a blast furnace into shallow pans lined with a dried paste of iron ore; in another process, a proportion of sodium nitrate was mixed with the iron ore.

Bull's process was designed to effect dephosphorization in either the Bessemer or the open hearth process by blowing steam through the bath. It was claimed that, after the other impurities had been removed, the steam reacted with the phosphorus forming a volatile phosphide of hydrogen. Owing to the chilling action of the steam, the process was not successful.

Chute's process (recently patented) would seem to be nothing but an application of the Ellershausen process (see below), his claim of discovery being "that by adding powdered ore to a stream of high-silicon pig iron flowing in a runner to the pig beds that the silicon and manganese were reduced in amount." The process was to be used in connection with the open hearth process, the metal being added in a molten condition.

In the **Detmold process** pig is melted in a reverberatory furnace similar to that used for puddling, and air is blown on the surface.

A. de Vathaire suggested the use of cyanide of barium or other alkaline earth to effect desulphurization. The operation was to be performed in a non-oxidizing atmosphere, preferably in a revolving drum lined with carbon or lime.

The **distillation process**, so called, was performed in a crude form of blast furnace: before tapping, the tuyeres were inclined, and the blast directed upon the molten pig iron in the hearth.

Eaton's process was claimed to effect the removal of phosphorus, carbon, and silicon from planed bars of cast iron by immersing them in fused alkaline carbonates.

The **Ellershausen process** consists in treating the molten metal flowing from a blast furnace with oxides lining the runners, which effects a partial removal of the silicon and carbon (probably some of the phosphorus and manganese also). The process was designed originally for treating pig to be used for puddling. A modification has occasionally been employed abroad in foundries, where a certain amount of silicon is removed by throwing fine ore, previously heated and dried, upon the stream of metal as it flows out of the cupola.

In **Fament's process** phosphorus and sulphur were to be removed from any grade of iron by treating it in heated retorts with a current of hydrogen.

Farrar's process consisted in treating pig with a mixture of sal ammoniac, ferrocyanide of potash, and manganese (oxide?).

Garnier's process for dephosphorizing is practically identical with present basic open hearth practice. It consisted in charging lime and ore before the other materials.

James Gregory and William Green claimed that, by allowing broken or granulated pig iron to remain in water for some time, it was made better and tougher.

Fernand Hamoir's process was for refining pig iron previous to puddling. The pig, while being tapped from the blast furnace, was to be subjected to a jet of air derived from the blast used for the furnace.

J. Haythorne's process was evidently to be used in connection with the puddling process, and would seem to have been based upon questionable principles. While the metal was molten, he added a mixture of dioxide of manganese, oxide of tin, zinc, or lead (!), quicklime, potassa or soda, saltpeter or ammonia, and brick dust or calcined clay.

In **Heaton's process** nitrate of soda was placed in the bottom of a ladle or other suitable vessel, being kept in place by an iron grating, and the molten pig iron was poured on top. It was claimed that the action of the nitrate removed some of the phosphorus, all of the silicon, and nearly all of the sulphur.

The **Henderson process**, as originally applied to the puddling process, consisted in adding fluorspar and titaniferous iron ore to the slag, with the idea that the impurities would pass off as volatile fluorides. At Birmingham, Ala., a modification (**Henderson steel process**) was used for a time in making steel from phosphoric pig. The molten pig was first desiliconized and partly decarburized in an auxiliary chamber of a special furnace, and was then run into a basic lined furnace and treated with dolomite and fluorspar. It would appear that the dephosphorization was due to the dolomite rather than to the fluorspar.

Heerzele and Paulis attempted to purify pig (and to make steel) by heating it in contact with steam.

Marcus Lane's process consisted in running the fused metal from a melting furnace into a special refining furnace, so placed that the metal, on entering, had a rotary motion. This motion was continued by means of a blast striking the metal at an angle which also served to decarburize it. As this action was apt to be too rapid, carbon was added at intervals to give time for the impurities to be removed.

In **J. G. Martien's process** the molten metal from the blast furnace or the refinery furnace passed through gutters where jets of air or steam were blown up through it.

The **Massenez process** (**Hoerde process** or **Hilgenstock process**) for desulphurizing is based upon the fact that sulphur combines with manganese in preference to iron, the resulting manganese sulphide being insoluble in the molten iron, and therefore passes off into the slag if sufficient time is allowed. Pig iron, high in sulphur and low in manganese, is mixed with pig containing a considerable proportion of manganese (ferromanganese may also be used) both being in the molten condition. A modification consists in charging oxide of manganese in a bath of metal, part of the manganese being reduced and effecting the removal of the sulphur.

J. B. Nau's process is designed to purify pig to a certain extent by running it into a cupola of special construction filled with lumps of iron ore and lime previously heated, the metal being tapped out after a few minutes.

Parry melted wrought iron in a cupola or blast furnace and repuddled it to obtain a further elimination of phosphorus and sulphur, sometimes repeating these operations. He employed a special form of cupola in which one tuyere was horizontal, while another, at the opposite side, was inclined downward to obtain a very high temperature at the bottom of the furnace. He also used a reservoir or vessel provided with a number of sets of tuyeres in which the carburized metal could be softened by jets of air from the bottom or on top.

Peckham's process was intended for the purification of iron and steel in a Catalan forge or puddling furnace. It consisted in removing the impure cinder as fast as formed, and replacing with a pure slag, a flux being used for thinning when the slag was too viscous.

Charles Peter's process consisted essentially in the use of a small reverberatory furnace at the top of a special narrow cupola of which it formed a part. As the iron was melted in the former it fell in granules through the latter where it was acted upon by the air which entered the tuyeres at the bottom end.

In **Prince's process**, cast iron is treated in a ladle by blowing air through it, and it is claimed that 30 to 50% of the sulphur is removed by causing it to unite with manganese oxide and so pass into the slag; ferro-manganese may be added to promote this action.

In **Jacob Reese's process** steel (probably wrought steel) was to be refined with an oxidizing blast in a coke refinery, a layer of metallic oxide being interposed between the fuel and the metal.

Rollet's process consisted in melting pig iron with a slag composed of lime, iron ore, and fluorspar in a basic lined cupola of special construction in which the tuyeres were so arranged that the conditions could be made oxidizing or reducing as desired. This process was intended to be auxiliary to some steel-making process.

The **Saniter process** for desulphurizing depends upon the use of calcium chloride in a slag containing a high proportion of lime, the principal action of the calcium chloride being, apparently, to render the slag fluid. Fluorspar is also added for this purpose. It may be used in treating (a) molten pig iron in a ladle before it is cast into pigs, and (b) in the basic open hearth process or the basic Bessemer process.

Thomas Shaw's process is for purifying pig iron by directing a jet of dry steam upon it as it flows out of a cupola furnace.

The **Sherman process**, like Brown's, had for its object "neutralizing" but not removing the phosphorus in steel, and is equally absurd.

Siemens' purifying process consisted in heating iron oxide

spread uniformly over the hearth of an open hearth furnace, followed by or mixed with scrap metal or puddled iron. These were heated to a white heat, and molten pig iron added. The partially purified metal was then run into another open hearth furnace and finished as usual.

In **Smyth's process** pig iron was purified in a Bessemer converter by introducing various chemical compounds with the blast.

B. P. Stockman's process is similar to that of Heaton (see above). It effects a preliminary refining by running molten pig iron upon a mixture of nitrate of soda, magnetic iron oxide, common salt, and black oxide of manganese (manganese dioxide) contained in a suitable vessel. The action is very violent and as soon as it is over the metal is finished in an open hearth furnace in the usual way.

O. Thiel, one of the originators of the Bertrand-Thiel process, refines pig iron in a stationary open hearth furnace, using a basic oxidizing slag in a manner very similar to Surzycki's modification of the Talbot process (see page 316), there being a number of tap holes at different levels, and only a portion of the charge being tapped out each time, which is finished in another furnace; the charge may also be finished in the same furnace.

E. A. Uehling's process consists in treating molten cast iron while in the ladle with various materials to eliminate impurities.

E. von Maltitz refines molten pig iron by putting it in a ladle or other vessel and covering it with a basic slag; it is caused to circulate, and a jet of air is directed against the surface under the slag covering.

Walrand's process is intended to effect dephosphorization of a bath by successive removals of the basic slag and further additions of iron oxide and lime.

Warner's process is somewhat similar to that of Heaton (see above), nitrate of soda being replaced by ground lime, soda ash (crude sodium carbonate), and small amounts of other materials, upon which the molten pig iron is run, to be later cast in molds when the purifying action is complete; this was stated to require about 10 minutes.

Wellman and Schwab's process was to effect a preliminary partial refinement of pig iron in a basic-lined mixer or other suitable vessel in which the metal could be kept molten. Lime and ore were added and at intervals portions of the bath were removed and used in the regular open hearth process.

J. G. Willans' process does not seem to possess any special novelty. Pig iron, in contact with carbonaceous matter, is melted in a cupola, a small amount of silicon being removed, but probably not any phosphorus.

Purifying Process.—One in which impurities are removed.

Purity of Chemicals.—See page 89.

Purple Ore.—See page 245.

Purple Temper.—Oxide color: see page 230.

Put On.—Of the blast, to start.

- Pyramidal Cleavage.**—See page 124.
- Pyramidal System.**—Of crystallization: see page 120.
- Pyrheliometers.**—See page 207.
- Pyrite.**—See page 245.
- Pyrocrystalline.**—See page 122.
- Pyroelectrolysis.**—See page 89.
- Pyrognomic.**—See page 204.
- Pyrolusite.**— MnO_2 ; an ore of manganese employed in the manufacture of ferro-manganese.
- Pyrolysis.**—See page 204.
- Pyrometallurgy.**—Where heat is applied to induce the desired reaction, usually by causing partial or complete fusion.
- Pyrometamorphism.**—See page 122.
- Pyrometer.**—See page 205.
- Pyrometer Effect.**—See page 203.
- Pyrometric Scale.**—See page 204.
- Pyrometry.**—See page 205.
- Pyrophoric.**—See page 204.
- Pyrophotometer.**—See page 208.
- Pyroscope.**—See page 208.
- Pyrrhotite.**—See page 245.

Q

- Quadratic System.**—Of crystallization: see page 120.
- Quadravalent.**—See page 86.
- Quadruple Puddling Furnace.**—See page 376.
- Qualitative Analysis.**—See page 82.
- Quality.**—(1) The suitability of a material for the purpose for which it is intended; (2) by common acceptation (a) the process by which steel is manufactured (*e.g.*, open hearth steel) and (b) the purpose for which it is intended (*e.g.*, boiler steel).
- Quality Figure; Formulæ.**—See page 340.
- Quality Steel.**—See page 443.
- Quantitative Analysis.**—See page 82.
- Quantitative Microscopy.**—See page 284.
- Quarternary Alloy.**—See Alloy.
- Quarternary Compound.**—See page 88.
- Quarternary Steels.**—See page 443.
- Quarternary System.**—Of crystallization: see page 120.
- Quasi Tempered.**—See page 231.
- Quench Bend Test.**—See page 476.
- Quenching.**—(1) Of coke: see page 96; (2) of steel: see page 227.
- Quenching Bath.**—See page 227.
- Quenching Charge.**—See page 233.
- Quenching Hardening.**—See page 227.
- Quenching Medium.**—See page 227.
- Quenching Temperature.**—See page 227.
- Quick Cement.**—See page 67.
- Quick Lime.**—See pages 175 and 396.
- Quick Speed Steel.**—See page 446.
- Quincke's Hypothesis.**—Of foam cells: see page 121.

R

- R.**—(1) Réaumur scale: see page 204; (2) to indicate a rising temperature: see page 205
- Ra.**—Chemical symbol for radium: see page 84.
- Rb.**—Chemical symbol for rubidium: see page 84.
- Rh.**—Chemical symbol for rhodium: see page 84.
- Ru.**—Chemical symbol for ruthenium: see page 84.
- Raapke Converter.**—See page 24.
- Rabble.**—An iron instrument resembling a hoe used to stir a metallic bath on the hearth of a furnace; sometimes called clot Eng.), rarely, **rake**.
- Rabble Plate.**—An iron plate welded to the end of a rod to form a rabble.
- Rabbling Hole.**—See page 375.
- Rack.**—A mechanical device for transmitting power, consisting of a long bar (generally of cast steel) on one surface of which are teeth which engage with those of a pinion which it rotates or by which it is moved. It is commonly employed for regulating the height of the top roll in a blooming mill, etc.
- Radial Crystals.**—Forming a radiating structure: see page 125.
- Radiant Energy; Heat.**—See page 200.
- Radiating Arc.**—See page 153.
- Radiating Structure.**—See page 125.
- Radiation.**—(1) General: see page 200; (2) law of: see page 200.
- Radiation Curve.**—See page 200.
- Radiation Furnace; Heating.**—(1) Electric furnace: see page 153; (2) heating furnace: see page 183.
- Radiation Pyrometer.**—See page 207.
- Radical.**—In chemistry: see page 87.
- Radio-Balance.**—See page 207.
- Radiograph.**—See page 285.
- Radiometer.**—See page 205.
- Radiomicrometer.**—See page 205.
- Ragging.**—See page 407.
- Rail Failures.**—"Because of the increased attention now being given to the rail question it is important that the distinction between **rail failures** and **broken rails** be clearly understood by the public as well as by railway men. **Failed rails** as reported by the railways, comprehend all rails removed from the track because of defects, including those broken; those having crushed or split heads, broken bases, etc. Many of these defects appear gradually, affording ample opportunity for removal of the rail before complete failure, and seldom causing serious accidents. It is only the rails actually broken, and but a small proportion of

these, which give rise to accidents. An analysis of the failures reported in a tonnage aggregating $1\frac{1}{2}$ million tons shows but 25% of the rail failures reported can be properly classed as rail breakers" (*Ry. Age Gaz.*, May 24, 1912, p. 1143).

Railer.—A kind of buggy or car, without sides, for carrying ingots, etc.

Raising Hammer.—See Hammer.

Rake.—(1) Of shears: see page 412; (2) a rabble (rare).

Ramage Process.—See page 166.

Ramdohr Process.—See page 145.

Ramming.—See page 296.

Ramming Block.—See page 300.

Ramsbottom Reversing Mill.—See page 408.

Ramshorn Test.—See page 476.

Rapid Cement.—See page 67.

Rapid Combustion.—See page 202.

Rapid Tool Steel.—See page 446.

Rapping; Rapping In.—Of patterns: see page 296.

Rare Metal Couple.—See page 209.

Rash.—On sheets: see page 430.

Rat Tail.—See page 17.

Ratch.—See page 508.

Rate of Combustion.—See page 203.

Rating of a Rolling Mill.—See page 410.

Ratiometer.—See page 208.

Rational Formula.—See page 86.

Rattle Barrel.—See page 58.

Raw.—(1) Material in its natural state, or as produced, without any subsequent treatment, *e.g.*, ores which are not roasted, or iron which has not been refined; (2) of cement bars: see page 71.

Raw Coal Iron (rare).—Pig iron smelted with coal.

Raw Gas.—See page 33.

Raw Limestone.—See Flux.

Raw Steel.—Natural steel: see page 304.

Raw Steel Processes.—See pages 76 and 78.

Rawson Process.—See page 371.

Razor Temper.—See Temper.

Reaction.—(1) In chemistry: see page 86; (2) in connection with stresses: see page 336.

Reaction Slag.—See Slag.

Reaction Velocity Theory.—Of passivity: see page 364.

Reactivity.—Ability to react.

Ready Iron.—In puddling: see page 376.

Reagent.—See page 86

Réaumine.—"Iron of Réaumur:" name suggested for malleable cast iron.

Réaumur Iron.—See page 257.

Réaumur Method.—Of quenching: see page 229.

Réaumur Process.—See page 258.

Réaumur Scale.—See page 204.

Recalesce; Recalescence.—See page 265.

Recalescence Curve.—See page 267.

Recalescent Point.—See page 265.

Recarbonization.—Recarburization, *q.v.*

Recarburization.—Sometimes called **recarbonization**; in its special sense, adding carbon in some form to metal (partially decarburized in some steel-making process to obtain the proper percentage of carbon in the finished steel; also used as a general term for the addition of all material used to give steel the desired composition and to effect its deoxidation. In the latter sense it is perhaps preferable to call this material **additions** (also called **recarburizing additions**, **final additions**, or **finishing metal**). To indicate some particular material its name is prefixed, *e.g.*, manganese addition. The additions are frequently made cold, generally in the ladle (**ladle additions**), but if they are in such large amounts that there is danger of chilling the metal they may be (*a*) preheated to a cherry red, (*b*) melted, or (*c*) added in the furnace (**furnace additions**), either wholly or in part. The practice of adding pig iron in the furnace to increase (**bring up** or **fetch up**) the percentage of carbon (called in England **pigging back** or **pigging up**), is usually restricted to the acid processes on account of the danger of rephosphorization. The **ladle additions** are made while the heat is being tapped, and an important point is to get them in before much of the slag has appeared. **Darby's process** of recarburizing consists in adding fine coal to the metal as it runs into the ladle; a hopper and funnel are generally employed to control the rate of flow of the coal. In the **Dudelingen process** (**Meyer process**) fine coal, with about 10% of milk of lime as a binder, is pressed into bricks and dried, these being thrown into the ladle; it was devised for use in the manufacture of basic Bessemer steel. **Robert Mushet's process** consisted in adding spiegel or some other form of manganese. Nickel, as nickel scrap or ingot nickel, is usually charged at the beginning of the heat. Other materials, as a rule, are added toward the end of the heat or in the ladle. Ferro-titanium and ferro-vanadium (claimed to have the property of combining with and removing nitrogen) are put into the ladle after the other additions.

Following is a general classification:

I. Carbon additions:

1. Pig iron:

(*a*) Solid: added in the furnace.

(*b*) Molten: added in the furnace or in the ladle.

2. Coal or coke (crushed):

(*a*) In paper bags.

(*b*) Fed from a hopper.

(*c*) In briquettes.

3. Contained in other additions (*e.g.*, ferro-manganese).

II. Manganese additions:

4. Ferromanganese.

5. Spiegel (usually molten).

6. Silico-spiegel.

7. Ordinary pig iron.

III. Silicon additions:

8. Ferro-silicon (10 to 16% silicon).
9. Ferro-silicon (50% silicon or over).
10. Carborundum.
11. Silico-spiegel.
12. Ordinary pig iron.

IV. Sulphur additions:

13. Roll sulphur.
14. High sulphur pig iron (rare).

V. Phosphorus additions:

15. Ferro-phosphorus (up to about 30% phosphorus).
16. Minerals containing phosphorus (as P_2O_5 , part of which is reduced).

VI. Special additions:

Chromium, tungsten, etc.; see page 351.

Recarburizing Additions.—See Recarburization.

Receiver.—See Mixer.

Reciprocal Proportions.—Law of: see page 85.

Reciprocating Mill, Brown's.—See page 417.

Recording Extensometer.—See page 471.

Recording Pyrometers.—See page 210.

Recover; Recovery.—See pages 96 and 333.

Recrystallization; Of Deformed Iron.—See pages 122 and 216.

Recuperation.—See page 204.

Recuperative Furnace.—See page 183.

Red Charcoal.—See Charcoal.

Red Fossil Ore.—See page 244.

Red Hard Sheet.—See page 430.

Red Hardness.—See page 446.

Red Heat.—Temperature color: see page 210.

Red Hematite; Iron Mine; Iron Ore; Red Mine Stone.—See page 243.

Red Ochre.—See page 244.

Red Short; Shortness.—See Brittleness.

Red Short Ore.—See page 243.

Red Slag Ironstone (Eng.).—See page 243.

Reduction.—(1) In chemistry: see page 88; (2) draft, in rolling: see page 407; (3) lowering the amount of a constituent, *e.g.*, the reduction of (the percentage of) carbon in a metallic bath.

Reduction of Area.—See pages 336 and 472.

Reduction Ring.—See Cold Working.

Reed Process.—(1) For electrolytic iron: see page 166; (2) for pickling, *q.v.*

Reediness (Eng.).—In piled iron, a tendency when rolled (into plates) to split sideways.

Reek (Eng.).—To smoke the inside of molds.

Reel.—A device for coiling up small sections, such as wire, hoop, etc. which may be operated by hand or by power.

Reeling Machine (Eng.).—Cross rolls for straightening: see page 490.

Reese Mill.—See page 419.

Reese Process.—(1) Direct process: see page 145; (2) galvanizing process: see page 370; (3) refining process: see page 387.

Refined Bar.—See page 378.

Refined Cast Iron.—See page 383.

Refined Grain.—See page 214.

Refined Iron.—See page 378.

Refined Metal.—See page 383.

Refined Structure.—See page 214.

Refiner.—See page 316.

Refinery (Refining); Refinery Hearth; Process.—See page 383.

Refining by Hardening.—See page 229.

Refining Heat.—See page 214.

Refining Point; Temperature.—Critical point: see page 214.

Refractory.—Capable of withstanding high temperatures without fusing or softening.

Refractories.—Refractory substances are those which possess, at least in some degree, the following qualities (Diehl):

1. Ability to prevent heat losses through radiation (and conduction).
2. Ability to withstand the degree of heat to which they are subjected without altering their chemical or physical relations.
3. Sufficient hardness to prevent abrasion and yet not spall.
4. Low coefficient of expansion and contraction.
5. Inertness to the chemical reactions taking place.

They are classified, according to their chemical properties, into acid, basic, and neutral refractories.

Acid refractories.—Sand: Consists essentially of silica, SiO_2 , and is usually obtained from natural deposits in fine grains, sometimes by crushing or grinding up silicious rocks. It should contain not over 10% of impurities as these tend to make it more fusible, iron oxide and the alkalis being the most undesirable. It is used loose for lining furnaces and in molding. Silicious rocks (firestone, ganister, and sandstone) are composed almost entirely of silica, and may be used, in their natural state, in large pieces or lumps (Eng.) for lining acid converters and cupolas. Their principal application, however, is in the manufacture of silica bricks or Dinas bricks, for which purpose they are crushed and mixed with about 1 to 2% of lime as a binding material, moistened with water, molded, dried, and then burned (*i.e.*, heated) at a very high temperature, during which they expand lineally about 3%. Bricks thus made are also designated as lime Dinas bricks or English bricks; where clay up to about 10 to 20% is used instead of lime, the bricks are not so good and are termed clay Dinas bricks or German Dinas bricks. Particularly with new or difficult sections, unequal ramming producing a variation in the density of the green brick (before burning), results in cracks (fire cracks) due to unequal expansion when the brick is burned. Fused silica, produced in an electric furnace, is too expensive to use except for certain chemical apparatus. The name ganister was first applied to a variety of sandstone found near

Sheffield, but is now used for any rock very high in silica. **Silicious clays** or **clays**, comprising **fireclay** and **loam** are hydrous silicates of alumina resulting from the decomposition of feldspar; pure clay or **kaolin** has the formula $\text{Al}_2\text{O}_3, 2\text{SiO}_2, 2\text{H}_2\text{O}$. If the proportion of silica is higher than this the clays are termed **acid** or **silicious**; if lower, **basic** or **aluminous**. **Fireclay** has low impurities (lime, magnesia, iron oxide, and alkaline oxides), and is not easily fusible. It is used in the manufacture of **fire-bricks** or **fire-clay bricks**, which are molded and then burned at a high temperature, during which they shrink lineally about 8%, the amount varying with the nature of the clay. Burnt fireclay is called **chamotte** (French), **schamotte** (German), and **grog** (English), and bricks made from it, mixed with a little unburnt clay as a binder, are similarly designated. A brick made with part silica and part chamotte is called **half-silica** or **half-chamotte brick**.

Ball stuff, for repairing acid linings, consists of fireclay mixed with sand or loam and a little water to make it plastic. **Loam** is a clay containing a higher percentage of silica than fireclay (say over 70%) which makes it somewhat more fusible. According to Mellor, clays and shales may be divided into **refractory clays** which soften above 1500°C . (2730°F .), and **non-refractory clays** which soften below this. He further classifies the refractory clays into (1) **low grade fireclay**, softening between 1500 and 1650°C . (2730 and 3000°F .); (2) **medium grade fireclay**, softening between 1650 and 1750°C . (3000 and 3180°F .); and **high grade fireclay**, softening only above 1750°C . (3180°F .). This **softening point** is to be determined under standard conditions. A natural substance known as **infusorial earth**, **diatomaceous earth**, or **kieselguhr**, contains a fairly high percentage of silica (see analysis below); being the skeleton of tiny organisms (diatoms) it is extremely porous, hence most excellent as a heat insulator, but it is not suitable to resist very high temperatures. A similar material found on the Pacific Coast is called **celite**; it is ground and made into bricks known under the trade name of **silocel bricks** and used for hot blast stoves, etc. J. W. Richards mentions a material of similar nature found in Jutland, called **moler**, used for refractory bricks.

Basic Refractories.—**Oxides of iron**, either natural as ore or artificial as scale or cinder, are rather easily reduced at a high temperature in the presence of carbon, etc., and are also fairly fusible, and hence are employed only when the temperature is comparatively low, *e.g.*, for the lining of puddling furnaces and the bottoms of some heating furnaces. **Lime** and **magnesia** are obtained almost entirely as the minerals limestone, magnesite, and dolomite. **Limestone**, CaCO_3 , when burned (calcined) yields lime, CaO , also called **quick-lime** or **burnt lime**, which tends to absorb moisture and carbonic acid (*i.e.*, to **slack** or **slake**) unless kept at a high temperature. Except for the bottoms of basic converters (mixed with tar) it is used principally as a flux. **Magnesite** MgCO_3 , when burned yields **magnesia**, MgO , which slacks very little

and, next to carbon, is probably the most refractory substance. Its principal use is for making bricks (**magnesia bricks** or **magnesite bricks**) for which purpose it is crushed, burnt at a very high temperature, then moistened with a little water, molded, and burnt again, a small amount of impurities which it contains acting as the binding material. It may be either **massive** or **crystalline**; the former occurs in serpentine and is widely distributed, the most important deposit being probably in Euboea Greece; the crystalline variety is found only in Austro-Hungary where it occurs in the dolomite to which it owes its origin in becoming metamorphosed (Morgenroth). **Dolomite**, $\text{CaMg}(\text{CO}_3)_2$, is widely distributed in this country and hence cheaper than magnesite, practically all of which must be imported. When low in magnesia it is sometimes called **magnesian limestone**. When burnt it does not slack nearly so readily as lime. It is used principally in this country as a lining for basic open hearth furnaces, after crushing, and either calcined or raw; abroad also for basic Bessemer converters, crushed, calcined, and mixed with tar.

Patented substitutes for regular dolomite or magnesite have recently been placed on the market under various trade names, some typical analyses being given in the table at the end of the article, and certain processes being described below. These substitutes usually consist of some form of magnesian limestone or dolomite rock, which is burned once or twice, and frequently with additions of some form of limestone, such as basic slag. The process for producing **magdolite** or J. E. Baker's **double-burned dolomite** is described in the patent papers as follows: Raw dolomite, in lumps 2 to 4" in diameter, is charged in a cupola furnace with alternate layers of coke and, after burning as in ordinary dolomite burning, is crushed and screened through about a $\frac{3}{4}$ " mesh. The product thus obtained has a considerable percentage of ash, coke, and fines mixed with the good material; it is preferably, without further treatment, subjected to a second burning in a rotary kiln. By subjecting to a temperature of about 2400°F . (1315°C .) the coke and cinder constituents of the mass are consumed, and the finer particles of dust either fused or carried away by the draft. The dolomite granules are subjected to sufficient heat to drive off any volatile matter which may have remained after the first burning, and are rendered much less pervious to moisture. The product is much heavier than dolomite obtained by ordinary burning and is more uniform in character. **Syndolag** is produced according to the patent papers as follows: Dolomitic limestone is crushed to about $\frac{5}{8}$ " size, put through a drier, the dust screened out, and the granular material fed through a rotary kiln, under conditions similar to those obtaining in the burning of Portland cement. In the kiln the material first passes under the direct influence of a hot flame, where it is raised to a temperature sufficiently high to cause incipient fusion or sintering. This temperature should be around 2800°F . (1535°C .) The sintered granules of dolomite are then cooled in a rotary cooler, and mixed with granulated basic open hearth

slag. With a dolomite running 40% magnesia (MgO), a mixture of 90 parts of dolomite and 10 parts of slag works well. **Bauxite** is a mineral consisting principally of alumina, Al_2O_3 (which should run over 85%), with small amounts of silica, iron oxide, etc., as impurities. It is usually crushed and washed before using but, owing to difficulties in preparation, and its excessive shrinking and cracking, it finds practically no employment in the iron industry. It is sometimes made into bricks (**bauxite bricks**).

Neutral Refractories.—**Chrome iron ore** or **chromite**, FeO , Cr_2O_3 , is highly refractory and is generally used in the form of bricks (**chrome bricks**), occasionally simply after crushing. It is employed to make a separation between acid and basic linings in the basic open hearth furnace. **Carbon** is the most refractory substance known. The form known as **graphite** is found natural or is manufactured in the electric furnace. Only the natural variety is used for making graphite crucibles (see page 111). Carbon, usually crushed coke, is also used in the manufacture of clay crucibles. It is sometimes made into bricks (**carbon bricks**), with pitch or tar as the binding material. A deposit of carbon is found in the bricks forming the lining of blast furnaces which serves to protect the walls from corrosion. **Carborundum** (**silicide of carbon**, **silicized carbon**, **silicon carbide**), SiC , is manufactured in an electric resistance furnace. Aside from its principal use as an abrasive, it finds some application as a refractory owing to its being almost unaffected by chemical reactions (except in special cases) even at high temperatures. Possessing similar properties is another form called **silundum** which may be of two varieties, of steel-gray appearance with the formula SiC , and slate-green with the formula $\text{Si}_4\text{C}_4\text{O}$. **Silfrax** a silicized carbon is also very similar to carborundum, being obtained by the action of vapors of silica or silicon on solid carbon. It is claimed to possess all the chemical and heat resisting properties of carborundum and, in addition, great density and toughness. **Silit** is the name given to material of practically the same nature, which may consist of a mixture of silicon carbide and free silicon, or silicon carbide only, prepared in an electric furnace. **Fibrox** is the name given to a fibrous material consisting of an oxycarbide of silicon without any definite chemical composition. It is soft and resilient, and has high insulating properties for heat. **Vitricarbo** is the trade name for a carbonaceous refractory material which contains a vitrifying ash as a binder. (See table of analyses on next page.)

Refractory Clays.—See page 396.

Refreshment.—See page 333.

Refrigerant; Refrigerating Agent.—See page 200.

Refroidissoir (French).—A cooling chamber, e.g., a chamber in which iron sponge, produced by some direct process, is protected from oxidation during cooling.

Regeneration.—(1) Of a cement: see page 67; (2) in heating: see page 203.

Regeneration Quenching.—See page 228.

Regenerative Chamber.—See pages 203 and 310.

Typical Analyses of Certain Refractories

Substance	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	Loss	Iron Oxides	Cr ₂ O ₃	TiO ₂
Sand.....	97.15	0.26	1.54	tr.	0.45	0.60			
Firestone.....	93.47	0.36	4.64	tr.	0.95	1.58			
Ganister.....	98.64	0.29	0.74			0.33			
Sandstone.....	97.82	0.26	0.92	tr.	0.30	0.70			
Silica brick.....	96.20	0.40	0.85	2.00	0.41	0.15			
Fireclay.....	48.52	3.08	45.70	tr.	1.36	10.34			
Firebrick.....	52.10	2.00	44.80	0.12	0.52				
Kieselguhr.....	87.86	0.73	0.13	0.42		10.71			
Limestone.....	0.92	0.60		53.68	1.43	43.50			
Magnosite.....	0.10	0.08	0.03	0.50	47.09	52.20			
Magnesite brick.....	4.00	0.40	0.30	5.00	90.01	0.20			
Dolomite.....	0.42	0.40		31.00	21.50	46.60			
Magdolite.....	6.90 to 8.90			48.33 to 50.80	32.70 to 35.20		2.00 to 4.71		
Syndolag.....	4.08 to 8.70			49.76 to 54.84	30.83 to 35.34		2.00 to 5.50		
Magnite.....	0.90 to 3.82			55.66 to 57.78	37.17 to 39.24		1.29 to 1.86		
Dolite.....	1.62 to 3.85			54.71 to 56.08	37.14 to 39.10		0.86 to 1.29		
Magnobrent.....	1.87 to 3.12			58.65	34.18		5.29		
Standard roasted dolomite.	5.46 to 6.30			51.00 to 53.26	33.70 to 37.30		0.86 to 2.57		
Double burned dolomite....	1.71 to 2.78			51.41 to 55.48	36.93 to 38.83		3.86 to 4.15		
Double burned dolomite....	3.08			56.83	36.50		1.29		
Bauxite.....	2.00	90.00		2.00		12.15	1.00		5.00
Chrome ore.....	1.87	3.17		5.10	3.79		36.63	51.23	

- Regenerative Crucible Furnace.**—See page 183.
- Regenerative Furnace.**—See page 183.
- Regenerative Stove.**—See page 203.
- Regenerator.**—See pages 183 and 203.
- Regnault Calorimetric Pyrometer.**—See page 207.
- Regular Cementite.**—See page 273.
- Regular Coil.**—See Coil.
- Regular System.**—Of crystallization: see page 120.
- Regulator Test Piece.**—See page 70.
- Reheated Carbon.**—See page 272.
- Reheating.**—Of steel: see page 232.
- Reheating Furnace.**—See pages 184 and 377.
- Reichinstein's Theory.**—Of passivity: see page 364.
- Rejection.**—Material thrown out on account of defects arising in the course of manufacture.
- Relative Deformation.**—See page 334.
- Relative Elastic Limit.**—See page 470.
- Relative Hardness.**—See page 478.
- Relief Polishing.**—See page 286.
- Remelting Process.**—Founding; sometimes a purification process.
- Removable Bottom, Holley's.**—See page 17.
- Removable Top Furnace.**—See page 313.
- Reniform Iron Ore.**—See page 244.
- Rennerfelt Furnace.**—See page 162.
- Reoxidation.**—Oxidation of metal which has once been reduced, more especially in connection with the reducing process employed, or immediately after the operation.
- Repeated Stresses.**—See page 333.
- Repeated Twinning.**—See page 124.
- Repeater; Repeating Mill.**—See page 416.
- Repetitive Stressing.**—See page 482.
- Rephosphorization.**—In any purification process where phosphorus is eliminated and taken up by the slag, and is then partially or wholly reduced again by a reaction, generally with some addition, and reenters the metal.
- Repouring Process.**—A process in which metal, partially refined in one furnace or vessel, is run into a ladle and then poured into another furnace or vessel to be finished: see page 21.
- Rerolling.**—See page 419.
- Reservoir.**—See Mixer.
- Reservoir Cupola.**—See page 182.
- Residual.**—Remaining; as the percentage of impurities which are not removed in a purifying process, etc.
- Residual Energy.**—See page 481.
- Residue Analysis.**—See page 82.
- Resilience.**—See page 331.
- Resistance.**—See page 330.
- Resistance-Arc Furnace.**—See page 153.
- Resistance Furnace; Heating.**—See page 153.
- Resistance Pyrometer.**—See page 208.
- Resistance Weld.**—See page 503.
- Resisting Moment; Shear.**—See page 337.

- Resistor.**—See page 154.
- Resolve.**—In microscopy: see page 285.
- Resonance Test.**—See page 483.
- Resquared Plate.**—See page 433.
- Rest.**—(1) To allow material to remain without applying any load to it or otherwise disturbing it; (2) in a rolling mill; see page 415.
- Restitution, Coefficient of.**—See page 478.
- Restored Steel.**—See page 226.
- Resulphurization.**—The reabsorption of sulphur by metal from which it has been removed, usually in the same process.
- Retained Carbon.**—In hardening: see page 279.
- Retardation.**—(1) In the cooling of alloys: see page 264; (2) of corrosion: see page 364.
- Retarded Coke.**—See page 97.
- Retarded Combustion.**—See page 202.
- Retention Theories.**—Of hardening: see page 279.
- Retentive.**—Able to hold, *i.e.*, prevent subsequent removal, as of slag with regard to phosphorus.
- Reticular Structure; Reticulated Structure.**—See page 126.
- Retort Coke.**—See page 95.
- Retort Furnace.**—See page 184.
- Retort Oven.**—See page 96.
- Returns (Eng.).**—Material rejected by customers.
- Reverberatory Furnace.**—See page 182.
- Reversed Mold.**—See page 300.
- Reversible Alloy; Process; Transformation.**—See pages 265 and 327.
- Reversing Class.**—In hardening: see page 279.
- Reversing Mill.**—See page 408.
- Reversing Overstrain.**—See page 282.
- Reviving (obs.).**—Producing (reducing) metal from its ores or from its oxidized condition.
- Revolving Screen.**—See Screen.
- Revolving Top.**—Of a blast furnace; see page 32.
- Rewelded Pipe.**—See page 490.
- Rhabdite.**—See page 292.
- Rhombic Sulphur.**—See Sulphur.
- Rhombic System.**—Of crystallization: see page 120.
- Rhombohedral Cleavage.**—See page 124.
- Rhombohedral (-ic) System.**—Of crystallization; see page 120.
- Riband (Eng.).**—Ribbon or band.
- Rich; Richness.**—Of pig iron; high in silicon.
- Rich Iron.**—See page 343.
- Riddle.**—In molding; see page 301.
- Rider.**—(1) In a rolling mill: see page 406; (2) of a testing machine: see page 469.
- Riemer Hot Top Process.**—See page 61.
- Riepe Process.**—See page 380.
- Rifled Pipe.**—See page 490.
- Rigidity.**—See page 330.
- Ring.**—(1) In blast furnace practice: see page 35; (2) in cold drawing; see page 101.
- Ringling Test.**—See page 483.

- Rinsing Bath.**—See page 507.
- Rinton Process.**—See page 145.
- Ripper; Ripping Block.**—In wire drawing: see page 508.
- Riser.**—Of castings: see pages 56 and 299.
- Rising Casting.**—See page 57.
- Rising Gate.**—See page 299.
- Rising Head.**—See page 56.
- Rising Steel.**—See page 55.
- Riveted Pipe.**—See page 489.
- Roach Belly Core.**—See page 299.
- Roak.**—See Seam.
- Roasted Red Mine (Eng.).**—Roasted hematite.
- Roasted Steel.**—See page 226.
- Roasting.**—(1) In briquetting; see page 44; (2) see Ore.
- Roasting Heap; Mound; Pile.**—See page 181.
- Robert Converter.**—See page 24.
- Roberts-Austen Equilibrium Diagram.**—See page 272.
- Roberts-Austen Recording Pyrometer.**—See page 210.
- Robertson Process.**—See page 492.
- Robin's Reagent.**—For etching; see page 287.
- Rochussen and Daelen Process.**—See page 22.
- Rock Sand (Eng.).**—The débris of abraded rock.
- Rock Wool.**—See Slag Wool.
- Rod.**—Generally understood to be a round bar. Standard wire rods are round bars having a section 0.2 to 0.3" diameter, which are coiled in bundles. U. S. Government limits size of wire rods to No. 6 B. W. G. or 0.203", and if smaller than this: wire.
- Rod Casting Process.**—See page 65.
- Rod Mill.**—See page 415.
- Rodney (Eng.).**—See page 377.
- Roebing Gage.**—See page 187.
- Roehling-Rodenhauser Furnace.**—See page 162.
- Roger Process.**—(1) Direct process: see page 145; (2) for sulphur prints: see page 288.
- Rohl's Reagent.**—For etching; see page 287.
- Rohnitz Process.**—See page 78.
- Roke (Eng.).**—See Seam.
- Rolls.**—See page 403.
- Roll-Knobbling.**—See page 369.
- Roll Mark.**—See page 405.
- Roll Scale.**—See Scale.
- Roll Table.**—See page 407.
- Roller.**—(1) The man in charge of a rolling mill: see page 430; (2) a metal cylinder mounted on a shaft which is driven (live roller) or is not driven (idle roller or idler), for transporting pieces of steel, etc. When a live roller is broken it is called a dead roller.
- Roller Pot.**—In coating sheets, a vessel filled with molten metal through which the sheets are drawn by means of several pairs of rolls.
- Roller's Side.**—See page 415.
- Rollet Process.**—See page 387.
- Rolling; Rolling Mills.**—Rolling is the operation of reducing

the section of pieces of metal by passing them between revolving cylinders termed rolls. A rolling mill consists essentially of the rolls set in a suitable framework to support them, called **housings, standards** (Eng.), or **holsters** (Eng.), and connected with the engine by pinions and spindles as will be described later.

Rolls.—These consist of (a) a middle portion called the **body or barrel** which comes in contact with the piece being rolled; (b) the ends which rest in the bearings, called **necks, journals,** or rarely **spindles,** which are always of smaller diameter than the middle portion to permit the rolls to come close together; and (c) the portion at the fillet connecting the body

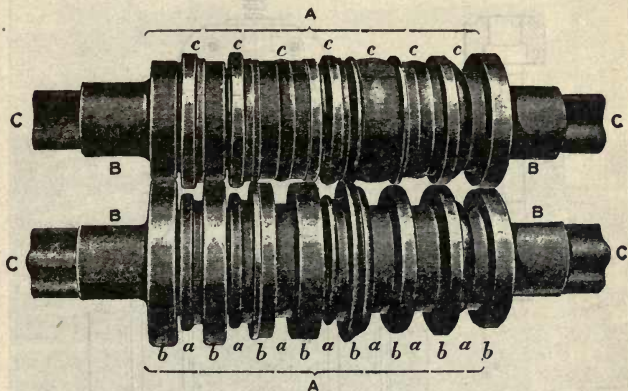


FIG. 54.—Pair of rollers by Messrs. Akrill & Co., Ltd., West Bromwich for rolling rails. AA, bodies of the rolls; B, B, B, B, necks which revolve in bearings in the chocks; C, C, C, C, wobblers, by means of which the rolls are driven. The openings between the bodies of the rolls from the passes, consisting of the grooves *a, a*, bounded on each side by a collar, *b, b*, and closed in at the top by the closers or formers, *c, c*.

and the necks, called the **shoulders.** Rolls are practically always cast, almost never forged (steel rolls), to rough shape and then turned down to the exact size. On account of the greater hardness, cast iron is generally employed for finishing a piece; if cast in a chill (iron) mold to make the surface portion as hard and smooth as possible it is called a **chill (chilled) roll;** if not chilled, a **grain roll;** if only part of the barrel is chilled, a **part chill roll.** Steel rolls are always cast in sand without any chilling effect and are subsequently annealed to break up the coarse crystallization produced by slow cooling. They are softer than cast iron, hence are sometimes termed **soft rolls,** and are used for the preliminary working or roughing,

or where a very smooth surface on the piece is not required. If the barrel is perfectly smooth, as for the production of plates, it is termed a **plain roll** or **flat roll**. Where material of uneven section is to be produced, such as beams or angles, the rolls are cast with depressions or **grooves** and raised portions or **collars** to correspond (**grooved rolls**). A **half roll** has only

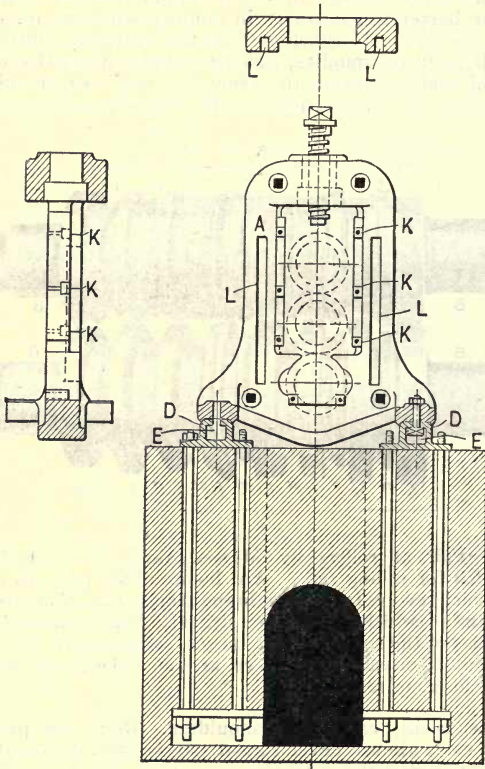


FIG. 55.—Typical American housing.—(Harbord and Hall, *Met. of Steel.*)

half of the barrel grooved; this is generally only in a three-high mill where the grooved halves of the top and the bottom roll are at opposite ends, the whole of the middle roll being grooved. **Hollow rolls** are those (a) which have a hole passing through them or (b) which are worn or turned slightly concave in the middle. The rolls while in use are usually sprayed with water

to prevent them from becoming overheated, which causes cracks on the surface, termed **water cracks**, **heat cracks**, or **fire cracks**, as these produce on the surface of the piece slight elevations or **roll marks** which, in the case of small sections, may become rolled over, giving a defect called a **lap**. Rolls which are cracked to any extent are turned smooth (**dressed**) in a lathe.

A **pass** is the opening between a pair of rolls formed by corresponding grooves or collars. A **closed pass**, **box pass**, or **box groove** is formed by a groove in one roll with a collar on each side, and fitting into this opening a raised portion on the other roll called a **former** or **closer**. An **open pass** consists of a groove or grooves without adjacent collars. A **blind**

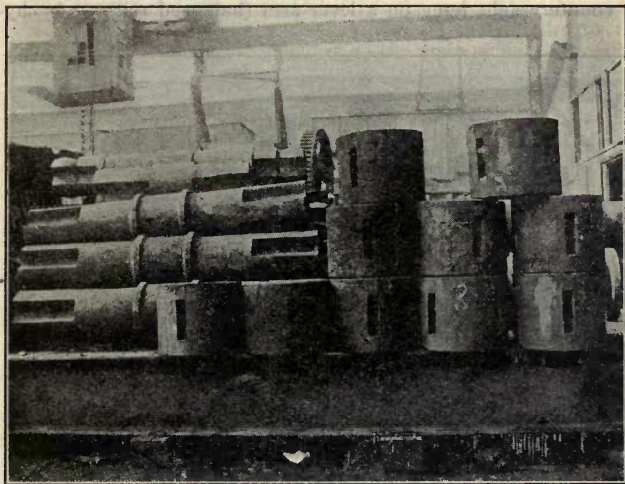


FIG. 56.—Pinions and coupling boxes.

pass or **false pass** occurs in a three-high mill where there is no pass in the top (or bottom) roll corresponding to the groove in the bottom (or top) roll complementary to that in the middle roll. Passes are named according to the section they produce: **gothic pass** (like a double gothic arch); **diamond pass**; **oval pass**; **convex pass**; **belly pass** or **bellied pass**. A **live pass** is one in which the piece is worked, and a **dead pass** is the reverse.

Pass is also the term used for the travel of the piece of metal being worked, once between the rolls. It is called a **lost pass** in the case of a two-high non-reversing mill when the piece is returned to the original side over the top roll, during which it receives no work.

The **housings** are cast of cast iron or, better, for heavy work,

of steel. They are secured to massive foundations so they will be perfectly rigid. They **kick in** when the tops incline toward each other. Each housing looks like an elongated letter "U" set upright, the open space being large enough for the necks of the rolls resting in suitable bearings or brasses, which in turn are held in place by **chucks** or **chocks**. The chuck on the top of a lower roll which supports the chuck or bearing of the roll above is sometimes termed a **carrier**. The chuck or cap over the top roll, against which the housing screw rests to keep the roll in the desired position when the piece is going through, is called the **rider**. In a two-high mill, when the top roll is adjusted for every pass, this is raised by rods resting against the bearing from below and forced up by a counterweight hung on a lever arm (**balanced roll**), or by hy-

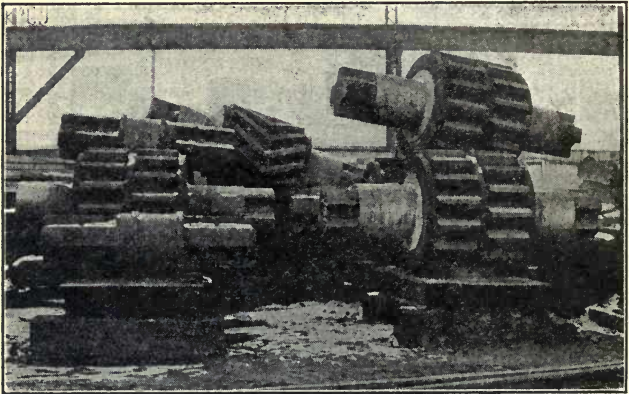


FIG. 57.—Pinions and spindles.

draulic means. Across the top of the housing is a cap (**housing cap**) through which passes the **housing screw** or **pin** (Eng.) to force the roll down and keep it in the proper position. This screw is operated by a hand lever (**spanner**) for three-high shape or bar mills, or mechanically for two-high mills when the top roll must be adjusted for each pass. In the latter case the distance between the rolls is indicated on some form of **gage**. Sometimes, with a three-high mill, to prevent the top roll from bending, a girder or bar may be fastened across the tops of the housings, giving the middle of the roll an additional bearing; this is called a **stiffener**. A set of rolls and the housings which hold them are called a **stand**, and two or more stands connected together constitute a **train**.

One end of each roll, or both if there is more than one stand in the mill, is given a cruciform or other section to fit a corre-

sponding opening in the **coupling box** by which it is connected with the spindle in a similar manner, and this again to the pinion and the engine. The end of a roll (or spindle or pinion) which has this section is called the **wobbler** (or **wabblers**). The **spindles** are like large pieces of shafting and connect the rolls with the pinions, or the rolls in one stand with those in another; they have wobblers on the ends similar to those on the rolls. In some cases a spindle is designed to break if the piece sticks in the rolls, to save the latter, and is then termed a **breaking spindle**. The **pinions** are gears which transmit the power to the rolls. They somewhat resemble short rolls with teeth cast on the barrel, and provided at the ends with wobblers. The pinions are also supported in housings (**pinion housings**). The **jack shaft** is the one which takes the power from the engine shaft and transmits it by the pinions and the spindles to the rolls. In some cases it is known as the **main spindle** or **leading spindle**. The manner in which the power is supplied by the engine varies according to the size and the type of mill. If the spindle or shaft is driven directly by the engine shaft, by means of a casting bolted on, known as a **crab**, the mill is **direct driven**, while if gears are interposed either to reduce or increase the speed (almost always the former), it is **gear driven**. With small mills the driving may be done by a belt or a rope, and these are **belt driven** and **rope driven** respectively. If a motor is employed the mill is **electrically driven**.

If small sections are being rolled the pieces may be handled by hand, but those which are too heavy are supported on a series of rollers on each side of the rolls, such a set being known as a **table** or **roll table**. If these are not driven they are termed **idle rollers** or **idlers**; if driven, **live rollers**; if one of the latter becomes broken, a **dead roller**. Underneath the rolls a pit is usually provided to catch the scale which comes from the piece, and called a **scale pit**.

The piece of metal being rolled is usually referred to as the **piece**. The amount by which it is reduced in section for a given pass is called the **reduction** or **draft** (**draught**). When the piece enters the rolls, the angle determined by the lines drawn from the center of one of the rolls (*a*) to the point on the circumference which the piece first touches, and (*b*) to the center of the other roll, is called the **entering angle** or **angle of contact**, and must in general be less than 30° or otherwise the rolls will not **bite**, *i.e.*, be able to seize the piece and draw it through. To assist in this, a little sand is occasionally put on the end of the piece, or where marks on the surface of the piece are not objectionable the rolls are chipped out, called **ragging**, **roughing**, or **cogging**, whereby a better grip is obtainable. From experiments it would appear that the rolls exert a squirting action on the piece, *i.e.*, the piece on leaving the rolls is traveling faster than the circumference of the rolls. The difference in rate will vary with the thickness of the piece, the diameter of the rolls, and the amount of draft. In practice, in arranging the successive speeds of the sets of rolls in a tandem

continuous mill all these factors must be taken into consideration. If there are four such stands of rolls, each effecting a 25% reduction, and the first rolls are driven at 64 revolutions per minute the others will have approximately the respective speeds of 80, 100, and 125. **Creeping** is the difference in rate between different parts of the piece passing through the rolls. If the sides of the piece are not supported by grooves, collars, or supplementary rolls set at right angles to the others, the width of the piece is slightly increased, and this is called the **spread**. The extension takes place in the direction in which the piece is traveling. If the rolls are horizontal the thickness of the piece will be reduced, while the width will be slightly increased; with vertical rolls, the width will be reduced and the thickness somewhat increased. Consequently, if both the thickness and the width are to be reduced, it will be necessary either to (a) turn the piece 90°, or (b) employ both horizontal and vertical rolls. In rolling flat material it is usually customary to give it one pass vertically, toward the end of the operation, to insure having the width right, called an **edging pass**. The operation of rolling a piece down to a smaller section is sometimes termed (Eng.) **rolling off** or **bolting**.

The earliest type of rolling mill consisted of two plain horizontal rolls superimposed, which were revolved continuously in one direction, hence, when the piece had been given one pass, and before it could be given another, it was necessary to bring it back to the side of the rolls on which it had started. To do this it was laid on top of the top roll, and so carried back, of course without receiving any work. This type is called a **pull over** or **pass over mill** and is still employed practically exclusively in the sheet and tin plate industry. George Fritz improved on this by placing a third roll on top and rotating it in the same direction as the bottom roll, so the piece would be worked between the top and the middle roll on the way back. This is called a **three-high mill** (rarely a **Fritz mill**) and the former type a **two-high mill**; German designations for them are respectively **trio mill** and **duo mill**. With the three-high mill, since the ingot or piece must be raised or lowered for each pass an amount equal to the diameter of the middle roll, the tables must provide for this by being raised or lowered by hydraulic means (**lifting table**), or else must be pivoted in the middle and arranged with gears so the end nearest the rolls can be sufficiently raised or lowered (**tilting table**). The former type is generally used for blooming mills, the latter for plate and shape mills. In the case of two-high mills the tables are **stationary**, *i.e.*, do not move up or down.

R. M. Daelen devised a mill with both vertical and horizontal rolls so that all four sides of a piece could be rolled in one operation without the necessity for turning it over, and this is termed a **universal mill** (**Daelen's universal mill**). Ramsbottom built a mill with two rolls which could be rotated in either direction, thereby avoiding the use of three rolls run continuously in one direction. This is called a **reversing mill** (**Ramsbottom's reversing mill**), the other a **non-reversing mill**.

The first grooved rolls were introduced by Henry Cort (Cort's mill), and were used for rolling plain rectangular pieces, but were easily modified to produce various irregular sections. When used for small pieces such a mill is called a **bar mill** or **merchant mill**, while for large sections, such as beams, it is known as a **shape mill** (in England, a **section mill**). In this country, bar and shape mills are nearly always three-high, or in stands of two-high, non-reversing, on the continuous or semi-continuous principle which will be considered later; abroad they are frequently two-high: for large sections reversing, and for small sections of either the reversing or the non-reversing type. The types just described are those at present in use, recent improvements consisting in the arrangement of the stands and the method of driving the rolls. Thus there may be a number of stands arranged end to end, called a **train**; the stands may be arranged one in front of the other called a **tandem continuous mill**; or there may be several combinations of the first two. There are also several patented mills which will be described farther on.

CLASSIFICATION OF ROLLING MILLS

I. Mills which depend upon the arrangement and the rotation of the rolls:

1. Two horizontal rolls: two-high:

(a) Reversing:

(i) Top roll adjustable:

Blooming, cogging, slabbing, plate, (foreign).

(ii) Both rolls fixed:

Shape.

(b) Non-reversing: pull over:

(i) Top roll adjustable:

Sheet and tin plate.

(ii) Both rolls fixed:

Merchant mills (foreign).

2. Three horizontal rolls: three-high; non-reversing:

(a) All three rolls fixed:

Shape, merchant, bar.

(b) Top roll adjustable, middle roll movable:

Plate (Lauth); blooming.

3. Universal mill:

(a) Reversing:

(i) Two horizontal and two vertical rolls:

Slabbing; plate; shape (Grey, Sack, etc.).

(ii) Two horizontal rolls and two sets of vertical rolls (two each), one at each side of the horizontal rolls:

Plate.

(b) Non-reversing:

Three horizontal rolls, and either one or two sets of vertical rolls as above:

Plate.

II. Mills which depend upon the arrangement of the stands.

1. Two or more stands end to end in one line: train:
 - (a) Reversing, two-high (foreign):
Plate; shape.
 - (b) Non-reversing:
 - (i) Two-high:
Sheet and tin plate.
 - (ii) Three-high:
Shape; bar or merchant.
2. Two or more stands one in front of the other:
Two-high, non-reversing:
Continuous; Morgan continuous; Bedson continuous.
3. Combinations of trains and continuous:
 - (a) Two or more trains usually staggered: there may be one stand alone, but all rolls are of the same size:
Shape; rail; merchant.
 - (b) One train of small rolls, with stand of larger rolls in front for roughing:
Tandem roughing or Belgian (for small sections).
 - (c) Two or more stands tandem, and one or more trains staggered:
Garrett semi-continuous; Morgan semi-continuous.

III. Mills for special products, or in which there is no reduction:

1. No reduction:
 - (a) Slitting mills.
 - (b) Tube mills (welded).
2. Reduction or change of form:
 - (a) Tire and wheel mills.
 - (b) Mills for seamless tubing:
 - (i) Piercing.
 - (ii) Rolling.

IV. Mills based upon the nature of their product:

1. Semi-finished: Roughing:
Blooming; billet; cogging; slabbing; muck bar.
2. Finished: Finishing:
Shape; plate; rail; bar or merchant; hoop; cotton tie; etc.

The size or rating of a rolling mill for everything but plates is based upon the pitch diameter of the rolls, which in case the rolls are of exact (nominal size) is the distance between their centers. The measurement, however, really is based on the distance between centers of the pinions, on account of the variations in the size of rolls due to turning or allowance for turning;

for example, a 30" blooming mill or a 16" bar mill. In the case of plate mills the size has to do with the width of plate which can be rolled, which in turn depends upon the type of mill. Thus a 48" universal mill (where the edges are rolled) can produce finished plates up to 48" wide; a 140" sheared mill indicates that the length of the barrel of the rolls is 140", but on account of the danger to the mill of having the plate project beyond this, the extreme width as rolled will be about three or four inches less than this; and in addition, a certain allowance (about four to eight inches), varying with the thickness and the length of the plate, must be made for side shearing.

Product.—In using large ingots, or where the product is very small in size, it is generally the practice to roll down partially on one mill, and finish on another. These two classes are termed respectively **semi-finished products (semi-products)** and **finished products**. Semi-finished products are divided into (1) **blooms and billets**, the names being more or less interchangeable, both being rectangular in cross-section, and square or nearly so; in general billets are considered as having a cross-section of from 4 up to 36 square inches, the width never being equal to twice the thickness; smaller sizes are usually classed as bars, but in certain cases are termed **small billets**; blooms is the name applied when the cross-section is greater than 36 square inches. (2) **Slabs** are rectangular pieces to be rolled down into plates (they may be considered as very heavy plates), where the width is at least equal to twice the thickness. (3) **Sheet bars or tin bars** are small slabs used for making sheets and tin plates; if made of charcoal wrought iron they are termed **charcoal bars**; ordinary sheet bars are called **coke bars**.

Mills for semi-finished products.—Billets, blooms, small slabs, and sheet bars are produced on a mill called a **billet mill, blooming mill, or cogging mill**. The first two names are used in this country, more particularly where the product is not used directly in some finishing mill, the last name being sometimes used to cover this case; in England cogging mill is used for all. The ordinary style of mill consists of one stand of rolls, either two-high or three-high, about 30" to 40" in diameter. The rolls are divided into passes of different widths by collars, and are usually ragged, at least for the first few passes; they are called **blooming rolls or billeting rolls**. The ingots used generally weigh from about 4000 up to 8000 lbs. or over, and, as it is necessary to turn them 90° after every few passes, a mechanical device must be employed which is called a **manipulator** (rarely a **tilter**). With a three-high mill it usually consists of a framework mounted on wheels so it can be moved backward and forward under the roll table. It has vertical projections called **fingers or tappets** which, by lowering the table, will pass up between the rollers and catch the ingot near the edge and thereby force it over. By lowering the table sufficiently the ingot will rest on the carriage, between the fingers, which can then be moved so as to bring the piece in front of the pass it is to enter. In the case of a two-high mill,

where the tables are stationary, the manipulator must be capable of movement in a vertical as well as a horizontal direction; by certain arrangements vertical movement may not be necessary. Turning a billet over 90° for the last pass to remove any fin is sometimes called **curing** (Eng.). A piece which twists on its axis when entering the rolls is sometimes said to **turn down**; as a result the piece is not a true rectangle in cross section and is said to be rolled **diamond**.

Another type of mill for small billets and sheet bars is the **continuous mill** with rolls about 12" to 16" in diameter. This consists of a number of stands of two-high, non-reversing rolls, one behind the other, which are driven at progressively increasing speeds. In some arrangements, the last or finishing stand, placed at a little distance from the others, is called the **bull**

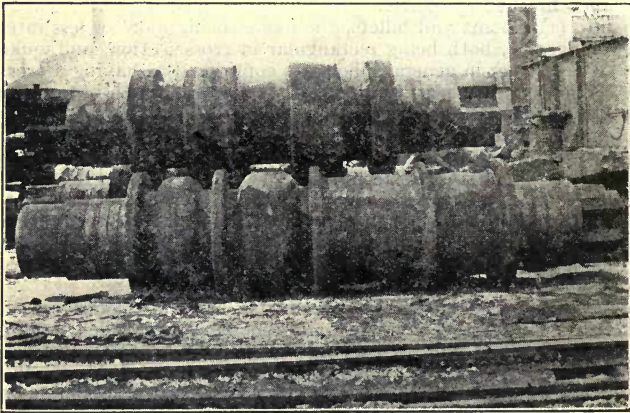


FIG. 58.—Shape roll (top) blooming roll (bottom).

head. To work all sides of the piece one of two arrangements is necessary: in the **Bedson continuous mill** the rolls in successive stands are alternately horizontal and vertical, or else set at an angle of 45° alternately to the right and the left. In the **Morgan continuous mill** all the rolls are horizontal, and the piece is turned or twisted by special guides (**twisted guides**) which look something like a bell open at both ends, and with a spiral or angular groove cut in them.

With the ordinary type of blooming mill first described the ingot is rolled out into one piece which is subsequently cut up by shears, consisting of two knife blades, one fixed and one movable, the latter actuated by gearing from a steam engine (**steam shears**) or motor (**electric shears**), or by a hydraulic cylinder (**hydraulic shears**); if the blades are set at a slight angle (**rake**) to each other it is termed a **guillotine shears**. In

the case of continuous billet mills the lengths obtained are so great that the length of the tables would be excessive if the shearing were not done until the entire piece had been rolled. Hence a special type of shears has been devised (**Edwards' flying shears**). This cuts the piece while it is issuing from the last stand, and is operated by two steam cylinders, one of which brings the knife down on the piece, while the other, immediately afterward, throws the knife outward so it will not interfere with the progress of the remainder. It is operated by a trigger which is set for the desired length, and is sprung by the piece itself striking it.

Slabbing mills may be considered as heavy plate mills, and are usually of the two-high, universal type, sometimes provided with a manipulator for turning the ingot. The rolls are about 30" in diameter and are smooth (without any ragging) as all precautions must be taken to prevent scale from being rolled into the surface of the piece, as this would cause a bad surface on the finished plate. **Muck mills** are the mills used in connection with puddling for rolling the puddle balls, after squeezing, into rough bars (**muck bars**). They are usually three-high (rarely two-high, pull over) with rolls from about 18" to 24" in diameter.

Mills for finished products.—These may be divided into **plate mills** and **shape mills**, for large sections, and **bar mills** or **merchant mills** for small sections. On them slabs, billets, or blooms are rolled down into finished material. The term **merchant mill** was first used in connection with the manufacture of wrought iron to distinguish the mill or train on which the material was finished ready for sale from the **muck train** or **forge train** (**forge rolls** or **puddle train**) which rolled the puddle balls after squeezing or shingling into muck-bar: the term has been retained to designate a mill on which small sections are rolled.

Plate mills are divided into **sheared plate mills** where the edges are not rolled and must be sheared off (**side shears**); and **universal mills** where the edges are rolled and hence only the ends need be cut (**end shears**). The size of sheared mills is about 60" to 200", and of universal mills, about 18" to 48". The universal mills are nearly all two-high, reversing, with two sets of vertical rolls, one on each side of the horizontal rolls. They may roll slabs or slab ingots (wide flat ingots). In this country and on the Continent, nearly all the sheared mills are three-high, non-reversing, but in England the preference is for two stands of two-high, reversing rolls, one stand for roughing and the other for finishing; slabs are generally rolled. The barrels of the rolls are smooth, and as soon as they become rough must be dressed (turned down). In Germany there is a modification where the rolls have collars for producing plates of narrow width, very similar to the bar mills used elsewhere for the purpose. With universal mills the slab or ingot is rolled back and forth until the desired **gage** (thickness and width) is obtained. With sheared mills this practice may be fol-

lowed or else, with narrow slabs, the rolling may proceed until the length of the slab has been increased sufficiently for the width of the plate, when it is swung around 90° by hooks suspended from overhead beams. In the first case the plate is said to be rolled **longitudinally**, in the second case, **transversely** (in England called **spreading and turning**). Rolling transversely, particularly semi-finished material, is also called **cross rolling**. It is claimed to effect almost complete elimination of seams and surface defects in the case of billets or slabs. The type of three-high mill used in this country is called the **Lauth mill**, the special feature being the middle roll which is about two-thirds the diameter of the other rolls. This smaller roll gives greater kneading action to the piece. The bottom roll is fixed in its bearings, but the height of the top roll is adjustable by means of the housing screws which are regulated by a man called the **screw down**. The middle roll rests against either the top or the bottom roll to stiffen it, depending upon the direction in which the piece is traveling. There is bound to be a certain amount of spring in the rolls, even when supported, particularly when rolling wide plates and this together with the greater wear or channeling of this portion of the rolls causes the plates to be thicker in the middle than at the edges; the amount above the theoretical or normal thickness is known as the **crown** of the plate. After rolling, the plates are made flat by passing through **straightening rolls** which consist of a series of upper and lower rolls staggered. The tables on which the plates are taken to the shears and allowed to cool are called **cooling tables**, **cooling beds**, or **hot beds**.

Shape mills.—In this country they are usually composed of several stands of three-high rolls in one or more trains. The first stand is called the **roughing stand** or **roughing rolls** (rarely **roughing rollers**, **rough rollers**, **breaking down rolls**, **bolting down rolls**), the last, the **finishing stand** or **finishing rolls**, and those between, **strand rolls**. The problem of designing the successive passes in the rolls to produce the desired section is one requiring great experience and skill. In rolling sections, such as beams and channels, on an ordinary three-high mill, since different parts of the rolls have different diameters corresponding to the section, there is always a certain amount of tearing action going on which appears to effect horizontal as well as vertical reduction, but is not true rolling. The smaller parts of the section which have to be as long as the larger ones are said to be **drawn**. To reduce this tearing action as far as possible, and more particularly to provide clearance for the rolls, the flanges of a channel, beam, etc., must be tapered. With ordinary methods the flanges cannot be very high as the deep grooves required would make the rolls too weak, and also the metal would become too cold to penetrate to the bottom or, as it is commonly expressed, the section would not be **filled out**. Adjusting the rolls to produce a section of the proper gage and weight is called **lining** the rolls; when a heavier section is required the rolls must be separated slightly (**lining up**), and thin metal strips (**liners**) are inserted between the bearing blocks; for lighter

sections the rolls are lined down by removing one or more of these strips.

Guides and guards.—To avoid delays in inserting the piece in the right pass, two pieces of metal, called guides, are fastened, one on each side of the pass on the entering side of the rolls, to rods extending across the rolls. These pieces diverge at their outer ends so it will be easy to introduce the piece, the inner ends which nearly touch the rolls converging so the distance between them is the same as the width of the pass. Particularly in rolling shapes, the piece, instead of coming out flat, may stick to one of the rolls and become wrapped around it, an action known as **collaring**. Any piece which does this, or has become so bent or twisted it cannot be finished, is termed a **cobble**. To prevent this as far as possible **guards** or **stripping plates** are placed at the top and the bottom of a pass on the issuing side; the inner side is tapered and rests on the rolls. The bottom guard is usually bolted to a rod running across the rolls while the top one is hung on a similar rod and held in place by a counterweight, and is called a **hanging guard** (rarely a **yielding guard** or **clearer**). In connection with the roughing rolls for muck bar, pieces called **scrapers** are sometimes employed, which are similar to guards, but placed slightly above, to scrape off any pieces of iron which fall from the bloom or which stick to the roll.

Bar mills, also called **merchant mills** or, on account of the special product which they make (but to which they are not necessarily restricted), **rod mill**, **hoop mill** or **strip mill**, **cotton tie mill**. As a rule they are of the three-high, non-reversing, or of the two-high, continuous type, and the sections rolled rarely exceed 3" square. The simplest type is where there are a number of stands in train, all the rolls being of the same size. With six such stands they are designated as follows:

1st stand (three-high)	roughing stand (roughing rolls).
2d " "	pony roughing stand.
3d " "	first strand.
4th " "	second strand.
5th " (two- or three-high)	planishing rolls.
6th " " "	finishing stand or chilled rolls.

The side of the mill on which the piece first enters is sometimes called the **roller's side**, and the opposite, the **catcher's side**; these terms are generally restricted to pull over mills, such as those described under Sheets and Tin Plate. **Fore plate** is the name sometimes applied to a plate at the bottom of and connecting the two housings; it is supported by **cramp bars** to which the guides and guards are fastened. **Rests** are pieces placed before the rolls and just below the top of the lower roll upon which the bloom or bar may be rested while being pushed into the rolls. A **feed roll** is a small driven roll sometimes placed immediately in front of a stand of rolls to facilitate the introduction of the piece. **Pinch rolls** are for the same purpose as the preceding, and consist of two small driven

rolls which grip the piece just tightly enough to carry it into the rolls.

To increase the speed of rolling and so permit greater lengths to be rolled, instead of simply passing the piece backward and forward through the rolls (*i.e.*, the end which is the first to enter the rolls on one pass is the last to enter on the next), when the piece is sufficiently reduced in section the end issuing from the rolls may be bent around and inserted immediately in the next pass (**looping**), and in this way a piece may be in two or three passes at the same time; where this is done the mill is called a **looping mill**. With the smaller pieces it is necessary to enter them by hand, but with those of intermediate or larger size labor-saving devices known as **repeaters** or **turn-overs** are frequently employed. With the intermediate sections these consist of a vertical curved guide with a driven roller at some distance from the rolls which serves to bring the end around and return it to the rolls for the next pass; in the **Morgan semi-continuous mill** (also called a **repeating mill**) this is effected by curved grooves cast in the heavy iron plates forming the floor or bed of the mill.

Hand mill and guide mill.—These are the two forms of an ordinary bar mill. In both the piece is handled by men with tongs. In the case of the hand mill for the last pass the piece must be entered in the right position and, if necessary, held with the tongs to prevent it from turning, and, when rolling rounds, the piece must be put through the last pass about three times, being turned each time 90° to insure a true section. In a guide mill, which is generally of small size, at least the last pass is provided with a **closed guide**. This is a bell-shaped tube, the outward end, into which the end of the piece is thrust, having a pronounced flare, and the other end, which is as close to the rolls as possible, having a hole just the shape of the piece in order to hold it in the right position and prevent it from turning or twisting when gripped by the rolls. This second type of mill requires only one pass through the finishing pass, and is very generally used for rolling small sections such as hoop, etc., where the speed of the rolls is great. In certain districts a mill operated by hand without closed guides is called a **hand guide mill**. A **guide roll** (Eng.) is the smallest size used in an iron works, and is employed in the production of the smallest sections which are only one size thicker than wire rods (Turner).

To enable the finishing rolls to be driven at a higher speed than the roughing, and also to be able to handle a larger billet, one stand of roughing rolls of larger diameter, driven independently, is sometimes placed in front of and a short distance away from the first stand of the regular train. This arrangement is termed a **Belgian mill** or a **tandem roughing mill**.

The **Allis-Andrew process** for rolling very thin sheets or strips consists in coating a number of strips with a composition to prevent them from sticking, and riveting them together at one end. They are then heated and rolled down on the principle of a pack of tin plates.

G. Balthasar's universal mill for rolling bars consists of a pair of horizontal and a pair of vertical rolls so arranged that any groove of the horizontal rolls may be brought into position with a similar groove in the vertical rolls.

The **Belgian wire rod mill** is one in which the stands of rolls are placed in train, *i.e.*, end to end; the modification where the piece was first subjected to a preliminary rolling in an independent stand constitutes the **German mill**, although this is now generally called a Belgian mill.

The **Bickley mill** for hoop and cotton ties consist of three-high rolls through which the piece is passed by repeaters, and provided with devices for taking care of the slack, followed by a number of two-high finishing stands.

J. J. Bleckley's four-high mill for wire rods consists of two sets of rolls one above the other in the same housing with a repeater for bending down the piece from the upper to the lower set; a number of such stands could be provided, driven at progressively increasing speeds.

The **Boecker mill** is somewhat similar to the Belgian mill, having two lines of stands two-high, one on each side of a driving shaft.

Brown's reciprocating mill has two pairs of rolls in one set of housings on the same level, the two pairs being run in opposite directions. Alternately in each pair the passes are considerably larger than in the other, the piece being rolled in the small passes and passing through the large passes without touching them. The object is to run the rolls without reversing and to avoid the necessity for a lifting table.

Brownhill and Smith's mill is three-high with the middle roll slightly larger than the bottom, and the top roll slightly larger than this.

In **Bunsen's mill** for rolling hoop there are three pairs of rolls arranged one behind the other, the first and the third set having grooves cut in the bottom roll, and the middle set a groove cut in the top roll.

The **Dowlais mill** consists of two pairs of rolls in one set of housings, the bottom roll of one set being on a level with the top roll of the other set, the two pairs being run in opposite directions. The advantage claimed is that there are no dead passes as with an ordinary three-high mill.

In the **Garrett semi-continuous mill**, used principally for rolling wire rods, there are a number of stands placed one behind the other, following which are a number of trains of two or three stands each, and driven at successively increasing speeds, the piece being louped around by trough guides in the floor, and arranged so that from two to four pieces can be finished at the same time.

Gillon and Dujardin's mill is about the same as Lauth's three-high mill.

The **Grey universal mill** is designed principally for rolling beams with deeper and thinner flanges than are possible on an ordinary shape mill. The ingots are first rolled into shaped

blooms (the section roughly started) on an ordinary cogging or blooming mill, which are then taken to the Grey mill. This consists of two stands, the first of which contains one pair of horizontal rolls only. In these only the edges of the flanges are rolled, *i.e.*, the bloom is rolled down to a thickness corresponding to the depth (width) of the flanges required. The second stand has one pair of horizontal rolls and one pair of vertical rolls arranged so they both act on the piece simultaneously, the horizontal rolls being power driven, while the vertical rolls are **friction driven** (*i.e.*, from the pressure of the piece against them). The section is guided through the rolls by laterally adjustable guide-bars, and is supported underneath by guide-rollers. It is never lifted or turned, but passes backward and forward until finished. The horizontal rolls must be changed to conform to the depth of the section, but the vertical rolls which work the outer surfaces of the flanges are wide enough for all sections and therefore need not be changed except when they become badly worn.

The **Josserand and Jacquet process** is for rolling bright steel bars. The bars are turned and then rolled to within between 0.01" and 0.05" of the finished size. Special finishing machines consist of six stands tandem, on a common bed plate but driven independently: (1) straightening, (2) pulling through, (3) roughing cut, (4) pulling through, (5) finishing cut, and (6) planishing (*J. I. & S.*, 1915, 1, 591).

The **Kirkstall process** for producing rods which are very straight and accurate as to gage consists in taking bars rolled in the ordinary manner to a diameter slightly larger than desired, and then finishing them at a dull red heat between two disks which are parallel to each other and revolve in the same direction, but with their horizontal axes not in the same plane.

The **Kloman process** for making eye bars consisted in rolling the billets between reversible and adjustable rolls in such a manner as to leave the ends of the bar thicker than the body. The ends were then spread and forged,* and the eye punched out under a steam hammer.

F. Kogel's universal mill is designed to produce a variety of sections difficult to roll on an ordinary mill by a combination of various processes in some of which the piece is acted upon by rolls without getting any forward movement; it was apparently intended principally for wrought iron.

The **Lackawanna or Mathias deseaming process** was devised principally for the purpose of removing the seamy portion of billets entering into the manufacture of rails. "The machine by which the metal is removed subjects the hot rail bar on the top and bottom surfaces to the cutting action from the teeth on two opposed rotating saw disks, just after the hot bar comes down the mill table from the last roughing pass. During this stage of travel a collar turns the rail bar so that its head is down and the base up. The bar then enters a tunnel about 20 feet long and lined with fire-brick to check heat radiation. It is then forced between the saw disks by a pair of driven pinch rolls, adjustable

to bars of various sizes and having guides for the top, bottom and sides of the bar. Adjustment of the saws is made for a cut $\frac{1}{8}$ " or at the extreme $\frac{3}{16}$ " deep. A second set of driven pinch rolls, on the delivery side, helps to force the bar against the cut of the saw teeth and similarly a second set of guides here helps to hold the bars rigidly and firmly during the passage through the saw. From the delivery set of pinch rolls the bar travels through about 40 feet more of tunnel similar to that on the entering side and then to the finishing stand. The hot bar enters the saw at a speed of about 350 feet per minute, is slowed down by the cutting operation to about 79 feet per minute, and on leaving the saw rapidly picks up speed and enters the finishing stand at about 500 feet per minute. The upper saw disk (operating on the base) has an 8" and the lower a 6" face. Both are driven from belted motors, are 5 feet in diameter, and run at a peripheral speed of 25,000 feet per minute or both disks together make 800,000 tooth contacts with the bar per minute. The rail bars after passing through the machine are further reduced in the rolling operation in 5, more or less, passes to the finished section, so the rail has a rolled surface after the defective material has been removed "(pamphlet, Lackawanna Steel Co., 1914)."

In **S. McCloud's process** for rolling old steel rails into flat plates, heavy steel rails are cut into short lengths, heated in the ordinary manner, and then passed endwise through a set of specially prepared rolls which gradually flatten both the head and the flange of the rail without permitting any folding, as the steel would not weld.

E. W. McKenna's process for rerolling old rails into lighter sections (of rails) is to take the worn rails, heat them in long furnaces, and give them, while at a comparatively low temperature, two passes in a tandem mill. The reduction varies with the condition of the worn section, but as a rule gives a rail of about from 10 to 12% lighter weight than the original section (R. W. Hunt).

The **Morgan semi-continuous mill** for bars is somewhat similar to the Garrett mill, having a number of stands of rolls one behind the other, and then one train of rolls through which the piece is louped by trough guides in the floor.

A. Reese's universal mill for beams and channels consists of two sets of rolls; in the first or roughing set the web is rolled by horizontal rolls, and at the same time the width of the flanges is regulated by collars on a pair of vertical rolls; the finishing is done in the second set where the outer sides of the flanges are rolled and the shape finished. It may also be used for plates.

Rerolling is the term applied to the operation of rolling worn out material into something else; it is used principally for old rails. Rails which are to be rerolled into bars and angles are usually first split longitudinally by putting them through a pass (slitting pass) with collars which slightly overlap and act as a shear, whereby they are divided into three pieces: the head, the web, and the flange. The first is used for rolling

into bars, and the two last for angles and flats. A mill for cutting up nail plate in this manner is called a **slitting mill**, and no reduction is effected.

The **Sack universal mill**, designed principally for rolling cruciform sections, has horizontal and vertical rolls which act upon the piece simultaneously, the general arrangement being much like that of the Wenstrom mill.

Slick's angular method of rolling (patented by E. E. Slick), which allows shapes with wide flanges to be rolled on ordinary mills other than universal mills having horizontal and vertical rolls, consists in so designing the passes that one flange in the case of a channel, or alternate (diagonally opposite) flanges in the case of a beam, are rolled at an angle considerably greater than 90° to the web, the other flange or flanges going through a **dead pass** (*i.e.*, not worked), the action being reversed on the subsequent pass. In this way the sides of the flanges receive a considerable amount of work, which is not the case with the ordinary method of rolling. After the various parts of the section have been reduced to the desired thickness the flanges are bent into their final position in a series of passes. In all the reducing passes the web is at an angle to the axis of the rolls, this angle being reversed in successive passes. The web is also supported during the passes in which the flanges are bent into their final position. The bending of the flanged shape in passes which support the web is also of importance, as this prevents distortion of the web and insures a good product. In all passes there is no turning of the blank to a position at right angles to that in the previous pass.

D. Turk's system of rolling wire rods consists of special means of automatically bringing oval or square rods from one pass to another.

E. D. Wassell's process consists in rerolling old steel rails by the use of rolls of a special form into flat bars about $7\frac{1}{2}$ " wide which are cut, piled, and reheated in a bath of slag, by which means their percentage of carbon can be reduced as desired; the piles are then rolled into the desired shape.

The **Wenstrom mill** is a modification of a universal plate mill, designed principally for rolling flats. Instead of acting upon the top and bottom and the two sides at different times, it does this simultaneously. The top roll can be adjusted vertically, and the bottom roll transversely, whereby pieces of different thickness and width can be produced with the same set of rolls.

Williams' mill consists of two trains of different size rolls designed for producing small bars.

Certain modifications in details of wire rod mills have been introduced by **Martin and Beavis**, and **F. H. Daniels**.

Rolling Crack.—See Crack.

Rolling Furnace.—See page 312.

Rolling Hardness.—See Hardness.

Rolling Mill.—See page 403.

Rolling Mills, Classification of.—See page 409.

- Rolling Off.**—(1) In rolling: see page 408; (2) of tubes: see page 490.
- Rolling On.**—Of tubes: see page 490.
- Rolling Open Hearth Furnace.**—See page 312.
- Ronay Process.**—See page 44.
- Röntgen Ray Spectrometer.**—In the study of crystals: see page 120.
- Roofing Tin.**—See page 433.
- Roozeboom's Equilibrium Diagram.**—See page 272.
- Rope Driven.**—See page 407.
- Ropiness (Eng.).**—A term applied to steel when side ruptures occur in ingots which are being rolled down.
- Rose; Rose Steel.**—See page 135.
- Rosenhain's Amorphous Cement Theory.**—See page 282.
- Rosenhain's Equilibrium Diagram.**—See page 272.
- Rosenhain and Haughton's Reagent.**—For etching: see page 288.
- Rosetti Radiation Pyrometer.**—See page 207.
- Rossi's Process.**—This is somewhat similar to Goldschmidt's, employing aluminum for the reduction of metals from their ores or oxides. A bath of molten aluminum is used and on this the ore is thrown. This bath is usually maintained in an electric or other type of furnace so any additional heat required may easily be supplied.
- Rotary Kiln Process.**—See page 45.
- Rotary Movement.**—See page 281.
- Rotary (Rotating) Puddling Furnace; Machine.**—See page 379.
- Rotary Shears.**—See Shears.
- Rotary Squeezer.**—See page 377.
- Rotation Effect.**—Of oblique light: see page 127.
- Rotator.**—See page 379.
- Rotten; Rottenness.**—A piece of metal is said to be rotten when, on account of burning, high sulphur, or imperfect deoxidation in manufacture, it crumbles or falls to pieces, or cracks when rolled or forged; a term rarely applied to brittleness.
- Rough Fracture.**—See page 178.
- Rough Roller.**—See page 414.
- Roughened Tin Plate.**—See page 433.
- Roughing.**—(1) In general, preliminary, as roughing rolls, roughing passes (of ingots, etc.), roughing out (machining), etc.; (2) ragging (Eng.): see page 407.
- Roughing Block.**—In wire drawing: see page 508.
- Roughing Cinder.**—See Slag.
- Roughing Hole (South Staffordshire).**—In old blast furnaces provided with a tymp, etc., a hole in the runner at the bottom of the cinder fall, where the cinder was collected around an iron rod and so removed.
- Roughing Loam.**—See page 301.
- Roughing Roll; Roller; Stand.**—See page 403.
- Roughing Cinder; Slag.**—See Slag.
- Round.**—In charging a blast furnace: see page 33.
- Round Top Furnace.**—See page 313.
- Rowling (obs.).**—Rolling.
- Rub Up (Eng.).**—To stir up or rabble a metallic bath.

- Rubble.**—(1) Rabble; (2) a mixture of gravel and cement.
- Rubble Ironstone.**—See page 244.
- Rudolphs-Landin Process.**—See page 145.
- Ruelle Test.**—See page 482.
- Ruff's Equilibrium Diagram.**—See page 272.
- Rumble; Rumbling Mill.**—See page 58.
- Run (verb).**—(1) Of a crucible: see page 113; (2) of a cupola: see page 182.
- Run Down; Running Down.**—Of a cupola: see page 182.
- Run a Melt.**—Melting iron in a cupola for foundry work.
- Run-of-Mine Coal.**—See Coal.
- Run-out Fire.**—See page 383.
- Run Steel.**—See page 257.
- Runner.**—(1) Of a blast furnace: see page 36; (2) of a casting: see pages 57 and 299.
- Runner Head.**—See page 57.
- Running Mold.**—See page 57.
- Running-out Fire.**—See page 383.
- Running Stopper.**—See Ladle.
- Runnings (obs.).**—Molten metal from a blast furnace.
- Rupture.**—See pages 177 and 330.
- Rupture by Bursting.**—See page 179.
- Russell Test.**—See page 482.
- Russia Iron; Russian Sheet Iron.**—See page 431.
- Rust.**—See pages 106 and 367.
- Rust Coating.**—For wire: see page 507.
- Rust Proof Coating.**—See page 367.
- Rust Proof Processes.**—See page 367.
- Ruthenburg Process.**—See page 163.

S

- S.—Chemical symbol for sulphur, *q.v.*
- Sa.—Chemical symbol for samarium: see page 84.
- Sb.—Chemical symbol for antimony (Latin, *stibium*), *q.v.*
- Sc.—Chemical symbol for scandium: see page 84.
- Se.—Chemical symbol for selenium: see page 84.
- Si.—Chemical symbol for silicon, *q.v.*
- Sn.—Chemical symbol for tin (Latin, *stannum*), *q.v.*
- Sr.—Chemical symbol for strontium: see page 84.
- S.A.E.—Society of Automotive (formerly Automobile) Engineers.
- S.C.I.—Swedish charcoal (wrought) iron.
- S.W.G.—(1) Steel wire gage; (2) British standard or imperial wire gage; (3) Stubs' wire gage.
- Sack Mill.—See page 420.
- Sackur's Theory.—Of passivity: see page 364.
- Sadden or Saddening Heat.—See page 116.
- Safe Load; Range of Stress.—See page 468.
- Safety, Factor of.—See page 468.
- Sag; Sagg.—To (cause to) sink down or become compacted.
- Saggar; Sagger.—(1) In making crucibles: see page 112; (2) for malleable castings: see page 258; (3) in molding: see page 300.
- St. Chamond Armor Plate.—See page 9.
- St. Etienne Process.—See page 64.
- Sainte-Claire-Deville Gas Pyrometer.—See page 207.
- Saklatwalla's Iron-Phosphorus Diagram.—See page 272.
- Sal ammoniac.—Commercial ammonium chloride.
- Salamander.—(1) The old name for the bloom from a direct furnace (see page 135); (2) the iron forming the scaffold in a cupola (rare); (3) a stove, usually cylindrical in shape, made of plates and filled with coke or coal, for warming portions of a mill building, particularly to prevent the freezing up of valves and pipes; (4) the infusible mass found in the hearth of a blast furnace when it is torn out for relining; also called **bear**, **sow**, or **horse**. This may consist of (a) iron containing considerably lower carbon than the regular pig iron, and (b) a copper-colored substance composed principally of cyano-nitride (nitro-cyanide) of titanium, to which the formula $(Ti_5CN)_4$ has been given. Contained in, or associated with, this bear or salamander is what has been erroneously termed **amianthus** (the name of a variety of asbestos), or **furnace amianthus**: "It is white, and of a finely fibrous structure (**fibrous silica**), and here and there it is distinctly seen to consist of more or less globular aggregations of radiating fibers. It is associated with minute brilliant crystals of cyano-nitride of titanium, and, freed from these it was found by analysis to contain 97.5% SiO_2 with traces of lime and manganese" (Percy).

- Salamander Furnace.**—See page 147.
- Salom's Formula.**—For tensile strength: see page 339.
- Salt.**—(1) Ordinary salt, sodium chloride, NaCl; (2) the combination of an acid with a base: see page 88.
- Salzburg Process.**—See page 78.
- Sample Spoon.**—See Spoon.
- Sampling Pig Iron.**—See page 349.
- Sand.**—(1) Of ingots: see page 56; (2) as a flux: see page 176; (3) as a refractory: see page 395.
- Sand Blower.**—See page 492.
- Sand Boil.**—See page 314.
- Sand Bottom.**—See Lining.
- Sand Cast Pig.**—See page 342.
- Sand Core Process.**—See page 65.
- Sand Mold.**—See page 296.
- Sandberg Process.**—See page 233.
- Sandstone.**—See page 395.
- Saniter Desulphurizing Process.**—See page 387.
- Saniter's Reagent.**—For hot etching: see page 287.
- Saniter Steel.**—Steel made by the Saniter desulphurizing process: see page 387.
- Saniter Wear Test.**—See page 480.
- Sankey Test.**—See page 482.
- Sap.**—In cementation: see page 71.
- Sappy Fracture.**—See page 178.
- Särnström Process.**—See page 145.
- Satisfied.**—Combined, so that the substance has no further chemical affinity under the existing conditions, as lime combined with the requisite amount of silica; this term must be distinguished from saturated.
- Sattman and Hornatsch Process.**—See page 145.
- Saturated Austenoid.**—See page 275.
- Saturated Compound.**—See page 85.
- Saturated Martensite.**—See page 276.
- Saturated Solution.**—See Solution.
- Saturated Steel.**—See page 273.
- Saturated Vapor.**—See page 202.
- Saturator.**—Of by-product gas: see page 96.
- Saucer Bosh.**—See page 27.
- Saunderson Process.**—See page 64.
- Sauveur's Critical Strain.**—See page 216.
- Sauveur's Equilibrium Diagram.**—See page 272.
- Sauveur's Formulæ.**—For tensile strength and elongation: see page 339.
- Sauveur's Hypothesis.**—On the allotropic transformation of iron: see page 278.
- Sauveur Process.**—(1) For sound ingots: see page 60; (2) of coarsening ferrite: see page 216.
- Sauveur's Reagent.**—For etching: see page 287.
- Sauveur and Whiting's Thermomagnetic Selector.**—See page 210.
- Saw File Temper.**—See Temper.

- Scab, Scabby.**—(1) On castings: see page 58; (2) a defect in plates, etc.: see page 357.
- Scaffold.**—See page 35.
- Scaffolding Down.**—Of a blast furnace: see page 37.
- Scale.**—(1) The coating of oxide which forms on the surface of metal which is heated. This scale is cracked and broken off during working, and according to the method is termed **roll scale** (**mill scale**) or **hammer scale**; (2) usually **scales**: an instrument for weighing, usually heavy bodies.
- Scale Pit.**—See page 407.
- Scaled Casting.**—See page 258.
- Scaling.**—(1) Of drawings or blue prints, measuring dimensions with a scale instead of depending on dimensions as marked: an inaccurate method; (2) a defect: see Pit.
- Scalping.**—Of crucibles: see page 112.
- Scar.**—In a blast furnace: see page 38.
- Scarf.**—(1) To bevel (also the bevel) the edges of skelp in the process of making lap-welded pipe: see page 489; (2) to hollow the side of a shaft, etc., in forging.
- Scarf Weld; Joint.**—See page 502.
- Scarfing Test.**—See page 476.
- Scattering.**—Of liquid steel in a mold, etc., spitting.
- Scelp (Eng.).**—Skelp.
- Schaffer and Budenberg's Thalpotassimeter.**—See page 21c.
- Schamotte.**—See page 396.
- Schiebler Process.**—See page 22.
- Schillerization.**—See page 127.
- Schiseophone.**—See page 483.
- Schmidhammer Process.**—See page 145.
- Schneider et Compagnie Process.**—See page 230.
- Schneider-Creusot Furnace.**—See page 163.
- Schneider Furnace.**—See page 161.
- Schönawa-Rodenhauser Furnace.**—See page 162.
- Schoop Process.**—See page 373.
- Schreibersite.**—See page 292.
- Schulte-Hemmis Process.**—For producing hollow bodies or shells from malleable metals, chiefly by pressure.
- Schumacher Process.**—See page 44.
- Schungite.**—See Carbon.
- Schwartz Process.**—See page 319.
- Sclerometer.**—See page 480.
- Scleroscope.**—See page 478.
- Scobel-Johnson Apparent Elastic Limit.**—See page 470.
- Scobel's Yield Point.**—See page 470.
- Scone (Scotch).**—A fireclay disk or biscuit used in patching the lining of furnaces, etc.
- Scorched Fracture.**—See page 178.
- Scorched Ingot (Eng.).**—See page 57.
- Scoria; Scoriæ (plur.).**—See Slag.
- Scoria Block; Plate.**—See page 32.
- Scoria Process.**—See page 44.

- Scoriaceous.**—Like or resembling cinder. A term applied to a structure presenting the appearance of slag. A term which has been used when the exact nature of the substance is not known when detected as inclusions in metals and alloys (I.A.T.M.).
- Scoride (rare).**—Cinder.
- Scorodite.**—See page 244.
- Scotch Iron.**—See page 350.
- Scotch Tuyere.**—See page 31.
- Scott Process.**—See page 61.
- Scouring; Scouring Barrel.**—See page 507.
- Scouring Cinder.**—See Slag.
- Scrag (Eng.).**—To straighten a spring, etc., which has been cambered (bent), by pushing in the bulge and releasing.
- Scrap; Scrapping.**—(1) In the Bessemer process, throwing steel scrap into the vessel when the metal is blowing too hot; (2) of molds, removing the steel which has run over the top and down the sides during pouring; (3) in general parlance, discarding anything, such as machinery, which is out of date or wornout; also the material which is discarded. See Discard.
- Scrap Ball; Bar; Furnace; Iron.**—See page 379.
- Scrap and Pig Process; Scrap Process.**—Usually called pig and scrap process: see page 310.
- Scraper.**—See page 415.
- Scratch Hardness.**—See page 331.
- Screen.**—A large sieve used for separating fine from coarse material. It consists of woven wire, or of a steel plate, having holes whose size depends upon the fineness of the product required. A revolving screen is a revolving cylinder made of steel plates, generally inclined slightly downward so that material will move forward by gravity, and usually having holes of a different size in different parts, the smaller being at the upper end.
- Screw Down.**—See page 414.
- Scribe Method; Scriber Method (Eng.).**—For yield point: see page 470.
- Scroll Bundle.**—See Coil.
- Scrubber.**—For gas: see page 33.
- Scruff; Scruffy.**—The dirt or impurities on the surface of an object causing roughness; also the condition.
- Scull.**—See Skull.
- Scum.**—See page 115.
- Scurf.**—To flake off, or the material which flakes off; dross.
- Sea Coal.**—See Coal.
- Seam.**—(1) In tubes: see page 489; (2) in welding: see page 502.
- Seam.**—Also called **roak** or **roke** (Eng.); a crack on the surface of a piece of metal which has been closed together but not welded up, usually produced by cutaneous or subcutaneous blowholes which have become oxidized. If very fine it may be called a **hair crack** or **hair seam**. A **lap seam**, **lap**, **cold lap**, or **cold shut** is produced when a fin or ridge is formed and doubled over in forging or rolling. A **snake** or **streak** is a long wavy seam. **Longitudinal** and **transverse seams** are those extending lengthwise or crosswise respectively of the piece as produced. A

spiral seam occurs in the manufacture of seamless tubing when a surface defect is extended spirally in the process of piercing.

- Seamless Tube.**—See page 490.
- Season.**—Of crucibles: see page 112.
- Season Crack.**—See Cold Working.
- Seaton and Jude Test.**—See page 482.
- Seaton Test.**—See page 482.
- Sebenius Process.**—See page 62.
- Seconds.**—Of sheets: see page 433.
- Second Annealing.**—Of sheets: see page 431.
- Second Class Foam Cells.**—See page 121.
- Second Order Cells.**—See page 121.
- Second Pickling.**—Of sheets: see page 431.
- Second Strand.**—See page 415.
- Secondary Crystals.**—See page 121.
- Secondary Crystallization.**—See page 121.
- Secondary Furnace.**—See page 316.
- Secondary Gas.**—See page 33.
- Secondary Hardening.**—See page 447.
- Secondary Metals.**—The term **secondary** is applied to metals recovered from scrap metal, sweepings, skimmings, drosses, etc., as distinguished from **primary metals** which are obtained direct from ore. The term "secondary" carries no implication of inferiority in quality (terms as used by the U. S. Geol. Survey).
- Secondary Slip.**—See page 283.
- Secondary Stress.**—See page 332.
- Secondary Twinning.**—See page 123.
- Sectile.**—See page 124.
- Section; Section Area.**—See page 468.
- Section of Failure.**—See page 337.
- Section Mill.**—See page 409.
- Seger Cones.**—See page 209.
- Seggar.**—See pages 112 and 300.
- Segregans.**—Mother metal: see page 56.
- Segregate.**—See page 56.
- Segregated Cementite.**—See page 273.
- Segregated Spot.**—See Hard Spot.
- Segregation.**—See pages 55 and 442.
- Segregation Deficit; Excess.**—See page 56.
- Seguin Process.**—See page 229.
- Selective Corrosion.**—See page 106.
- Selective Effect.**—Of oblique light: see page 127.
- Selective Freezing.**—See page 266.
- Selective Transformation.**—See pages 271 and 275.
- Selenium, Action of Light on.**—See page 208.
- Self-corrosion.**—See page 108.
- Self-fluxing Ore.**—See page 243.
- Self-hardening Steels.**—See pages 446 and 451.
- Self-roasting Ore.**—See page 243.
- Self-strained; Self-stressed.**—See page 332.
- Semicombined.**—See page 83.
- Semi-continuous Mill.**—See page 416.

- Semi-crystalline Structure.**—See page 125.
- Semi-direct Process; Recovery Process.**—In by-product coke ovens: see page 96.
- Semi-finished.**—See Finished.
- Semi-finished Products; Mills for.**—See page 411.
- Semimetal (obs.).**—Metalloid; possessed of some but not all the (physical) properties of a metal.
- Semi-products.**—See page 411.
- Semi-steel.**—Also called **toughened cast iron** or **Sterling's toughened cast iron**; it is produced by melting about one-third to one-fifth by weight of wrought iron or soft steel scrap with cast iron, usually in a cupola, and is employed in the manufacture of castings, known as **semi-steel castings**.
- Semi-steel Casting.**—See Semi-steel.
- Semi-water Gas.**—See Producer.
- Semi-wild.**—Same as lively, *q.v.*
- Sensible Heat.**—See page 199.
- Sentinel; Sentinel Pyrometer.**—See page 209.
- Set.**—(1) Of steel ingots, etc., after pouring, when a skin or crust of sufficient thickness has formed, so that when the molds are removed the metal will not run out; (2) distortion: see page 334. (3) in coating sheets: see page 432.
- Set Temper.**—See Temper.
- Setter In.**—In the crucible process: see page 114.
- Setting Down.**—In forging: see page 177.
- Settling Head.**—See page 56.
- Settling Tank.**—In the purification of water, a tank in which muddy water or water which has been chemically treated, is allowed to stand until the impurities have collected on the bottom.
- Seventy-two Hour Coke.**—See page 95.
- Shackles.**—Of a testing machine: see page 469.
- Shadow Line.**—See page 289.
- Shaft.**—(1) The interior of a shaft furnace above the boshes; (2) a circular bar or rod of steel used for conveying power by rotation.
- Shaft Furnace.**—See pages 114 and 181.
- Shaft Washer.**—See Ore.
- Shake Down.**—See page 314.
- Shaking Barrel.**—See page 58.
- Shank; Shank Ladle.**—See Ladle.
- Shape Mill.**—See page 409.
- Shape Work.**—See Hammer.
- Shaped Bloom.**—See page 417.
- Shaping Process (Howe).**—For giving to material a desired form or shape as by rolling or forging (working) or by melting and casting in molds.
- Sharp.**—(1) Of a casting: see page 58; (2) of a flame; oxidizing.
- Sharps.**—See page 432.
- Shaw Process.**—(1) For casting: see page 65; (2) for purifying: see page 387.
- Shears.**—A machine for cutting up or dividing pieces of metal consisting of two knife blades, one of which is fixed and the other movable and operated up and down (rarely sideways) by steam

or electrically driven gears or by hydraulic power. The usual gear-driven shears has the upper movable knife set at a slight angle (*rake*) to the lower and is termed a *guillotine shears*; its advantage is that only a small part of the edge is cutting at one time and hence less power is required than if the edges are parallel. A *rotary shears*, for producing round plates, has a horizontal revolving table to which the plate is fastened, and set at the proper distance are two vertical disks, one above the other and arranged so their edges slightly overlap; they revolve in opposite directions and cut off the edge of the plate between them. A type frequently used for cutting up scrap, muck bar, etc., called *alligator shears*, *crocodile shears*, *lever shears*, or *cropping shears*, has two jaws, one of which is fixed while the other is pivoted and actuated by a cam arrangement.

Shear Blade Temper.—See *Temper*.

Shear Steel.—Also called *sheared steel* or *German steel* (obs.).

It is the product obtained by welding and forging plated bars (see page 71), and is made principally in England. These bars are broken into suitable lengths, six piled together, constituting a *fagot*, covered with fireclay and borax to prevent excessive oxidation, and drawn out under a hammer into a bar (*single shear steel*). If this bar is doubled and rehammered it is known as *double shear steel*. The product is used for articles of cutlery, etc.

Sheared Plate Mill.—See page 413.

Shearing.—In general, cutting: see also page 101.

Sheared Steel.—See *Shear Steel*.

Shearing Modulus of Elasticity.—See page 335.

Shearing Resilience.—See page 331.

Shearing Strength.—See page 330.

Shearing Stress.—See page 332.

Shearing Test.—See page 477.

Sheathing.—A protective outside coating or jacket of metal or wood.

Sheet.—See below.

Sheet Bar.—See page 411.

Sheet Furnace.—See page 430.

Sheet Gage.—See page 188.

Sheets, Manufacture of.—See page 430.

Sheet Metal Gage.—See page 188.

Sheet Mill.—See page 430.

Sheets and Tin Plate.—The dividing line between sheets and plates is not sharply drawn, but depends principally upon the type of mill on which they are rolled; it may roughly be taken that plates are $\frac{1}{8}$ " thick and over, and sheets thinner than this.

U. S. Government has set the limit for sheets at No. 10 U. S. Standard Gage. **Tin plates** (*tinned plates*) are sheets (usually of light gage) coated with tin to protect them from corrosion; if of heavy gage, they are sometimes called *tinned sheets*. The material used in the manufacture comes in the form called generically *sheet bars*; those for tin plates are also called specifically *tin bars* or *tin plate bars*. The mills on which these bars are

rolled into sheets are of the two-high, non-reversing type known as pull over (see page 408), and are classed as **sheet mills** and **tin mills**. As a rule sheet mills do not roll much below No. 28 gage, although they can go down to about No. 30; tin mills commonly do not go above No. 20 although they can go up to No. 16. In this country sheets are started in one stand of rolls and finished in another (**double mill**); tin plates are rolled in one stand (**single mill**).

Manufacture of Sheets.—With extra heavy sheets only one is rolled at a time, and is called a **single** (**single steel**). Ordinarily two bars are rolled simultaneously and are called a **pair** (the sheets are then **doubles** or **double steel**), and the small reverberatory furnace in which they are heated, a **pair furnace**. In rolling pairs the bars are put successively through the rolls by the **roller** and are seized on the other side by another man (the **catcher**) who places each on top of the top roll, to be taken off by the roller as the other is going between the rolls. After receiving a certain amount of reduction they are taken to the finishing stand where they are rolled separately still further, and then one is laid on top of the other and rolling is continued until they are too cold. The rolls become heated, particularly in the middle, which causes a certain amount of expansion; this is partially offset by turning them slightly concave in a lathe; if the expansion is extreme, the rolls are said to be **puffed**. After the last rolling the two sheets are separated and a number, depending upon the desired gage, piled together in a **pack**, the longer ones on the bottom, this operation being known as **matching**, and the man who attends to it the **matcher**. They are now bent double transversely and the bend stamped flat by a machine called a **doubler**, a form of hammer having a long flat face. If the doubler forms part of a shear (in the case of light sheets) of the crocodile type, it is termed a **doubling shear**. The packs are reheated in the **sheet furnace** (a **rash** is occasioned when the outside is heated much hotter than the interior) and rolled down to the desired gage, after which the packs are sheared and opened, *i.e.*, the sheets are pulled apart. Sheets difficult to separate are called **stickers**. The operation is usually performed by pulling the sheets off by hand, or, in the case of stickers, with a pair of tongs, the rest of the pack being held down with the foot. In some cases the strip sheared from the edge of a pack, held in one hand like a sword, is brought down between two stickers, which is called **swording stickers**. To prevent sheets from sticking during hot rolling, it was at one time the practice, in certain localities, to sift coal slack, sawdust, etc., between them, called **dusting**; this practice has been almost entirely abandoned. **Horns** are projections at the end of a sheet caused by the sides rolling out longer than the middle. **Jumping** is where a sheet slips when the pack is rolled, causing buckling or lapping by the rolls. Such a sheet bent or doubled over is called a **lapper**, **pinched sheet**, or simply a **pincher**. Almost no sheets are sold as they come from from the hot rolls; in this condition they are known as **red hard sheets**. Practically all the product is an-

nealed to be sold as **black plate** (**finished black plate**) or is coated with zinc for galvanized sheets. For **annealing** they are piled on a bottom, and covered with a steel or iron box (**annealing box**, **annealing pot**) to exclude the air, the operation being known as **close annealing** or **box annealing**. They are then heated in a furnace to about 760° to 870° C. (1400° to 1600° F.), which requires, altogether, about 16 to 20 hours. The top sheets from various piles are known as **outsides**, and are oxidized more than the others. By another method, known as **blue annealing**, the sheets, if fairly heavy, are allowed to cool slowly after the hot rolling, or if of lighter gage, as is usually the case, they are passed singly through an open furnace where they are reheated to the proper temperature for the annealing or softening operation. As the name indicates, they have a bluish-black appearance. Aside from the color of the sheets, the properties resulting from the two methods are practically the same. This method is also known as **open annealing**, the sheets being exposed directly to the air. For **galvanizing** they are now pickled for 5 to 10 minutes in dilute sulphuric acid to remove the scale, being held loosely in racks or **cradles** so the acid may penetrate between. They are next washed with water (**swilled**) in tanks to remove the acid, and are kept submerged in water until just before they are galvanized, when they are put for a few minutes in a very weak solution of acid. Galvanizing is effected by passing the sheets through the **galvanizing pot** or **kettle**, a deep iron vessel filled with molten spelter (commercial zinc), this method, which is always used for sheets, being termed **pot galvanizing**. The markings or **spangles** on the surface of galvanized sheets is due to the crystallization of the zinc, the size depending upon the rate of cooling. **Russian sheet iron** or **Russia iron** is a special grade of sheet with a glossy black, slightly mottled appearance due to oxide adhering to the surface so tenaciously that it cannot be cracked off by repeated bendings. It is produced by hammering a pile of heated sheets having very slight projections or indentations on the surface, with or without charcoal powder sifted between before heating. Sheets hammered in this way to get a polished surface are said to be **planished** (rarely called **glanced sheets**).

Manufacture of Tin Plates.—The process up to the annealing operation is practically the same as that for the manufacture of sheets. Here, however, there is a slight change. The plates are first pickled (**black pickling** or **first pickling**) as already described. After swilling they are annealed in boxes (**black annealing** or **first annealing**), and are then cold rolled, *i.e.*, given a number of passes (usually three) cold through rolls (**cold rolls**) to make the surface perfectly smooth so the finished tin plate will have a high polish. As this renders them somewhat stiff they are reannealed (**white annealing** or **second annealing**) at a slightly lower temperature than before. Plates may be sold simply cold rolled or cold rolled and annealed. If to be tinned they are again pickled (**white pickling** or **second pickling**) and swilled. They are then passed through a pot filled with molten tin (**white pot**, **tin pot**, **tinning pot**). According to modern

methods the coating of sheets is performed in one operation by passing them through the pot of molten metal between driven rollers arranged in pairs, the last pair squeezing off the surplus metal. In England these **mechanical tinning pots** are sometimes called **patents**. The necessary equipment for coating tin or terne plates is called a **set**: For terne and coke plates it consists of a pot containing tin or the terne mixture covered with palm oil, and rolls; for charcoal plates there are a palm oil tin pot, a wash pot, and a roll pot (each separate). A **combination pot** means a white pot with rolls and then a tin pot with rolls. The early method of tinning, called **dipping**, was done by hand and was more complicated. The cleaned sheets were first put in a pot of grease (**tinman's pot**) the temperature of which was very low. A number of plates were next plunged into the **tin pot** containing molten tin covered with grease. From this they were passed to the larger of two compartments in the **wash pot** filled with molten tin of better quality than in the tin pot, in which they could remain some time without becoming **dry** (*i.e.*, becoming so hot very little tin would adhere); they were then taken out singly and rubbed on each side with a hemp brush, after which they were redipped in the smaller compartment of the wash pot, containing the best quality of tin, to obliterate marks made by the brush. They were next transferred to the **grease pot** (**grease pan**) filled with palm oil, or palm oil and tallow, at a fairly high temperature, where the surplus tin drained off, amounting sometimes to two or three times what remained on the plate. They next went to the **cold pot**, where they were allowed to cool exposed to the air. The excess of tin draining off the plate left an accumulation (**wire** or **list**) at the bottom edge which was removed by dipping in the **list pot**, a pot containing a layer of molten tin about $\frac{1}{4}$ " deep, and considerably above its melting-point. When the wire was perfectly fused it was removed by lifting the plate and giving it a quick blow with a stick. The plates were then worked in troughs with bran, and polished.

The surface of the molten tin in the tin pot is covered with a layer of palm oil to prevent oxidation and, as some of this adheres to the plates, it is necessary to clean them. This was formerly done by hand but now usually by a machine (**branning machine**) through which the plates are passed, a series of revolving brushes applying bran or a mixture of sawdust and lime to the surface. **Sharps** (the hard part of wheat) or **middlings** and **shudes** (the hulls of grain) are sometimes used for this purpose.

A **patch**, or **black patch**, on tin plates is a stain caused by scale which has not been properly cleaned off. **Black edged** or **smoky edged** plates are of infrequent occurrence and are due to too low a temperature in annealing; they coat with tin but show a dark stain along the edge. **White edged plates**, which also are of infrequent occurrence, are those which have been overheated in the white annealing; they do not coat well either with tin or lead.

Terne plates are made in the same way as tin plates, except

that the coating consists of a mixture of tin and lead, running from about 50 to 75% tin, ordinarily about 70%. The surface has a dull appearance and is covered with markings (**mottles**) caused by crystallization of the mixture, the size depending principally on the rate of cooling. According to whether the plates are passed through dry bran or bran moistened with oil, they have a **dry finish** or an **oil finish** respectively.

Tin and terne plates, after being finished, receive a final inspection in the **assorting room**, all first quality sheets being known as **primes**, if of inferior quality as **seconds**, while all badly defective material (**wasters**) is thrown out. They are then packed in boxes. The unit of measure, irrespective of the gage (which is always shown), is known as the **base box**. This is figured as the number of square inches on one side of each plate, and amounts to 31,360 square inches; in England it corresponds to 112 plates, 14" X 20", No. 30 gage, weighing 112 pounds. Ordinary plates are sheared to size immediately after the hot rolling, but those of small size may be cut up from a large plate after finishing. When required to be very accurate as to size, they may be trimmed after finishing, when they are known as **re-squared plates**.

Sheets (usually galvanized for roofing) are **corrugated** by passing between a pair of rolls in the surface of which corrugations (grooves) have been cut longitudinally. In England sheets or plates of 20 gage or thicker are called **singles**; 21 to 24 gage, **doubles**; 25 to 27 gage, **trebles** or **lattens**; and those down to 29 gage, **extra lattens**; **taggers** are very thin plates largely used for metal tags. **Coke plates** or **sheets** (**coke tins** or **cokes**) were formerly those made from iron puddled from coke pig, and **charcoal plates** or **sheets** were those made from charcoal hearth wrought iron or from iron puddled from charcoal pig; at present this significance has been lost as both are practically always made from soft steel (either Bessemer or open hearth), the charcoal plates carrying a heavier coating of tin, and therefore of higher quality (and price). The amount of coating is usually shown by letters, the numbers increasing with the thickness of coating, as **A**, and **AAAAA**. For tobacco cans and similar purposes the sheets are sometimes not cold rolled as the rougher surface takes more tin for coating and has a dull silvery finish; these are called **roughened tin plates**. All terne plates are commonly called **roofing tin**. Tinned or galvanized sheets were at one time called **white iron** and an artificer in them a **whitesmith**.

The **Bray continuous sheet mill** consists of six sets of two-high rolls tandem, the bars being fed separately, and two arms engaging the rear of each bar and moving it forward squarely into each set of rolls. After passing through these rolls a sufficient number of sheets are collected in a matcher, and the resultant pack is passed by feed rollers into the first of three sets of two-high rolls, also set tandem, between which it is carried forward by chain tables. After leaving the last set the pack is passed through a water bosh and thence through an opening machine in which the plates are loosened. The

pack is then doubled in a roller doubler, reheated, and finished as usual.

The **Donner continuous sheet mill** consists of four sets of two-high rolls set tandem, with feed tables or conveyors between each set. At a sufficient distance from the last of these to allow matching of the sheets which individually had received the four customary passes, two additional sets of two-high rolls are placed tandem, and after passing through these the pack is doubled, reheated, and finished much as usual.

Howell's mill, designed for rolling sheets, consists of a blooming train followed by a number (usually four) of stands of rolls on the continuous principle.

The **Wittgenstein mill**, for thin plates or sheets, consists of a Lauth three-high mill for roughing, followed by five stands of two-high rolls, one behind the other, and so close together that the plate may be in all five stands simultaneously.

Sheldon Process.—See page 384.

Shell.—(1) A defect: see Pit; (2) a casing; (3) in cold rolling or drawing: see page 101; in crystallography: see page 126.

Shelling.—(1) A defect: see Pit; (2) in cold rolling or drawing: see page 101.

Shelling Out; Shelly.—See Pit.

Sherard Process; Sherardizing.—See page 371.

Sherk and Rutter Converter.—See page 24.

Sherman Process.—See pages 380 and 387.

Shingling.—See pages 177 and 377.

Shock.—See pages 330 and 333.

Shock Test.—See page 481.

Shop Coat.—See page 365.

Shore Layers.—In the freezing of alloys: see page 54.

Shore Pyroscope.—See page 208.

Shore Scleroscope; Test.—See page 478.

Short; Shortness.—See Brittleness.

Short Heat.—See page 226.

Short-tailed Monkey.—See Monkey.

Short Ton.—See Ton.

Shortening.—In compression: see page 336.

Shot Iron.—Irregular globules of cast iron, usually about $\frac{1}{4}$ to $\frac{3}{4}$ " in diameter, produced when some of the contents of a ladle splash on a damp floor, or produced when a cupola is dumped.

Shoulder.—(1) Of a converter: see page 18; (2) of a roll: see page 403.

Shrink Hole.—See page 53.

Shrinkage Gage.—See page 296.

Shrinkage Test.—See page 484.

Shrinking.—See Cold Working.

Shrinking Head.—See page 56.

Shudes.—See page 432.

Shut.—See page 502.

Shutter.—See page 36.

Sibbering.—See page 376.

Sibut Process.—See page 64.

- Side Blown Converter.**—See page 18.
Side Fed Tuyeres.—See page 31.
Side Shears.—See page 413.
Siderite.—(1) Kind of iron ore: see page 244; (2) kind of meteorite: see page 290.
Siderography.—Engraving on iron or steel.
Siderolite.—See page 290.
Siderology (Juptner); Siderurgy.—Metallurgy of iron.
Siegen Process; Raw Steel Finery Process.—See page 78.
Siemens Calorimeter.—See page 201.
Siemens Calorimetric Pyrometer.—See page 207.
Siemens Electric Furnace.—See page 163.
Siemens Electric Resistance Pyrometer.—See page 208.
Siemens Furnace.—See pages 183 and 310.
Siemens Gas.—See Producer.
Siemens and Halske Recording Pyrometer.—See page 210.
Siemens-Martin Process.—See page 310.
Siemens Precipitation Process.—See page 146.
Siemens (C. W.) Process.—(1) Of casting: see page 64; (2) direct: see page 146; (3) open hearth: see page 310; (4) purification: see page 387.
Siemens (F.) Process.—See page 146.
Siemens Regenerative Furnace.—See page 310.
Siemens Reversing Process.—Regenerative Heating.
Siemens Squeezer.—See page 377.
Siemens Steel; Siemens-Martin Steel.—Open hearth steel, either acid or basic.
Silex (obs.).—Silica.
Silfrax.—See page 398.
Silhouette.—See page 126.
Silica; Silica Brick.—See page 395.
Silicate.—A combination of silica with some base.
Siliceous Clay.—See page 396.
Siliceous Ore.—See page 243.
Siliceous Rocks.—See page 395.
Silicide of Carbon.—See page 398.
Silicized Carbon.—See page 398.
Silico-Calcium.—A product of the electric furnace intended to be used as a deoxidizing addition for steel; an analysis shows:

Silicon	66.98 %
Sulphur	tr.
Phosphorus	0.056
Calcium.....	27.50
Aluminum.....	2.31
Iron.....	0.41
Magnesium	tr.
Manganese	nil
Moisture	0.13

Silico-Ferrite.—See page 272.

Silico-Ferro-manganese; Silico-manganese.—See page 354.

Silico-Manganese Steels.—See page 452.

Silico-Spiegel; Silicon Spiegel.—See page 354.

Silicon.—Si; at. wt., 28; melt. pt., 1200° C. (2192° F.); sp. gr., amorphous, 2.15, crystalline, 2.34 to 2.49. It is always found combined with oxygen as silica (sand) or a silicate. When pure it is a white metal, and, depending upon the method of preparation, may be amorphous or crystalline. "From differences that have been discovered, and from the close analogy that exists between silicon and carbon, it was at one time believed that three allotropes of this element existed, corresponding to those of carbon. **Amorphous silicon** was considered to represent charcoal. A crystalline substance obtained by **Wöhler**, by heating potassium silico-fluoride with aluminum, has been regarded as corresponding to graphite, and called **graphitic silicon (graphitoidal silicon)**; while the octahedral crystals of silicon prepared by other reactions (Deville) were thought to be the analogue of the diamond; and this substance has therefore been called **diamond silicon** or **admantine silicon**" (Newth). Silicon combines with iron to form a silicide (**iron silicide**) FeSi_2 . It is always a constituent of pig iron; if higher than about 6% it is called ferro-silicon (see page 354) in which form it is valuable as a deoxidizer (see page 394). In ordinary steel it is usually under about 0.030%; in steel castings it is generally under about 0.25%; while for certain purposes it may go as high as 1.00%. It is now recognized that it has no deleterious influence up to at least 1.00% and probably higher, and has only a slight effect in the amounts usually met with. In molten pig iron it lowers the saturation point for carbon, and during cooling tends to throw it out as graphite.

For influence on corrosion: see page 366.

Silicon Additions.—See Recarburization.

Silicon-Calcium-Aluminum.—See page 354.

Silicon Carbide.—See page 398.

Siliconeisen.—See page 354.

Silicon Ore.—See Codorus.

Silicon Steels.—See page 452.

Siliciuration.—See page 66.

Silit.—See page 398.

Silky Fracture.—See page 178.

Sill.—The bottom of the door of a reverberatory furnace.

Silocel Brick.—See page 396.

Siloxicon.—A trade name given to a highly refractory compound of silicon, carbon, and oxygen, having the formula $\text{Si}_2\text{C}_2\text{O}$ produced in the electric furnace.

Silundum.—See page 398.

Silvery Gray Iron; Silvery Iron; Pig.—See page 343.

Similarity.—Law of: see page 473.

Simple Alloy.—See Alloy.

Simple Axial Stress.—See page 332.

Simple Beam.—See page 468.

Simple Cells.—See page 121.

Simple Induction Furnace.—See page 153.

- Simple Mathematical Ratio.**—Law of for crystals: see page 120.
- Simple Metals.**—See page 125.
- Simple Microscope.**—See page 285.
- Simple Overstrain.**—See page 282.
- Simple Radical.**—See page 87.
- Simple Shear.**—See page 337.
- Simple Slip.**—See page 283.
- Simple Stress.**—See page 332.
- Simple Twinning.**—See page 124.
- Simpson Weld.**—See page 504.
- Singles.**—Of sheets: page 430.
- Single Acting Hammer.**—See Hammer.
- Single Blow Test.**—See page 481.
- Single Coil.**—See Coil.
- Single Furnace.**—See page 376.
- Single Level Furnace.**—See page 312.
- Single Melting Process.**—See page 75.
- Single Microscope.**—See page 285.
- Single Mill.**—See page 430.
- Single Puddling Furnace.**—See page 376.
- Single Refined Iron.**—See page 378.
- Single Rolled Iron.**—See page 378.
- Single Shear.**—See page 337.
- Single Shear Heat.**—See page 71.
- Single Shear Steel.**—See Shear Steel.
- Single Skip.**—See page 33.
- Single Steel.**—See page 430.
- Single Strand (Strip) Coil.**—See Coil.
- Sink Hole.**—See page 53.
- Sinker.**—See page 509.
- Sinkhead.**—See pages 56 and 299.
- Sinking.**—See page 79.
- Sinking Fire.**—A forge in which wrought iron scrap or refined pig is partially melted or welded together by means of a charcoal fire and a blast (Raymond).
- Sinking Head.**—See page 56.
- Sinking a Lump.**—See page 79.
- Sinter.**—(1) To fuse: see page 45; (2) cinder: see Slag.
- Size of Crystals; Grains.**—See pages 121 and 213.
- Size of a Rolling Mill.**—See page 410.
- Sizing.**—See Ore.
- Sizing Rolls.**—See page 490.
- Skelp; Skelper.**—See page 489.
- Skeletal Crystal; Skeleton Crystal.**—See page 122.
- Skeller; Skellering (Yorkshire).**—The warp sometimes produced in a piece of steel when quenched; also for castings on annealing.
- Skelp; Skelper; Skelping.**—See page 489.
- Skew Back.**—That part of the roof of a furnace at which the spring of the arch starts.
- Skew Plate.**—See page 135.
- Skew Rolls; Rollers.**—A series of rollers, set at a slight angle to the longitudinal direction of the table, for handling bars or other

small rolled products; the effect of the angle is to throw the pieces to one side where they are assembled against a guard.

Skimmer.—See page 36.

Skin.—(1) In an ingot, the layer of metal between the blow-holes and the outside; (2) in a forged or rolled piece, the thin outside layer which has a very fine structure due to the work and the chilling action of the machine.

Skin Annealing.—See page 232.

Skin Breakage.—See Cold Working.

Skin Dried.—See page 298.

Skin Hardening.—See page 69.

Skip; Skip Bridge; Skip Charging.—See page 33.

Skull.—Sometimes spelled scull; (1) the steel or cast iron which has solidified against the inside surface of a ladle, or to remove the same; (2) in a blast furnace: see page 35.

Skull Breaker; Cracker.—A heavy ball or piece of metal, with the necessary appliances, which is raised and dropped on a skull or other large piece of metal to reduce it to a size convenient for handling.

Slab.—See page 411.

Slab Ingot.—See page 53.

Slabbing Mill.—See page 413.

Slack.—(1) See Coal; (2) of lime: see page 396.

Slag.—Also called **cinder** or sometimes **scoria**; the molten substance, other than the metal under treatment, consisting of acid or basic oxides which may be composed (a) in smelting operations, of the gangue of the ore combined with some fluxing material (usually lime) added to render it fusible and easily separated from the metal, and also to effect a certain amount of purification, or (b) in purifying processes, of substances (usually lime and iron oxide) introduced for the purpose of effecting or assisting in the purification. A slag which is infusible or pasty is sometimes called a **dry slag**; one which is fusible and liquid, a **wet slag**. A **scouring cinder** is one, generally high in oxide of iron, which is very liquid and attacks and corrodes the lining of a furnace. A slag is **acid** or **basic** depending upon whether the principal constituent is respectively silica, or lime or oxide of iron. A **bastard slag** is the name sometimes applied (a) to a slag in a basic furnace which is not sufficiently basic, or (b) to a slag in an acid furnace to which lime has been added (usually toward the end of the heat) with the idea of effecting a slight elimination of phosphorus. A **preliminary slag** is (a) the slag existing shortly after the commencement of a refining process, or (b) that which is tapped out before the end of the process: in blast furnace work this is termed **roughing cinder** or **flush**; in puddling, **boilings**. A **final slag** is the slag existing at the end of a process, or what is tapped out at that time, usually called **tapping slag**; in puddling, **tappings** or **tap cinder**; puddling furnace cinder is rarely called **mill cinder** or **mill tap**. **Drop** is an obsolete name for the slag collected at the bottom of the hearth of a **Catalan** forge, or puddling furnace. The term **reaction slag** has been applied to that found in steel resulting

from a chemical reaction while molten as distinguished from that found in the furnace (**furnace slag**) during the process, particles of which may be mechanically retained in the metal during solidification. The slag expelled under a hammer from a ball or lump of wrought iron after drawing from the furnace is called **hammer slag** or **forge cinder**. In England blacksmith's slag is sometimes called **hards**. The slag very rich in oxides of iron formed by the oxidation of the iron in reheating furnaces is called **heating furnace cinder** or **flue cinder**. **Buckshot cinder** is blast furnace slag containing small particles of metallic iron. **Tarmac** (Eng.) is slag treated while hot with molten tar or pitch and used as a road-making material.

Slag-bearing.—Containing slags, as wrought iron.

Slag Bottom.—See Lining.

Slag Bottom Process.—See page 78.

Slag Brick.—See Slag Cement.

Slag Cement.—(1) Granulated or ground blast furnace slag mixed with slaked lime, referred to specifically as **blast furnace slag cement**; (2) a regular Portland cement in which blast furnace slag is used as the base. Greiner gives the following description of the manufacture (*J. I. & S. Inst.*, 1914, 1, 45+): a mixture of 75% of granulated slag and 25% of lime is fritted in the kilns usually employed in the Portland cement industry; by these means there are obtained nodules, or semi-fused agglomerates, possessing a special molecular texture and termed **clinker**. A mixture of 70% clinker and 30% granulated slag, finely ground, yields a cement of superior quality known in Germany as **Eisen-Portland**, and accepted during the last five years, under the same category as Portland cement, by public administrations and the International Sales Syndicate. The granulated slag mixed with a small percentage of slaked lime is put under presses, and **slag bricks** thus formed, and heated in autoclaves (pressure chambers) under steam at a pressure of one to eight atmospheres, acquire a remarkable degree of hardness. Uniformity of shape and a pleasing appearance create a demand for all kinds of masonry work which they render drier and more impervious to moisture than ordinary brick.

Slag Formation, Zone of.—See page 36.

Slag Inclusion.—See page 57.

Slag Ladle.—See Ladle.

Slagless.—Free from or containing only accidental traces, as steel produced in the fluid condition.

Slag Line.—In the crucible process: see page 115; (2) in the open hearth process: see page 311.

Slag Machine.—A machine for handling the slag from a blast furnace. It usually consists of a series of shallow iron pans in an endless chain on which the slag is chilled with sprays of water, after which it is dumped into cars.

Slag Notch.—See page 32.

Slag Pit.—See page 312.

Slag Pocket.—See page 311.

Slag Processes.—See page 384.

Slag Short, Shortness.—See Brittleness.

Slag Wool.—Also called **mineral wool**; it is a downy fibrous substance, somewhat resembling wool, produced by blowing a jet of steam of air against a small stream of molten slag. A similar substance, made from lime and silicious rocks melted together, is called **rock wool**.

Slake.—See page 396.

Slaty Fracture.—See page 178.

Slaviankoff Process.—See page 503.

Slavianoff Electric Casting.—See page 65.

Sleazy (Eng.).—Usually referring to fabrics but sometimes applied to iron or steel objects, particularly sheets, which are weak or lacking in body.

Sledge.—See Hammer.

Sleeve Brick.—See Ladle.

Slick Angular Method.—Of rolling: see page 420.

Slip.—(1) Of a blast furnace: see page 35; (2) of metals: see page 282.

Slip Band; Theories.—See page 282.

Slip Fracture.—See page 179.

Slip Plane; Slipping Plane.—See pages 123 and 282.

Slitting Mill; Pass.—See page 419.

Sliver.—A very thin piece of metal rolled into the surface of a piece to which it is attached by only one end.

Slopping.—See page 21.

Slow Cement.—See page 67.

Slow Combustion.—See page 202.

Slow Pouring.—See page 59.

Slow Test.—See page 468.

Sludge.—See page 33.

Small Billet.—See page 411.

Small Calorie.—See page 199.

Smelt.—To extract the metal or metals from an ore in a furnace by reduction, usually by means of solid carbonaceous matter, such as coal, coke, or charcoal, which also supplies the necessary heat. This term should be carefully distinguished from **melt**, which signifies simple fusion, for which it is sometimes incorrectly used.

Smelter Coke.—See page 97.

Smith-Casson Process.—See page 61.

Smith Coal; Smithy Coal.—See Coal.

Smith (Wm.) Process.—See page 232.

Smith's (Angus) Solution.—See page 365.

Smiths' Tool Temper.—See Temper.

Smithing (Eng.).—See Forging.

Smithy Slack (obs.).—Hammer scale.

Smithy Test (Eng.).—See page 476.

Smoke.—See page 202.

Smoky edged Plate.—See page 432.

Smooth Fracture.—See page 178.

Smyth Process.—See page 388.

Snake.—See Seam.

- Snarling.**—See page 476.
- Snelus Process.**—See page 147.
- Snipping (Eng.).**—Chipping off, as with a tool struck by a hammer.
- Snyder Furnace.**—See page 163.
- Soaking; Soaking Furnace; Soaking Pit; Soaking Pit Process.**—See page 184.
- Sodium.**—Na; at. wt., 23; melt. pt., 97.6° C. (207.7° F.); sp. gr., 0.97. It is never found in nature in the uncombined state. It is a soft white metal readily oxidized. The oxide and the carbonate have a very limited application as a flux, but practically never in the metallurgy of iron and steel.
- Sodium Picrate.**—As an etching medium: see page 287.
- Soft Annealing.**—See page 232.
- Soft Blast.**—Blast which is weak or low in pressure.
- Soft Centered Steel.**—See page 64.
- Soft Coal.**—See Coal.
- Soft Coke.**—See page 97.
- Soft Roll.**—See page 403.
- Soft Solder.**—See page 505.
- Soft Spot.**—See Hard Spot.
- Soft Steel.**—See page 455.
- Softener.**—See page 347.
- Softening Point.**—See page 396.
- Soldering.**—See page 505.
- Sole.**—(1) The hearth of a furnace: see page 183; (2) the bottom or bottom surface.
- Sole Plate.**—A plate placed under the bottom or sole, as of a furnace; a rail.
- Solid.**—(1) The condition of being solid or not readily mobile, as contrasted with liquids and gases; (2) sound; free from cavities, such as blowholes or pipe; (3) in one piece, as solid steel wheel; (4) see page 81.
- Solid Cement.**—See pages 67 and 68.
- Solid Contraction.**—See page 53.
- Solid Ingots.**—See page 59.
- Solid Solution (adj., Solid Solubility).**—See page 270.
- Solid State.**—See page 81.
- Solidification.**—See pages 53 and 266.
- Solidification Point.**—See page 201.
- Solidification Range.**—See pages 54 and 267.
- Solidified Solution.**—See page 270.
- Solidoid.**—See page 270.
- Solidus; Solidus Curve.**—See pages 268 and 270.
- Solubility Curve.**—See Curve.
- Solute.**—See pages 83 and below.
- Solution.**—In the ordinary sense a homogeneous mixture of either a gas, a liquid, or a solid with a liquid, this liquid being termed the solvent (Newth) and the dissolved substance the solute. A saturated solution is one which contains the maximum amount of a given substance which can be dissolved under the given conditions; it is supersaturated when there is more in solution than can normally exist, or, in other words, it is in unstable equilibrium.

A **solubility curve** is a diagram showing the different concentrations for changes in temperature and (sometimes) in pressure. **Solution pressure** is the energy with which molecules seek to leave the solid state and go into solution. The **coefficient of distribution** is the proportion of a third substance dissolved by each of two other substances, both of which are in contact with it and with each other. **Diffusion** is the tendency of a solution to mingle with one more dilute, or of different composition, until the mixture is homogeneous or of uniform composition throughout; this is the reverse of **segregation**. **Osmose** is the diffusion of a crystalline body in solution, or of two different solutions, through a porous membrane or diaphragm. The passage from the side on which it was originally is called **exosmose**; that to the other side, **endosmose**. The pressure exerted thereby on the membrane is known as **osmotic pressure**. A substance which will not so diffuse is called a **colloid**.

Solution Plane.—See page 127.

Solution Pressure.—See Solution.

Solution Theory.—Of hardening: see page 279.

Solvent.—See Solution.

Solvite.—See page 273.

Sonim.—See page 279.

Sonority Test.—See page 483.

Sorbite.—(1) In metallography: see page 276; (2) a name formerly given to ruby and blue crystals found by Sorby, and only in certain cast iron, which were shown to be nitride of titanium.

Sorbitic Pearlite.—See page 273.

Sorbitic Steel.—Steel containing a large proportion of sorbite.

Sorbitism.—See page 277.

Sorby's Reagent.—For etching: see page 287.

Sorting.—See Ore.

Sound.—Free from defects, particularly pipes and blowholes.

Sound Steel.—See page 59.

South Wales (Welsh) Process.—See page 79.

Sow; Sow Metal.—See page 342.

Space-Lattice; Theory.—See page 121.

Spall.—(1) Of bricks, etc., when they are easily abraded; (2) of car wheels, shelling out: see page 357; (3) of cast iron rolls, when particles crack or flake out of the surface.

Spangle.—See page 431.

Spanner.—See page 406.

Spar.—Fluorspar: see Flux.

Spark Test.—See page 484.

Sparry Ore.—See page 244.

Spathic; Spathose; Spathous.—Having an even lamellar or flatly foliated structure (Cent. Dict.).

Spathic Carbonate; Iron Ore; Ore.—See page 244.

Spawl.—See Spall.

Special Additions.—See Recarburization.

Special Cast Iron.—See page 351.

Special Ferro-Silicon.—See page 354.

Special Heat Treatment.—See page 212.

Special High Silicon Iron.—See page 354.

Special Long Ton.—See Ton.

Special Low Phos.; Low Phosphorus Pig.—See page 346.

Special Open Hearth Processes.—See page 315.

Special Steels.—Also called alloy steels, or combination steels, and rarely, alloyed carbon iron, are steels which owe their properties chiefly to the presence of an element or elements other than carbon (I.A.T.M.). If the carbon is over about 2% they are usually termed ferro-alloys (*q.v.*, page 351). The elements (alloy elements) principally concerned are nickel, chromium, vanadium, tungsten, molybdenum, manganese (over about 7%), and silicon (over about 0.5%). In contradistinction to the above, steel which owes its properties chiefly to various percentages of carbon is known as ordinary steel or carbon steel. In a general sense carbon steels which are prepared for some specific purpose are sometimes spoken of as special steels, but this is not the customary practice. In this class might be included what Longmuir calls high tension steels, a term which he employs to cover endurance to reversal of stresses as well as actual high tensile strength; in other words steels possessing high resistance to service conditions (more properly high resistance steels) which are not usually limited to tensile stresses. Quality steels (Eng.) are those of high quality intended for special purposes, and not necessarily containing special elements. Ternary steels are those which consist chiefly of iron, carbon, and one other special element; quaternary steels, of iron, carbon, and two other special elements.

Guillet's Theory of Ternary Steels.—Sauveur explains this as follows (*Metallography*, 326-7): "Too rigorous an application of the theory, however, should not be insisted upon for there are some facts not yet satisfactorily explained by it. Its use, nevertheless, will be found an invaluable guide in directing researches dealing with the manufacture and the application of these steels.

"Guillet's theory of the structure and properties of ternary steels may be briefly formulated by a few propositions. It is also represented graphically in Fig. 59.

"(1) On the introduction of a special element in carbon steel the latter remains at first pearlitic, but as the proportion of special element increases, the carbon remaining constant, it becomes first martensitic and then austenitic (polyhedral), as shown graphically in Fig. 59, and sometimes called cementitic (carbide steel) as later explained.

"(2) By increasing the amount of carbon present in a special steel, the proportion of the special element being kept constant, it is generally converted from a pearlitic into a martensitic condition or, if already martensitic, into an austenitic condition.

"(3) The greater the amount of carbon the smaller the proportion of the special element needed to cause a structural transformation, as for instance pearlite into martensite or martensite into austenite. This is indicated in Fig. 59.

"(4) The greater the amount of the special element the smaller

the proportion of carbon needed to cause a structural transformation. This is also shown in Fig. 59.

"(5) No very sharp lines of demarcation are observed between the different types of structures mentioned in the preceding propositions, relatively wide ranges of composition existing, on the contrary, in which the steel may be partly pearlitic and partly martensitic or partly martensitic and partly austenitic, etc. These transition ranges are indicated by shaded areas in the diagram of Fig. 59. Greater refinement in the construction of a troostitic zone between the pearlite and martensite areas and possibly also of a sorbitic zone between pearlite and troostite.

"To sum up, constituents may be formed during the *slow cooling* of many alloy steels which in carbon steels can only be produced by very rapid cooling through the critical range.

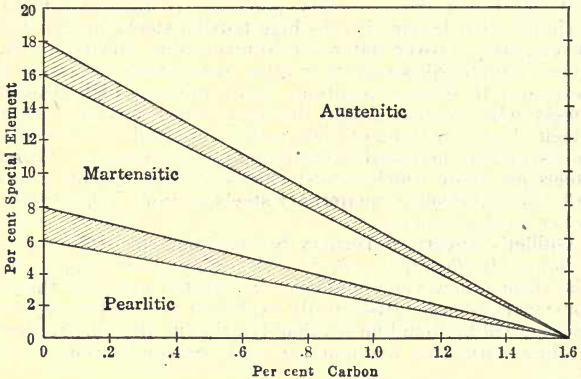


FIG. 59.—Ternary steels.—(Sauveur).

Carbon steels, moreover, even after very rapid cooling cannot be retained wholly in an austenitic condition while several special steels remain austenitic after slow cooling. It is evident from the above and from the diagram that in order to produce a certain structure, (1) the proportion of carbon may be kept constant while the proportion of the special element is increased until the desired structure is obtained, or (2) the proportion of the special element may be kept constant and the proportion of carbon increased, or (3) both the proportion of carbon and of the special element may be increased when the desired structure will be obtained more quickly."

Constitution of Special Steels.—As stated in Guillet's theory the normal condition of special steels at ordinary temperatures is dependent primarily upon the nature and amount of the special element or elements in conjunction with the percentage of carbon

and the heat treatment. Based on ordinary or slow cooling a classification may be made into:

1. **Pearlitic steels:** Similar to carbon steels, and, as a rule, relatively low in special elements. "In these steels the special element may (1) be dissolved in the ferrite forming with it a solid solution, (2) be combined with carbon in cementite as a double carbide of iron and the special element, or (3) be partly dissolved in ferrite and partly combined with carbon. According to Guillet nickel and silicon, for instance, are entirely dissolved in ferrite, while manganese, chromium, tungsten, vanadium, and molybdenum are partly held in solution by ferrite and partly present in cementite as double carbides" (Sauveur, *Metallography*, 331). "Guillet writes that pearlitic special steels may be divided into (1) those that are not very sensitive to annealing, namely, nickel and silicon steels, and (2) those that are very sensitive to annealing, namely, manganese, chrome, vanadium, tungsten, and molybdenum steels. It should be noted that in the first group the special elements are supposed to be entirely dissolved in the iron, while in the second group they are partly dissolved and partly present as carbides" (Sauveur, *ibid.*, 333-4).

2. **Martensitic steels:** With a higher combination of special elements and carbon than the preceding; except by very slow cooling they are hard, and are not affected by ordinary tempering operations.

3. **Austenitic (polyhedral) steels:** With a still higher combination of the special elements and carbon. They are **non-magnetic** as, for example, in the case of 11 % manganese steel or 25 % nickel steel. Sauveur points out (*ibid.*, 334) that air cooling may be required to produce truly austenitic steels; with slower cooling particles of carbide may separate out, and to cause reabsorption the steel is reheated to a high temperature followed by oil or water quenching, the latter termed **water toughening**.

4. **Cementitic (carbide) steels:** "Some special elements on being introduced in increasing proportions fail to convert the metal into austenite, free particles of a double carbide of iron and the special element being formed instead and embedded in a martensitic, troostitic, sorbitic, or pearlitic matrix. Guillet calls these carbide steels. Such elements as chromium, tungsten, molybdenum, and vanadium when present in sufficient quantity produce cementitic steels" (Sauveur, *ibid.*, 333).

Special elements were first used in the manufacture of steel for machine tools (**tool steel**), which was then called **special tool steel** to distinguish it from the **ordinary tool steel** or **carbon tool steel** formerly made exclusively. Mushet found that a steel containing about 1.50 % of carbon and 5 to 8 % of tungsten (a) would be rendered sufficiently hard by simple cooling in air (sometimes an air blast is employed) and (b) that the edge or temper of such a tool would remain practically intact at a temperature approaching a visible red, and as a result the tool would take a faster or a heavier cut. For these reasons such steels have been denominated **Mushet steel**, **air-hardening steel**, **air-**

quenched steel, self-hardening steel, high speed steel, quick speed steel, or rapid tool steel (rarely natural steel).

Taylor and White experimented with tool steels to obtain greater efficiency, and the method of treatment which they developed (Taylor-White process) improves nearly all kinds of special tool steel. Steel so treated is sometimes termed Taylor-White steel, high heat tools, or modern high speed tools, but as the method of treatment is the principal factor, these gentlemen object to the name new tool steel as being misleading. The process consists of two steps:

1. The first or **high heat treatment**:
 - (a) heating slowly to 1500° F. (816° C.);
 - (b) heating rapidly from that temperature to just below the melting point;
 - (c) cooling rapidly to below 1550° F. (843° C.); and
 - (d) cooling either rapidly or slowly from that point to the temperature of the air.
2. The second or **low heat treatment**:
 - (e) heating to a temperature below 1240° F. (671° C.), preferably to 1150° F. (621° C.), for about 5 minutes; and
 - (f) cooling either rapidly or slowly to the temperature of the air. The second treatment may also be produced by running the tool hot, and then cooling it down. Between 1550° and 1700° F. (843° and 927° C.) they term the **breaking down temperature**, as ordinary tool steel, if heated within this range, is seriously injured or broken down in its cutting speed. **Red hardness** is the name they give to the property of a tool when it maintains its cutting edge after its nose is red hot, obtained with chrome-tungsten steels (containing not less than 0.5% of chromium and 1% of tungsten or its equivalent) by heating them close to their melting point. They have published the following representative analyses (the range in composition for many self-hardening steels was communicated to Howe by J. A. Matthews):

	Jessop	Mushet Self- Harding	Original Taylor- White	Best Modern High Speed 1906	Range
Tungsten		5.441	8.00	18.91	3.44 to 24.00
Chromium... ..	0.207	0.308	3.80	5.47	0.00 to 6.00
Carbon.....	1.047	1.50	1.85	0.67	0.40 to 2.19
Manganese ..	0.189	1.578	0.30	0.11	.....
Vanadium ... ..		.....	.....	0.29	.....
Silicon	0.206	1.044	0.15	0.043	0.21 to 3.00
Phosphorus ..	0.017	.....	0.025	.....	.....
Sulphur	0.017	.....	0.030	.....	.....

E. K. Hammond states that the following is representative of the composition of the early Mushet steel: tungsten, 9.0%; manganese, 2.5%; carbon, 1.85%.

In the paper on "The Effect of Chromium and Tungsten upon the Hardening and Tempering of High-Speed Tool Steel" (*J. I. & S. I.*, 1915, 11, 29, 30), Edwards and Kikkawa reached the following conclusions:

"1. The first effect of tempering hardened high-speed steels it to make them softer, but when they are tempered at higher temperatures they again become harder, and after heating at or about 614°C . (1137°F .) they are much harder than in the initial air-quenched state. There can be no doubt that this **secondary hardening** is the cause of the improved cutting powers of a tool, which Mr. Taylor found was brought about by a secondary low heating to about 620°C .

"2. Chromium in conjunction with carbon is the cause of the great hardness of hardened high-speed steels, and further, it materially lowers the temperature at which these steels can be air-hardened.

"3. In the absence of chromium, tungsten raises the temperature at which tempering or annealing begins, and in the presence of chromium it increases the intensity of the secondary hardening, and raises the tempering temperature.

"4. Tungsten steel containing 18.0% of tungsten and 0.63% of carbon can be air-hardened only by rapid air-quenching from temperatures above 1050°C . (1920°F .)

"5. When high-speed steels are hardened at low temperatures, say 1050°C ., the tempering properties approximate to those of a pure chromium steel, by softening at a low temperature, and developing little or no secondary hardening. This is due to the tungsten being undissolved and remaining inactive.

"6. The maximum resistance to tempering and the greatest degree of secondary hardening can only be obtained by getting the tungsten into solution, and with modern high-speed steels this is not complete until a temperature of about 1350°C . (2460°F .) is reached.

"7. Specific gravity determinations seem to indicate that there is a direct connection between the hardness and volume of these steels. On tempering, an increase of hardness is accompanied by an increase in volume."

By **secondary hardening**, referred to above, is meant that resulting from the reheating or tempering of high-speed steels after a preliminary or initial hardening, which in contradistinction would also be termed **primary hardening**. Edwards has also employed the term **critical cooling velocity** to indicate the rate of cooling which must be maintained if self-hardening is to result. In connection particularly with tungsten steels it has been found that the higher the temperature for the primary treatment the lower would be subsequently the A_{c1} point; this has been termed the **lowering temperature**.

The following is an abstract (*J. I. & S. I.*, 1915, 1, 605 taken from *Cassier's Eng. Monthly*): "The high-speed steels of the present day are combinations of iron and carbon with tungsten and chromium; molybdenum and chromium; tungsten, chromium, and vanadium; tungsten, molybdenum, chromium, and vana-

dium. The control of the carbon limits is a very important matter. The best results are obtained from steels containing 0.5 to 0.7% of carbon. Higher percentages are not desirable, because great difficulty is experienced in forging the steel. With from 9 to 16% of tungsten and in conjunction with chromium the nature of the steel becomes very brittle, but at the same time the cutting efficiency is greatly increased. Sixteen percent of tungsten appears to give maximum hardness. The presence of chromium in high-speed steel varies from 1 to 6%. While a large percentage of tungsten is necessary in a good steel, it has been found that as low as 5% of molybdenum will make an excellent steel. Molybdenum steels do not require such a high temperature in hardening as do the tungsten steels. The presence of 1% of vanadium in a high-speed steel, containing at least 18% of tungsten, enables such a steel to be quenched from a white heat in water without cracking, and this fact led to the recent production of **water-hardening high-speed steels**; but it must be borne in mind that the percentage of carbon must not exceed 0.6%, otherwise there is danger of cracking in the operation of hardening."

In regard to the **effect of heat treatment on density** of alloy steels the same abstract as already quoted from (see Heat Treatment, page 224) states: "In alloy steels the difference in density as between water-hardened and oil-hardened steels is not nearly so great as in the case of ordinary carbon steels. Quenched alloy steels show no maximum at 430° C. (805° F.), but from that temperature upwards the density increases continually. Eutectoid steels tend more than others to develop hardening cracks, on account of their greater volume changes during quenching. Bars increase in length according to the carbon content, and the increase is proportional to the length of the bar. When quenched from 960° C. (1760° F.) several of the special steels always gave hardening cracks, so that the specific gravity could not be determined. The nickel and chromium steels show a smaller increase in volume with quenching than plain steels of the same carbon content. This is also true of the manganese steels, although not to so great an extent, while the chromium-nickel steels show a proportionally great change of volume. Although these results do not apply to all special steels, yet it is certain that through suitable special additions the change in volume due to quenching can be greatly reduced. The author considers that the change in volume brought about by quenching steel is only small if the quenching temperature be within a limit close to the critical temperature. Very great changes in volume are brought about if this limit is even slightly exceeded."

The special steels in common use contain one or more of the elements (in addition to carbon and manganese) nickel, chromium, silicon, and vanadium. With the exception of nickel steel (for certain structural purposes, such as bridges) they are usually given a special heat treatment to develop as far as possible the properties which warrant their extra cost. The following

Types of Steel (A. S. T. M.)

Elements considered	Type								
	A	B	C	D	E	F	G	H	
	Carbon Steel	Nickel Steel	Chrome-nickel steel						Chrome Steel	Chrome-vanadium Steel
Manganese, %	0.50-0.80	0.50-0.80	0.50-0.80	0.30-0.60	0.45-0.75	0.30-0.60	0.30-0.60	0.50-0.80	
Phosphorus, max., %	0.045	0.04	0.04	0.04	0.04	0.04	0.04	0.04	
Sulphur, max., %	0.050	0.045	0.045	0.045	0.045	0.045	0.045	0.045	
Nickel, %		Not under 3.00	1.00-1.50	1.50-2.00	2.75-3.25	Not under 3.00	Not under 3.00		
Chromium, %			0.45-0.75	0.90-1.25	0.60-0.95	Not under 1.00	0.60-0.90	0.80-1.10	
Vanadium, min., %								0.15	

table taken from the specifications for forging billets of the A. S. T. M. will serve to illustrate the types and grades (for carbon as well as alloy steels) commonly used for special forgings of any size (see preceding page).

Carbon Ranges for the Various Grades for Carbon and Alloy Steel

Carbon Steel—Type A.		Alloy Steel—Types B to H, Incl.	
Grade	Carbon, %	Grade	Carbon, %
1.....	0.05-0.15	11.....	0.10-0.20
2.....	0.15-0.25	12.....	0.15-0.25
3.....	0.20-0.30	13.....	0.20-0.30
4.....	0.25-0.40	14.....	0.25-0.38
5.....	0.30-0.45	15.....	0.30-0.43
6.....	0.35-0.50	16.....	0.35-0.50
7.....	0.40-0.55	17.....	0.45-0.60
8.....	0.45-0.60		

NOTE 1.—When the steel is to be used for case-hardening purposes, the manganese should be specified not to exceed 0.50%. When the minimum carbon specified is 0.35% or over, the manganese range may be specified 0.30-0.60%.

NOTE 2.—In selecting billets for making forgings of Classes K, L and M, as defined in the Standard Specifications for Carbon-steel and Alloy-steel Forgings (Serial Designation: A 18) of the American Society for Testing Materials, it is suggested that the use of steel with a relatively high carbon content will permit the use of a high drawback temperature and thus put the steel in its best physical condition for service, shock and similar conditions.

Tungsten steels (rarely called **wolfram steels**), as now made usually contain (Howe) from 5 to 10% (and sometimes even 24%) of tungsten, and from 0.4 to 2% of carbon. **Tungsten-chrome steels**, as used for cutting tools, have been discussed above. There is another class, known as **magnet steels** (**magnetic steels**), which is used for permanent magnets owing to its high retentivity; these contain (Rosenhain) tungsten about 7% and chromium up to 0.5%. They are usually quenched in oil or water to render them as hard as possible as this is necessary for the purpose (**magnetic hardness**). Tungsten probably goes into solution as the tungsten iron compound Fe_3W ; in the undissolved form it may exist as Fe_2W which was isolated by Arnold and Read.

Molybdenum steels are somewhat similar in their properties to tungsten steels, and apparently 1% of molybdenum is equivalent to 2% of tungsten (Howe).

Nickel steels (when no other special elements are present) ordinarily contain from 3 to 4% (usually not over 5%) of nickel, from 0.10 to 0.50% of carbon, and about 0.30 to 0.80% of manganese. This amount of nickel renders the steel much tougher and stiffer; it also raises the ultimate strength and the elastic limit, the latter to a greater extent than the former, and

this with an increase in the ductility, the composition otherwise, and the treatment, remaining the same. The 3 to 3½% grade has been used to a considerable extent for structural work, particularly bridges, of which some of the most important have been made partly or almost entirely of this material. With less than 3% nickel the principal application has been for case-hardening purposes. Nickel steel, containing about 36% of nickel, patented under the name **invar** (Guillaume's **invar**) has a lower coefficient of expansion than any other metal or alloy known and, in consequence, is largely employed for instruments of precision. Another patented alloy, termed **platinite**, contains about 46% of nickel, and at ordinary temperatures has the same coefficient of expansion as glass (and platinum), and for this reason is used as a substitute for platinum in the manufacture of incandescent lamps. Types of **nickel-chrome steels** are shown in table on page 449. Special types of nickel and particularly nickel-chrome steel are used in the manufacture of armor plate and armor-piercing projectiles.

Chrome steel or **chromium steel**, "which usually contains about 2% of chromium and 0.80 to 2% of carbon, owes its value to combining, when in the hardened or suddenly cooled state, intense hardness with a high elastic limit, so that it is neither deformed permanently nor cracked by extremely violent shocks. For this reason it is the material generally if not always used for armor-piercing projectiles. It is much used also for certain rock-crushing machinery and for safes. These last are made of alternate layers, usually five in number, of chrome steel and wrought iron, welded together, and then cooled suddenly so as to harden the chrome steel. The hardness of the hardened chrome steel resists the burglar's drill, and the ductility of the wrought iron the blows of his hammer" (Howe). More recently types containing a lower chrome content have received wide adoption both for plain chrome steel and in combination with nickel or vanadium (**nickel-chrome** or **chrome-nickel**, and **chrome-vanadium steels**—see table, page 449). Under the trade name **crucia steel** a type containing about 0.20 to 0.50% chrome, the same amount of manganese, and about 0.80 to 1.00% carbon has been considerably used for certain automobile springs. A recent patented alloy, called **stainless steel**, has been introduced for articles of cutlery (especially for fruit) and for rifle and gun barrels owing to its almost complete freedom from ordinary corrosion; it contains about 10 to 15% of chrome and carbon less than about 0.50%. An Austrian steel called **non-corro**, used for the same purposes, is probably of somewhat similar composition. Chrome steel is rarely referred to as **chromated steel**.

Manganese steel (**Hadfield's manganese steel**, **austenitic manganese steel**) contains about 12% of manganese and 1.25% of carbon (the manganese is usually between about 11 and 14%) and was discovered by Hadfield in 1883; in 1887 he called it **self-hardening steel**. Owing to its great hardness it is ordinarily cast nearly to shape and then finished by grinding; it has been

successfully rolled into rails. As cast or otherwise produced (with relatively slow cooling) it is extremely brittle and to remove this it is heated to a fairly high temperature (about 1000°C. – 1830°F.) and quenched in water. This has the effect of rendering it tough and ductile without materially altering its hardness (**tough hardness**), and for this reason the water treatment is known as **water toughening**. In contradistinction the brittleness allied with hardness which would be produced in an ordinary steel equally high in carbon has been called **brittle hardness**. Treated manganese steel after treatment has a tensile strength of about 54 to 63 tons (about 120,000 to 141,000 pounds) per square inch, and an elongation of 30 to 50%; the stretch is nearly uniform throughout the length tested as very little necking occurs. The Brinell hardness number is about 200, whereas, without such high manganese, ordinary carbon steel would have a hardness number of about 600 to 800. By heating sufficiently long, up to 700°C. (1290°F.), it can be made more or less magnetic; the best temperature is about 520°C. (965°F.) and after heating for 600 hours it has about two-thirds the magnetism of pure iron. The magnetism is almost completely destroyed by heating for a few minutes at 750°C. (Hadfield and Hopkinson, *J. I. & S. I.*, 1914, I). It is largely employed for railway crossings or rails subject to heavy wear, and is particularly valuable for safes, as it cannot be softened by any known treatment. Recently it has had quite extensive use for light armor.

Silicon steels, according to Guillet, should not contain more than 5% of silicon, as above this they are apt to be brittle. While the cutting capacity of a tool is increased to a certain extent, this is obtained without the other advantages resulting from the use of other elements. With about 1.5 to 2% silicon and low carbon and manganese a grade has been obtained especially suitable for transformer sheets and similar electrical purposes owing to the low magnetic hysteresis and high permeability. With about the same silicon but about 0.45 to 0.65% carbon and 0.5 to 0.8% manganese (**silico-manganese steel**) it has found considerable application for springs. With less than 0.5% silicon it is not generally considered as a special steel.

Vanadium steels may be roughly divided into two classes: those used for general purposes, such as automobile and similar parts (including springs), where the vanadium content varies from about 0.1 to 0.25%; and special tool steel where the content will commonly be about 0.5 to 1%. Vanadium raises both the tensile strength and the elastic limit, the latter more than the former. It confers the valuable property of making the metal very resistant to repeated stresses, and on this account such steel is sometimes termed **anti-fatigue steel**. Aside from the direct benefit, there is an indirect effect due to the removal of oxygen (either as oxide or gas), and probably also of the nitrogen, with which part of the vanadium combines and passes off into the slag.

Titanium steels (or more properly **titanium-treated steels**) are those to which a small amount of titanium (usually as ferrotitanium) has been added just before pouring.

The following steels have not so far achieved any commercial prominence:

Aluminum steels, according to Guillet, when containing less than 3% of aluminum, do not differ sensibly in their properties from ordinary steels; above this percentage the elongation is considerably reduced and the brittleness increased.

Boron steels, according to the same authority, have no commercial application in the natural state, but might prove useful after quenching. In that condition they have high tensile strength and elasticity and are no more brittle than other special steels at present in use. The most interesting results were obtained with a steel containing 0.5% of boron.

Cobalt steels, containing up to 30% of cobalt, have been examined by Guillet. The only item of commercial interest he noted was that they did not resemble nickel steels, although, from the fact that nickel and cobalt have very similar properties, this would have been expected.

Copper steels, according to Breuil, containing above 4% of copper, are incapable of being rolled, but with a smaller percentage the strength and toughness are increased, somewhat as with nickel. (See also Protection, page 371.)

Platinum steels, containing small percentages of platinum, have been stated to be malleable and easily worked, but very hard.

Tin steels, with up to about 10% of tin, have been experimented upon by Guillet, but the material could not be forged except with very small percentages; in certain respects they somewhat resembled silicon steels.

Uranium steels have recently been manufactured to a certain extent. It is claimed that a small addition (0.2 to 0.3%) largely replaced tungsten in tool steels, but definite information is not available.

Special Tool Steel.—See page 445.

Specific Gravity.—See Density.

Specific Heat.—See page 201.

Specific Heat Pyrometer.—See page 207.

Specific Line of Deformation.—See page 126.

Specific Path of Deformation.—See page 283.

Specific Tenacity.—See page 336.

Specific Work of Rupture.—See page 481.

Specifications.—Specifications for the purchase of iron and steel products are primarily an explanation or description—chemical, physical and mechanical—of the material desired for a given purpose or service, and provisions for tests and inspection to afford the purchaser reasonable assurance that he is obtaining the properties stipulated. Requirements for marking for test and service identification and permissible variations from ordered dimensions and weights are generally included, and sometimes definitions of terms and directions for packing and

shipping. For special materials certain manufacturing limitations may be specified, *e.g.*, a minimum amount of discard from ingots, a maximum amount of chipping on billets, the control of rolling temperatures, and directions for conducting heat treating operations.

Although the commercial manufacture of iron and steel is based on scientific principles, the results secured cannot be predicted with mathematical accuracy owing to the practical limitations of mill operations. It is, therefore, essential in writing specifications to have some knowledge of manufacturing processes, including the methods and possibilities of heat treatment, and a wide experience in testing the particular material which the specifications are to cover.

Specifications should be based on the indications offered by a sufficient number of representative cases; experience being necessary to avoid employing extremes, simple averages or figures of an unusual or irregular nature. Unfortunately it is not always possible to develop tests which will indicate the suitability of the material for a given service. The tests specified should furnish definite information as far as possible and those of an indefinite or irrelevant character should be disregarded not only as being of no value, but also likely to interfere with the production or employment of suitable material. Requirements should not be drawn rigidly simply to guard against incompetent or insufficient inspection, and it is unjust to make the requirements for material severe on the plea that they are necessary to cover irregularities in material and service conditions and to provide a sufficient factor of safety—perhaps more accurately “factor of ignorance”—but more probably on account of lack of the necessary engineering data. Proper design has quite as much and often more to do with the serviceability of an object than the quality of the material from which it is made.

In the United States there are a number of technical societies that issue specifications for iron and steel products. These include the Association of American Steel Manufacturers, American Railway Engineering Association, Master Car Builders Association, American Railway Master Mechanics Association, American Electric Railway Engineering Association, Society of Automotive Engineers, and American Society of Mechanical Engineers, but the Standards of the American Society for Testing Materials are fast becoming the national commercial specifications. The term “commercial” is used here in its broadest sense because the American Society for Testing Materials specifications are due to the joint work of the consuming and the producing interests to which is added the intermediate experience of independent or consulting engineers. As a result of an extensive system of committees, recent developments will always be found in the specifications contained in the Book of Standards (triennial) and the reports of committees in the Proceedings (annual). There are now (1918) 41 specifications for steel, 5 for wrought iron, and 6 for cast iron products including pig iron.

In referring to different kinds of steels for various purposes, the following distinctions should be made: Any divisions of products by size or designations of service to be covered by the term **class**; the term **type** to designate kinds of steel, that is, whether plain carbon or the various divisions of alloy steels; and the term **grade** to designate the divisions of any type by carbon content or physical properties. As the various grades overlap and as some have chemical limits only while others have physical limits, a table or chart showing chemical and physical requirements, with the allowable variations, for the different classes of iron and steel products, would be intricate and cumbersome. Furthermore, the terms **low carbon**, **medium carbon**, and **high carbon**, or **soft** (or **mild**), **medium** and **hard** must be considered in connection with the context; thus a hard structural steel of, say, 0.35 carbon, is much lower in this element than a soft spring steel with 0.70%. The safest and best method to follow is to furnish specific details and not trust to indefinite and ambiguous generalities.

The following table will give an approximate idea of the ordinary designations of carbon steels now in use:

Grades	Approximate Carbon Range	Common Uses
Extra soft (dead soft)	0.08-0.18	Pipe, chain and other welding purposes; casehardening purposes; rivets; pressing and stamping purposes.
Structural (soft medium)	0.15-0.25	Structural plates, shapes and bars for bridges, buildings, cars, locomotives; boiler (flange) steel; drop forgings; bolts.
Medium.....	0.20-0.35	Structural purposes (ships); shafting; automobile parts; drop forgings.
Medium hard...	0.35-0.60	Locomotive and similar large forgings; car axles; rails.
Hard.....	0.60-0.85	Wrought steel wheels for steam and electric railway service; locomotive tires; rails; tools, such as sledges, hammers, pick points, crowbars, etc.
Spring.....	0.85-1.05	Automobile and other vehicle springs; tools, such as hot and cold chisels, rock drills and shear blades.
Spring.....	0.90-1.15	Railway springs; general machine shop tools.

Since about 1905 the term **structural steel** has been assigned to a definite grade of about 0.15 to 0.25 carbon or 55,000 to 70,000 pounds per sq. in. in tensile strength. Previously the following divisions were in common use:

Grade	Carbon Per cent.	Tensile Strength Pounds per square inch
Soft Bessemer.....	0.08 to 0.10	55,000 to 65,000
Soft Open Hearth.....	0.15 to 0.22	
Medium Open Hearth..	0.18 to 0.30	60,000 to 75,000
Hard Open Hearth.....	over 0.30	over 70,000

Specimens for Metallographic Examination.—Preparation of: see page 000.

Specimen Tests.—See page 467.

Spectral Pyrometer.—See page 208.

Spectroscope.—See page 82.

Spectrum Analysis.—See page 82.

Specular Iron Ore.—See page 243.

Specular Pig Iron (obs.).—See page 355.

Speed of Testing.—See page 475.

Speed of Transformation.—See page 265.

Spell.—(1) To work intermittently on a job on account of the severity of the labor, there being usually two gangs or shifts for each turn; (2) one such period of work.

Spellerizing.—See page 369.

Spelter.—Crude zinc before refining, commonly used in galvanizing.

Hard spelter is the name given to the zinc recovered by melting the dross removed from the bottom of the galvanizing bath; it contains about 10% of iron.

Spent Acid.—See Pickling.

Spent Bone.—See page 68.

Spent Ore.—See page 258.

Sperry Ore.—See page 244.

Sphaerosiderite.—See page 244.

Spheroidizing.—See page 274.

Spheroidizing Graphite.—See page 38.

Spherulitic (rare).—Round in shape like a sphere.

Spherule.—See page 292.

Spherulite; Spherulitic Structure.—See page 125.

Spicule.—See page 123.

Spiegel; Spiegeleisen.—See page 355.

Spiegel Recarburized.—Recarburized with spiegeleisen, *e.g.*, in the case of Bessemer rail steel.

Spielfield Process.—See page 380.

Spike.—Of structure; see page 128.

Spike Indicator.—See page 210.

Spill, Spilly.—See Pit.

Spin Up.—Of crucibles; see page 112.

Spindle.—See page 403.

Spindle Temper.—See Temper.

Spiral Pyrometer, Féry.—See page 207.

Spiral Seam.—See Seam.

Spirally Riveted Pipe; Welded Pipe.—See page 489.

Spirit Thermometer.—See page 205.

Spitting.—The ejection of small particles of molten metal or slag,

- usually when somewhat thick or pasty, by gas which has formed underneath.
- Splayed.**—Of the shape of the groove in a swage, etc., having a greater angle or curvature than the finished section of the object for which it is used.
- Splendid Fracture.**—See page 178.
- Splint Coal.**—See Coal.
- Splintery Fracture.**—See page 178.
- Split.**—(1) Generally of the end of a rolled piece when the end opens up, due to a pipe or to the metal being red-short; (2) in casehardening: see page 68.
- Split Weld.**—See page 502.
- Sponge.**—Metal in a porous form, generally obtained by reduction without fusion (Raymond).
- Sponge Bloom.**—See page 138.
- Sponge-like Decay.**—See page 106.
- Sponge-making Processes.**—See page 134.
- Sponginess; Spongy.**—See page 55.
- Spontaneous Absorption of Heat.**—See page 199.
- Spontaneous Annealing.**—See page 334.
- Spontaneous Combustion.**—See page 202.
- Spontaneous Cracking.**—See pages 99 and 332.
- Spontaneous Crystallization.**—See page 269.
- Spontaneous Evolution (Liberation).**—Of heat: see page 199.
- Spoon.**—An instrument for taking samples of metal while molten, consisting of an iron cup or dish attached to a rod; also called sample spoon or test spoon.
- Sporadosiderite.**—See page 291.
- Spot Chipping.**—See Chipping.
- Spot Welding.**—See page 504.
- Spotted Iron.**—See page 342.
- Spout.**—The trough which conducts the molten metal, etc., from a furnace; in a blast furnace this is usually called the **runner**.
- Spouting.**—The pipe or material for spouts.
- Spread.**—In rolling; see page 408.
- Spreader.**—A tool for spreading refractory material (fettling) over a furnace bottom.
- Spreader Tuyere.**—See page 32.
- Spreading and Turning (Eng.).**—In rolling: see page 414.
- Sprig; Sprigging.**—See page 300.
- Spring Heat.**—See page 71.
- Sprue.**—(1) Of castings, runner scrap; see page 300: (2) a projection left on a casting to be broken off and used for testing purposes (rare).
- Sprue Heat.**—See page 257.
- Sprung.**—See page 56.
- Spy.**—See page 70.
- Squeezer.**—(1) In puddling: see page 377; (2) in molding: see page 301.
- Squeezer Board.**—See page 301.
- Stable Diagram.**—See page 271.
- Stable Equilibrium.**—See page 326.

- Stack.**—(1) A blast furnace; (2) a large high chimney.
- Staff.**—See page 79.
- Stage.**—In comparison with phase: see page 326.
- Stainless Steel.**—See pages 367 and 451.
- Stall.**—See page 181.
- Stamps.**—See page 79.
- Stamping.**—See Marking.
- Stampings.**—See page 378.
- Stand-By (Eng.).**—A spare, as an extra part for replacement.
- Stand.**—Of rolls: see page 406.
- Standards.**—Of a rolling mill; see page 403.
- Standard Bessemer Pig.**—See page 344.
- Standard Coil.**—See Coil.
- Standard Ferro-Manganese.**—See page 352.
- Standard Foundry and Furnace Coke.**—See page 96.
- Standard Roasted Dolomite.**—See page 399.
- Standard Solution.**—See page 83.
- Standard Test Piece.**—See page 473.
- Standard Wire Gage.**—See page 188.
- Standardization.**—Of a testing machine: see page 469.
- Stanton Test.**—(1) Impact test: see page 482; (2) wear test: see page 480.
- Star Fracture.**—See page 178.
- Star-like Crystallite.**—See page 122.
- Stare.**—Of a fracture: see page 115.
- Stassano Furnace.**—See page 163.
- State, Changes of.**—See page 81.
- State Diagram.**—See page 271.
- State of Ease.**—See page 332.
- Static Hardness.**—See page 331.
- Static Indentation.**—To determine hardness: see page 477.
- Static Load.**—See page 333.
- Static Metamorphism.**—See page 122.
- Static Strength.**—See page 330.
- Static Stresses.**—See page 333.
- Static Test.**—See page 468.
- Stationary Bottom.**—See page 182.
- Stationary Converter.**—See page 17.
- Stationary Furnace.**—See page 312.
- Stationary Table.**—See page 408.
- Stationary Top.**—Of a blast furnace: see page 32.
- Stave.**—(1) Pieces of wrought iron welded together as a basis for making shafts, etc.; (2) to swell up the end of a tube.
- Stay Tubes.**—In a boiler, a few of the tubes which are heavier than the rest and have a nut screwed on the ends outside the boiler shell to keep it from bulging outward.
- Stead's Brittleness.**—See page 216.
- Stead's Law.**—Of welding: see page 501.
- Stead's Reagents.**—See page 287.
- Stead Test.**—See page 482.
- Steadite.**—See page 277.
- Steam Hammer.**—See Hammer.

Steam Helve.—See Hammer.

Steam Refinery.—See page 383.

Steam Shears.—See page 412.

Steaming.—See Water Gas.

Steel.—(1) That form of iron produced in a fluid condition, and hence practically free from slag (difference from wrought iron), which contains less than about 2.20% of carbon—as a rule less than 1.50% (difference from cast iron). It is produced by the crucible, the Bessemer, and the open hearth process, and also in the electric furnace. (2) The product obtained by carburizing wrought iron (more rarely low carbon steel) by the cementation process, and generally known as **cement steel**. (3) Formerly steel was what could be hardened (usefully) by quenching, while iron could not.

Steel Bronze.—An alloy of about 90% copper and 10% tin (bronze) which on account of its strength and hardness is sometimes used in place of steel, particularly to resist corrosion.

Steel-cast (adj.).—Suggested to be used to indicate that a given object was a steel casting, as it was claimed that it would obviate any question as to whether crucible steel was meant, as would be the case if "cast steel" were used indiscriminately. Crucible steel should always be called "crucible steel," and the above term dropped.

Steel Castings.—Castings made of steel and not subsequently forged or rolled.

Steel Cleaning Sand.—See page 296.

Steel-faced Wrought Iron Armor Plate.—See page 8.

Steel Facing.—See page 166.

Steel Iron (Eng.).—Pig iron intended for conversion into steel.

Steel Ladle.—See Ladle.

Steel Melting-heat Processes.—See page 134.

Steel Mold.—See page 296.

Steel Molding Sand; Steel Sand.—See page 296.

Steel Side.—See page 18.

Steel-through Heat.—See page 71.

Steel Wire Gage.—See page 186.

Steel Wool.—An abrasive material consisting of very fine shavings of steel wire made by a special machine.

Steely Malleable.—White heart malleable; see page 258.

Stefan-Boltzmann's Law.—Of radiation: see page 207.

Stefan's Law.—Of radiation: see page 207.

Stellar Pyrometer.—See page 208.

Stellate Structure.—See page 125.

Stellate Twin.—See page 124.

Step.—See page 282.

Stereo-Chemistry.—See page 86.

Stereo-Formula.—See page 86.

Stereoisomer.—See page 86.

Stereoscopic Binocular Microscope.—See page 285.

Stereoscopic Radiograph.—See page 285.

Sterling Process.—See page 118.

Sterling's Toughened Cast Iron.—See Semi-Steel.

- Stewing.**—See page 376.
- Sticker.**—(1) An ingot from which it is difficult to remove the mold on account of sticking; (2) a pack in which the sheets stick together: see page 430.
- Sticking.**—(1) Of the charge in a blast furnace, hanging; see page 35; (2) of an ingot which is not easily removed from the mold; (3) in welding: see page 504.
- Stiefel Process.**—See page 491.
- Stiffener.**—See page 406.
- Stiffness.**—See page 330.
- Stinking Coal.**—See Coal.
- Stirring Rod.**—A rod or bar of iron or soft steel used in working an open hearth heat.
- Stock.**—(1) What is on hand ready for delivery; (2) the raw material used for charging a furnace in the manufacture of iron and steel; (3) the foundation for the anvil of a power hammer.
- Stock Coke.**—See page 97.
- Stock Converter Process.**—See page 22.
- Stock House.**—A building or structure to keep under shelter materials used in manufacturing.
- Stock Indicator; Line.**—Of a blast furnace: see page 35.
- Stock Pile.**—The pile of ore constituting the supply for a blast furnace, particularly during the winter months.
- Stockman Process.**—See page 388.
- Stone.**—(1) Limestone; (2) in connection with wire: see page 95; (3) a meteorite: see page 291.
- Stool.**—See page 57.
- Stopper.**—See Ladle.
- Stopper; Stopper Down (Eng.).**—To close or stop up a hole, *e.g.*, the tapping hole of a furnace, or the hole in the top of an ingot mold; to cap.
- Stopper Head.**—See Ladle.
- Stoppering (Eng.).**—Closing up.
- Stopping.**—Material used for closing up a hole.
- Stopping In.**—See page 182.
- Stoughton Converter.**—See page 24.
- Stove.**—See pages 27 and 34.
- Stove Coke.**—See page 97.
- Straight Open Hearth Processes.**—See page 310.
- Straight Pane.**—See Pane.
- Straightening Mangle (Eng.).**—Straightening rolls, *q.v.*
- Straightening Press.**—Or **gag press**; a machine consisting of a fixed straight side and a movable side, operated by a cam or eccentric, which is brought against a bar resting against the piece where it is bent, to straighten it.
- Straightening Rolls.**—A machine comprising an upper and a lower set of several rolls each, the rolls in the two sets being staggered. The distance between the two sets is so regulated for pieces of different gage that in passing through they are made perfectly flat, *i.e.*, straight. For plates the rolls are plain, while for shapes they contain grooves corresponding to the section. See also page 414.

- Strain.**—(1) General: see page 333; (2) effect on growth of ferrite: see page 216; (3) effect on grain growth: see page 216; (4) effect of time beyond elastic limit: see page 472.
- Strain Gage.**—See page 471.
- Strain Hardness.**—See pages 99 and 331.
- Strand Rolls.**—See page 414.
- Stranded Wire.**—See page 509.
- Stratification.**—A formation consisting of layers or bands.
- Stratification Foliation.**—See page 124.
- Straw Temper.**—Oxide color: see page 230.
- Straw Tinted Wire.**—See page 508.
- Streaks.**—See Seam.
- Stremmatograph.**—See page 484.
- Strength.**—See page 330.
- Strength of Materials.**—See page 330.
- Stress.**—(1) General: see page 331; (2) lines of: see page 283.
- Stress-Deformation Diagram.**—See page 471.
- Stress Difference.**—See page 333.
- Stress-Strain Diagram.**—See page 471.
- Stress Theories.**—Of hardening: see pages 279 and 280.
- Stretch.**—See page 336.
- Stretch Limit.**—See page 471.
- Strickle.**—See page 301.
- Striction.**—See page 336.
- Stridberg's Hearth.**—See page 79.
- Stridsberg Process.**—See page 62.
- Striking; Striking Up.**—See page 301.
- Striking Energy.**—See page 481.
- Stringing Up.**—Of wire: see page 508.
- Strip.**—(1) Of ingots, to remove the mold; (2) of patterns, the taper or draft: see page 296; (3) a coil: see page 95; (4) of mines which are open worked, to remove the surface covering.
- Strip Mill.**—See page 415.
- Stripper; Stripping.**—See page 57.
- Stripping Plate.**—(1) In molding: see page 300; (2) in a rolling mill: see page 415.
- Stroh Steel Hardening Process.**—See page 504.
- Stromborg Process.**—See page 147.
- Strong Contact Metal Theories.**—See page 282.
- Strong Iron.**—Close-grained, gray pig iron.
- Structural Composition.**—See page 337.
- Structural Formula.**—(1) In chemistry: see page 86; (2) for physical properties: see pages 337 and 339.
- Structural Properties.**—Formulæ for: see page 337.
- Structural Saturation Point.**—See page 273.
- Structural Steel.**—Classification: see page 455.
- Structural Tests.**—See page 468.
- Structurally Free Cementite.**—See page 273.
- Structurally Free Ferrite.**—See pages 272 and 275.
- Structure.**—See pages 125 and 289.
- Structure of Crystals.**—See page 121.
- Strut.**—See page 468.
- Stubs' Gage.**—For iron wire and steel wire: see page 188.

Stuck Oven.—See page 147.

Stückofen.—See page 147.

Stud.—See page 299.

Stud Gage.—See page 186.

Styloid.—See page 290.

Styrian Charcoal Process; Open Hearth; Raw Steel Process.—

See page 79.

Styrian Walloon Process.—See page 80.

Subaerial (rare).—In air, *e.g.*, rusting; in contradistinction to subaqueous.

Subaqueous.—In water.

Subcarbide Theory.—Of hardening: see page 280.

Subcarburized (obs.).—Applied to steel, meaning very low in carbon like wrought iron.

Subcooling.—In hardening: see page 279.

Subcrystalline.—Non-crystalline and in unstable equilibrium.

Subcutaneous Blowhole.—See page 55.

Sublimation.—See page 202.

Sub-punching.—See Cold Working.

Sub-transformation Range.—See page 271.

Suction Producer.—See Producer.

Sudden Cement.—See page 67.

Sudden Fracture.—See page 178.

Sudden Load.—See page 333.

Sudre Process.—See page 118.

Sull.—Coating: see page 507.

Sullage.—See page 56.

Sullage Piece.—See page 56.

Sulphide Area.—See page 289.

Sulphide Coating.—See page 374.

Sulphide Ore.—See page 245.

Sulpho-Film.—See page 289.

Sulphur.—S; at. wt., 32; melt. pt., 114.5° C. (238° F.); boil. pt., 448° C. (838° F.); sp. gr., rhombic, 2.05, prismatic, 1.98, plastic, 1.95. It is found both free and combined. When pure and in its ordinary condition it is a pale yellow, crystalline solid. It may exist in four allotropic varieties: (1) **rhombic** crystals, stable at ordinary temperatures; (2) **prismatic** needles, obtained by allowing melted sulphur to cool slowly; unstable at ordinary temperatures, and tending to pass back to the rhombic variety; (3) **plastic sulphur** (amorphous), obtained by heating sulphur until it reaches a certain viscous condition, and then pouring it into water; unstable at ordinary temperatures; (4) **white amorphous sulphur**, obtained by sublimation; stable at ordinary temperatures. Sulphur combines with iron to form ferrous sulphide, FeS, and ferric sulphide FeS₂ (pyrites). With manganese it forms manganese (manganous) sulphide, MnS, which is nearly if not quite insoluble in metallic iron. In ordinary steel it usually runs from about 0.02 to 0.10%. If combined with iron its effect is to make the metal red-short, and it sometimes appears to exert a slight similar effect on the metal when cold. In cast iron it makes

the molten metal thick and sluggish, and appears to reduce the saturation point for carbon, and to keep that present in the combined state. What is termed a **sulphur ball** is a segregate very high in sulphur which sometimes separates out from high sulphur pig during solidification. For influence on corrosion see page 366.

Sulphur Additions.—See Recarburization.

Sulphur Ball.—See Sulphur.

Sulphur Coal.—See Coal.

Sulphur Print.—See page 288.

Sulphuric.—Sulphur in chemical combination in its highest valence VI.

Sulphurous.—(1) Containing a large or excessive percentage of sulphur; (2) sulphur in chemical combination in its lower valences II or IV.

Summerlee Process.—Same as the Neilson process, for the recovery of tar and ammonia from the gas of a blast furnace using raw coal.

Supercarburized.—Cemented; used for Harvey process: see page 67.

Superficial Cementation.—See page 67.

Superfusion.—See page 268.

Superheated.—(1) Of steel: see page 202; (2) of blast, heated in modern fire-brick stoves to above 600° F. (315° C.), which was about the limit of temperature with the old cast-iron pipe stoves; (3) of steam which has been heated to above the temperature at which moisture can form, and out of contact with water; dry steam.

Supermolten.—See page 202.

Superoxidation.—Oxidation beyond what is usual, as for special purification in the electric furnace process, etc.

Superposing Method.—See Alloy.

Supersaturated Solution.—See Solution.

Supersaturated Steel.—See page 273.

Supersilicated (rare).—Containing a large (or extra) percentage of silica, e.g., of slag.

Supersolubility Curve.—See page 269.

Surface Band.—See page 127.

Surface Blowhole.—See page 55.

Surface Cementation.—Case hardening: see page 67.

Surface Combustion.—See page 203.

Surface Deformation.—See page 283.

Surface Force.—See page 331.

Surface Hardening.—Case hardening: see page 67.

Surface Resistance.—See page 200.

Surface Resistance Furnace.—See page 153.

Surface Scratching.—See page 478.

Surface Traction.—See page 331.

Surfusion.—The abnormal or unstable condition of a body which, under certain conditions, may remain liquid after the temperature has fallen below the freezing point: see pages 268 and 327.

Surplus Carbide.—Cementite: see page 273.

- Surplus Ferrite.**—See page 272.
- Surzycki Process.**—See page 317.
- Swab; Swab Pot.**—See page 298.
- Swab Up.**—In the crucible process: see page 115.
- Swaff (Eng.).**—Swarf.
- Swage Work.**—See Hammer.
- Swan Process.**—See page 367.
- Swarf (rare).**—Fine particles of metal (usually iron or steel) produced in machining or grinding.
- Swarfing Furnace.**—See page 379.
- Sweating.**—A method of fastening two metallic surfaces together by means of a very thin invisible layer of solder.
- Sweating Heat.**—Wash heat, *q.v.*
- Swedish Bessemer Process.**—See page 23.
- Swedish Fixed Converter.**—See page 23.
- Swedish Lancashire Process.**—See page 77.
- Swedish Metallic Sponge.**—See page 147.
- Swedish Walloon Process.**—See page 79.
- Sweep.**—(1) In structural shapes and rails, side curvature: see page 49; (2) in molding: see page 300.
- Sweep Molding.**—See page 300.
- Sweeping Up.**—See page 301.
- Swell.**—(1) A defect in castings: see page 58; (2) in cold rolling or drawing: see Cold Working; (3) a raised portion on a piece of rolled material, such as a rail, from the pressure of gas, in a gas pocket located near the surface, while the metal is hot and soft.
- Swill.**—In pickling: see pages 341 and 431.
- Swording Stickers.**—See page 430.
- Symbol.**—In chemistry: see page 86.
- Symmetry, Law of.**—For crystals: see page 120.
- Syndolag.**—See page 397.
- Synthesis; Synthetic Chemistry.**—See page 82.
- Synthetic Reaction.**—See page 87.
- Synthetic Steel.**—The opposite of natural steel; sometimes applied as in the case of an alloy steel to which the alloy elements are specially added in amounts as desired, as opposed to **natural steel** where the composition depends entirely or principally on the composition of the ore.
- Syssiderite.**—See page 291.
- System.**—(1) In connection with the phase rule: see page 326; (2) of crystallization: see page 120.
- Systematic Deviation.**—Of slipping: see page 283.
- Szekely Process.**—See page 65.

T

- T; t.**—**T**: absolute temperature; transverse (of tests, etc.); **t**: time; thickness.
- Ta.**—Chemical symbol for tantalum: see page 84.
- Tb.**—Chemical symbol for terbium: see page 84.
- Te.**—Chemical symbol for tellurium: see page 84.
- Th.**—Chemical symbol for thorium: see page 84.
- Ti.**—Chemical symbol for titanium, *q.v.*
- Tl.**—Chemical symbol for thallium: see page 84.
- Tm.**—Chemical symbol for thulium: see page 84.
- T. A. I. M. E.**—Transactions of the American Institute of Mining Engineers.
- T Hammer.**—See Hammer.
- T.U.**—Thermal or heat unit.
- Table.**—See page 407.
- Taenite (Reichenbach).**—See page 291.
- Tag Butt Welding.**—See page 489.
- Tagger.**—See page 433.
- Tail Helve.**—See Hammer.
- Take the Blast.**—See page 35.
- Take a Heat.**—Melting iron in a cupola for foundry work.
- Take Off.**—The blast: see page 37.
- Talbot Furnace.**—See page 316.
- Talbot Process.**—(1) For treating ingots: see page 64; (2) open hearth process: see page 316; (3) purification process: see page 384.
- Talbot and Stirling Process.**—See page 118.
- Tamping.**—(1) A molder's term which signifies the ramming up of the sand around a pattern; (2) stopping the tap hole of a cupola furnace with clay; the term is derived from the beating down a charge into a hole in blasting and mining operations (Horner).
- Tandem Continuous Mill.**—See page 409.
- Tandem Roughing Mill.**—See page 416.
- Tangential Stress.**—See page 332.
- Tank Converter.**—See page 20.
- Tank Cupola.**—See page 182.
- Tap.**—Of a furnace: see page 315.
- Tap Bar.**—See page 70.
- Tap Cinder.**—See Slag.
- Tap Hole.**—See page 311.
- Tap Wagon (obs.).**—A ladle of small size.
- Taper.**—Of a foundry pattern; draft: see page 296.
- Tappet.**—See page 411.
- Tappings.**—(1) In puddling: see page 377; (2) molten metal from the blast furnace (obs.); (3) of slag: see page 438.

Tapping Hole.—See pages 32 and 182.

Tapping Rod.—A rod or bar used to open the tapping hole of a furnace.

Tapping Slag.—See Slag.

Tardy Hydrate.—Of calcium chloride: see page 30.

Tarmac.—See Slag.

Taussig Furnace.—See page 164.

Taylor Process.—See page 380.

Taylor-White Process; Steel.—See page 446.

Teaming (obs.).—Teeming: see page 57.

Tear.—(1) Of metal which does not cut crisply, usually the fault of the tool; (2) the rupture of material in drawing, due to too heavy draft or to dirt or scale in the die.

Tearing Stress.—See page 336.

Technical Chemistry.—See page 81.

Tectotherm.—See page 267.

Tedge.—See page 299.

Teem; Teeming.—See pages 57 and 115.

Teeming Hole.—See page 115.

Telegraph.—A hook or pair of tongs suspended by a rod from a pulley running on an overhead beam or rail, and used for transporting small billets, puddle balls, etc.

Temper.—(1) Of crucibles: see page 112; (2) hardness, *q.v.*

Temper.—The percentage of carbon in steel (usually crucible steel) with special reference to the purpose for which it is suitable: **Razor temper**, 1½%; **saw-file temper**, 1⅜%; **tool temper (drill temper)**, 1¼%; **spindle temper**, 1⅛%; **chisel temper**, 1%; **set temper**, ⅞%; **die temper**, ¾%. Breaury ("Heat Treatment of Tool Steel," page 10) gives the following figures:

Die Temper	0.70-0.75 approx. carbon
Smiths' Tool Temper	0.80-0.85
Shear Blade Temper	0.90
General Purposes Temper	0.90-0.95
Axe Temper	0.95-1.05
Cutlery Temper	1.00-1.10
Tool Temper	1.20-1.30
Razor Temper	1.30-1.40

The content of carbon also may be roughly indicated by the terms **low temper steel**, **medium temper steel**, and **high temper steel**. **Irish temper** was a grade of cement bars formerly made containing about 0.3%.

Temper Carbon.—See pages 257 and 278.

Temper Casting.—See page 257.

Temper Graphite.—See page 257.

Temper Test.—See page 476.

Temper Tinting.—See page 288.

Temperability.—See page 227.

Temperature.—See page 199.

Temperature Colors.—See page 210.

Temperature of Combustion.—See page 203.

Temperature-Density Curve.—See page 225.

- Temperature Interval.—See page 265.
- Temperature Measurement.—See page 204.
- Temperature Stresses.—See page 333.
- Tempered Casting.—See page 257.
- Tempering.—(1) Of steel: see pages 212 and 230; (2) of molding sand: see page 296.
- Tempering Charge.—See page 233.
- Tempering Colors.—See page 230.
- Tempering Martensite.—See page 276.
- Tempering Plate.—See page 231.
- Tempering Temperature.—See page 230.
- Tenacity.—See page 330.
- Tender.—Brittle, *q.v.*
- Tensile Formulæ; Properties.—See page 337.
- Tensile Resilience.—See page 331.
- Tensile Strain; Strength; Stress.—See pages 330 and 333.
- Tensile Test.—See page 469.
- Tension; Tensional.—Tensile.
- Terminal Grain Boundary.—See page 283.
- Ternary Alloy.—See Alloy.
- Ternary Compound.—See page 88.
- Ternary Steels.—See page 443.
- Terne Plate.—See pages 371 and 432.
- Terre-Noire Process.—(1) For quenching: see page 229; (2) for tempering: see page 233.
- Terreault and Hilzinger Process.—See page 258.
- Terrestrial Iron.—See page 291.
- Tertiary Crystals.—See page 121.
- Tesseral System.—Of crystallization: see page 120.
- Tessular System.—Of crystallization: see page 120.
- Test.—See Furnace Test.
- Test Bar.—See page 70.
- Test to Destruction.—See page 467.
- Test Piece.—Influence of form: see page 473.
- Test Spoon.—See Spoon.
- Testing.—(1) In general, any method for determining the chemical or physical quality of material; (2) specifically (and as commonly understood), the determination by physical means (**physical testing**) of the suitability of a material for the purpose intended, and having no direct connection with the chemical composition or defects which properly belong under chemical analysis and inspection respectively; (3) in connection with ordnance material, the term **proving** (*e.g.*, proving ground) is employed, and for armor plate ballistically tested, the term **attacking**.
- Tests may be divided into two classes: (a) **destructive tests** (testing to destruction), where it is desired to learn the ultimate properties; and (b) **proof tests**, where it is desired to impose on material or objects, actually going into service, tests to determine that they are entirely suitable. Tests are commonly made on portions or samples selected to represent a given lot (**specimen tests**), usually tested to destruction, based on the well recognized assumption that material, or objects of such material, made

and treated at one time, is commercially uniform; they may also be made on entire objects (**full-size tests**), which may also be specimen tests. When made on built-up objects they are sometimes referred to as **structural tests**. Tests may be further divided, depending upon the nature of the stresses imposed, into (c) **static tests** or **slow tests**, and (d) **dynamic tests** or **impact tests**.

Composite structures, such as bridges, which are made up of many component parts of different sizes and properties, must be designed to support two kinds of loads: (a) **dead loads**, or the weight of the structure itself, including any permanent fixtures, and (b) **live loads** or **moving loads**, such as people or vehicles passing over it. A **uniform load** is one which is evenly distributed throughout the structure. A **concentrated load** is where one portion is more severely stressed than another, hence moving loads may also be referred to as **moving concentrated loads**. The load which the structure is designed to bear is called the **working load**, and the corresponding strength required, the **working strength**. This must always be less than the elastic resistance, and may be referred to as the **permissible working stress**, **safe range of stress** or **safe load**. As opposed to this, the ultimate strength is sometimes called the **absolute strength**. The factor obtained by dividing the ultimate strength by the total load is known as the **factor of safety**; French engineers, as a rule, base this factor on the elastic limit, which may be considered roughly as about one-half the ultimate strength, at least in the case of ordinary structural material. The **proof load** or **proof weight** is the load applied to determine the value of the material tested when it is not intended that observable deformation (or above a prescribed maximum value) shall take place (Thurston); the strength required for this is known as the **proof strength**, and is usually equal, or nearly so, to the maximum elastic resistance of the piece. The **proof strain** (**practical proof strain**) is determined by taking one-half of the intensity of the stress the piece can sustain, a certain maximum number of times, without injury.

By **bar** is understood a piece of uniform cross section. Its **cross sectional area**, used in computing certain values, is frequently referred to as **cross section**, **section area**, or simply **section**. A bar whose length is over about eight times its diameter or thickness is called a **column** or **strut** when subjected principally to longitudinal forces. If the forces act principally transversely, it is a **beam**, when it is supported near the ends, a **simple beam**; when it is supported at one end and near the middle, the other end being unsupported, a **cantilever beam**; and when supported at more than two points, a **continuous beam**.

While in some cases the specimen tests may be made on a finished object or section, such as a railroad axle or a piece of rail, yet ordinarily, as with plates and shapes, this cannot be readily done, and hence a relatively small sample or test piece is taken. Further as most testing is carried to destruction this prevents a large amount of good material from being wasted

unnecessarily. If the length of the test piece is parallel to the direction of rolling or the extension which the material has undergone, it is called a **longitudinal test piece**; if perpendicular, a **transverse test piece**.

Tensile Tests.—Also called **tension tests**, **pulling tests**, or, rarely, **traction tests**. These are by far the most common and are carried out by making the specimen fast at one end and applying a load (in the direction of its length) to the other end until it has been pulled apart. For material of very small cross section, such as wire, this is readily done by suspending weights to it (**hanging test**), but with larger sections requiring a great many thousand pounds to effect rupture, mechanical means must be employed. A **testing machine** consists essentially of **clamps**, **grips**, or **shackles** for holding the specimen; mechanism for applying the load to the specimen; a lever (**beam**) or other device for weighing or measuring the load; and a heavy frame for holding the various parts together. The machine is **vertical** or **horizontal**, depending upon the respective position in which the specimen is held. The power is usually furnished by an electric motor (the variable speed type is coming largely into use) or in some cases, particularly for very large machines of a million or more pounds capacity, it may be hydraulic. With the common type of machines it is measured in the same manner as with an ordinary scales by a **jockey weight** or **rider** which is run out along the graduated beam to keep it balanced; in the case of some hydraulic machines, such as used for testing eye bars, this may take the form of a mercury column which rises in a graduated tube. While the load is below the elastic limit, the rider must be moved forward at a uniform rate of speed, but when it is just exceeded the beam drops (**drop of the beam**, **fall of the beam**), and the corresponding reading is ordinarily taken to represent the **elastic limit** or more properly the **yield point**. Testing machines must be checked or **calibrated** at intervals to assure their accuracy. Inaccuracies may be due to worn or broken knife edges or to dirt or grease interfering with the sensitiveness, or to the beam or other part becoming bent or distorted. Calibration may consist in loading the platen with standard weights, or more frequently, to secure a greater range, an arrangement of levers is provided which multiplies (usually twenty or twenty-five times) the force exerted by the known load. The corresponding reading of the machine will indicate its degree of accuracy. **Standardization** is a term sometimes employed to designate the relative accuracy with another machine as determined by the comparative results of testing a number of similar pieces on each.

The term **elastic limit** is of such variable meaning that it is well to consider briefly its various synonyms and applications. T. D. Lynch ("Elastic Limit," *Proc. A. S. T. M.*, 1915) makes the following observation:

"We are accustomed to hear the free use of the following ten distinct terms, namely, (1) proportional limit, (2) elastic limit, (3) permanent set, (4) true elastic limit, (5) apparent elastic

limit, (6) commercial elastic limit, (7) elastic limit by extensometer, (8) elastic limit by drop of beam, (9) elastic limit by the dividers, (10) yield point.

"The first term, proportional limit, is very generally understood to be at point *P* on the curve (Fig. 60), and the tenth term, yield point, at the point *Y*, whereas the other eight designations are located on the curve more or less indefinitely between the points *P* and *Y*, depending upon the interpretation peculiar to different engineers."

(It will be noted that in the following additional terms are described.)

The following definitions have been adopted by the A. S. T. M.:

"Elastic limit is the greatest load per unit of original cross section which does not produce a permanent set. (This determination is rarely made in the commercial testing of materials.)

"Proportional limit is the load per unit of original cross section at which the deformation ceases to be directly proportional to the load. (This determination is rarely made in the commercial testing of materials.)

"Yield point is the load per unit of original cross section at which a marked increase in the deformation occurs without increase of load. It is usually determined by the drop of the beam of the testing machine or by the use of dividers."

Permanent set and true elastic limit are covered by the definition above for elastic limit. The **apparent elastic limit** as defined by a French commission was "the load per square mm. of the original section where the deformation begins to increase sensibly with no increase in the external force applied." It will be noted that this agrees with the A. S. T. M. definition for yield point. Johnson proposed to extend its meaning in accordance with the following definition: "The **apparent elastic limit** is the point on the stress diagram of any material in any kind of test, at which the rate of deformation is 50% greater than it is at the origin." This is commonly known as the **Johnson elastic limit**, and its method of computing is shown in Fig. 61. Johnson at first proposed for this the term **relative elastic limit**.

The **Scoble-Johnson apparent elastic limit** or **Scoble's yield point** is much the same and is determined (by a tangent method) by the point of intersection of those portions of the curve which represent respectively a state of perfect elasticity and of flow.

Commercial elastic limit is a term loosely used in the same sense as yield point. **Elastic limit by extensometer**, as its name indicates, requires the use of an instrument for determining the rate of stretch. It may actually correspond with the true elastic limit but more often signifies something approximating the proportional limit. **Elastic limit by drop of the beam** is calculated from the reading on the beam when it drops. The **elastic limit by dividers** in its ordinary sense is determined by fitting the points of a pair of dividers in the gage marks on the specimen, and taking the reading when one of the points no longer rests in its respective mark. A special method known as the **scribe or scriber method** is carried out as follows: With the

dividers set at the gaged length, and with one of the points resting in the punch mark, a fine scratch is made on the specimen with the other; after applying and removing the load corresponding to the specified elastic limit, a line is again scribed. If only one line is visible the material is recorded as having exceeded the requirement, if a difference of about 0.005" (for a 2" gaged length) is noted, the actual figure is recorded; with any greater difference or yield the test is considered to have failed. **Primitive elastic limit** is used by Rosenhain to indicate that the results with a material as originally tested may be altered if repeated after subsequent treatment. **Stretch limit** has been used in the same sense as yield point. The Engineering Standards Committee (British) states that "a steel test piece at the yield point takes rapidly a large increase of extension amounting to more than $\frac{1}{200}$ of the gage length." This is sometimes referred to as the **British or English yield point**. The **yield stress** corresponds to the state for which the stress-strain curve becomes parallel to

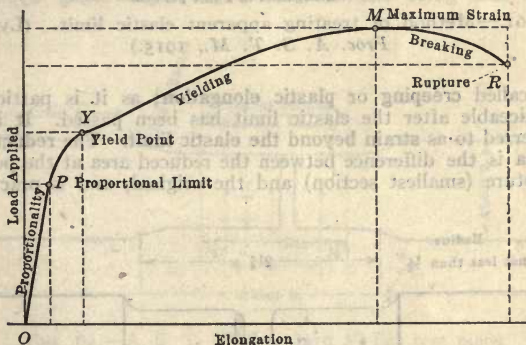


FIG. 60.—Stress-deformation diagram of a tension test.
(Lynch, *Proc A. S. T. M.*, 1915.)

the axis of strain. At the yield point the amount of strain depends to a certain extent on the length of time during which the load acts (Smith and Wedgwood).

An **extensometer** is an instrument for showing the amount (or rate) of stretch which the specimen undergoes during tensile test. In one form commonly employed it is called a **strain gage**. A **recording extensometer** or **autographic recorder** is an instrument arranged to draw a curve automatically. A **stress-strain** or **stress-deformation diagram** is a curve plotted with its coordinates as stress (load) and strain (deformation) respectively. When the elastic limit has been passed the rate of stretch is fairly uniform with increase in load until **necking** occurs, at which point the maximum load is registered on the beam (or otherwise), and it is then necessary to run the rider back a short distance if it is desired to register the load (**breaking load**)

at the moment of rupture; this term is frequently used improperly for maximum load. **Tonnage** (Eng.) is sometimes used for tensile strength (measured in gross tons per square inch). In a specimen being tested, continued extension from continued application of the same load, the **time** being an important factor,

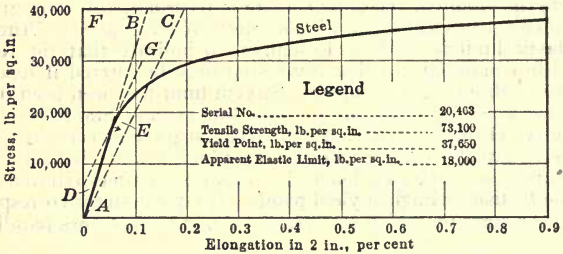
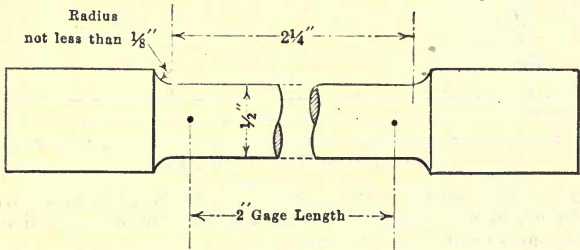


FIG. 61.—Method of treating apparent elastic limit. (Lynch—*Proc. A. S. T. M.*, 1915.)

is called **creeping** or **plastic elongation**; as it is particularly noticeable after the elastic limit has been passed. It is also referred to as **strain beyond the elastic limit**. The **reduction of area** is the difference between the reduced area at the point of rupture (smallest section) and the original, and is practically



Note: The Gage Length, Parallel Portions and Fillets shall be as shown, but the Ends may be of any Form which will Fit the Holders of the Testing Machine.

FIG. 62.—A. S. T. M. standard 2" turned test piece.

always expressed as a percentage; it is nearly independent of the gaged length. It may be expressed by the formula

$$R = \frac{a - a'}{a} \times 100$$

Where R = reduction of area percent;
 a = original cross-sectional area;
 a' = reduced cross-sectional area.

The test pieces are either round or rectangular in cross section. They may be cut from material as rolled, such as bars, in which case they are of sufficient length to provide space at the ends for gripping. For particular work, or if the material is inconveniently large, as in the case of forgings or other heavy objects, they are machined down to provide a middle portion of parallel section connected by fillets with collars or enlarged ends for holding in the machine. Upon the parallel section is laid off the length (gage length, gaged length) in which the elongation is to be measured, usually indicated by prick-punch marks (pop marks, datum points). In this country, for plates or similar flat material permitting of having two of the surfaces rolled, the specimen is usually rectangular (the other sides being machined or milled), with a gage length of 8", the thickness being that of the

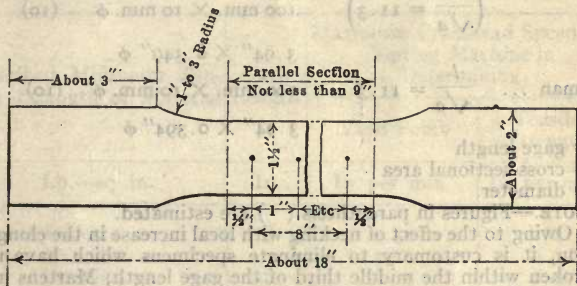


FIG. 63.—A. S. T. M. Standard 8" flat test piece.

given material; for turned specimens, cut from large pieces, the gage length is commonly 2", with diameter of $\frac{1}{2}$ ". The standard test pieces of the American Society for Testing Materials are shown in Figs. 62 and 63. The effect of form of the test piece must be taken into consideration, particularly as regards the elongation. It has been found approximately true that the same results will be secured by two test pieces if they are of identical dimensions or of similar form; this is known as Barba's law or the law of proportionality, or similarity. This is given by the formula

$$P = \frac{l}{\sqrt{a}}$$

Where P is the proportionality; l is the gaged length; and a is the cross-sectional area. The values of P in various standard test pieces are given in the following table:

Comparative Requirements for Elongation for Different Test Specimens

Name	Formula	Size	Comparative elongation, %
British.....	$\frac{l}{\sqrt{a}} = 4$	2" × 0.564" φ	(20)
U. S.....	$\left(\frac{l}{\sqrt{a}} = 4.5\right)$	2" × 0.505" φ	(18)
French.....	$\frac{l^2}{a} = 66.67$	100 mm. × 13.8 mm. φ	
	$\left(\frac{l}{\sqrt{a}} = 8.2\right)$	3.94" × 0.543" φ	(12)
Italian.....	$l = \frac{D}{10}$	5" × 0.5"	
	$\left(\frac{l}{\sqrt{a}} = 11.3\right)$	100 mm. × 10 mm. φ	(10)
German....		3.94" × 0.349" φ	
	$\frac{l}{\sqrt{a}} = 11.3$	100 mm. × 10 mm. φ	(10)
		3.94" × 0.394" φ	

l = gage length

a = cross-sectional area

D = diameter.

NOTE.—Figures in parenthesis () are estimated.

Owing to the effect of necking with local increase in the elongation, it is customary to eliminate specimens which have not broken within the middle third of the gage length; Martens has shown that in some cases the elongation for specimens breaking near one end, as compared with those breaking in the middle, has been lowered as much as 20%. It is pointed out by Martens (*Resistance of Materials*, Henning's trans., pp. 121-2) that elongation really consists of two parts: (a) the extension (nearly uniform) before local contraction or necking occurs, and (b) the local elongation due to such necking. He gives the following formula for determining the elongation for any gage length in the case of material of known properties:

$$e\% = 100 \left(\beta + \frac{e_c}{l_g} \right)$$

Where e = elongation, β = extension of unit length up to the moment of local contraction, e_c = extension during local contraction, l_g = gage length. This is of course not practicable for ordinary work, and a direct determination is the only accurate method for obvious reasons. Prof. Unwin also showed by experiment for turned test pieces, that if the value obtained by dividing the gaged length by the diameter was constant, the

elongation would be approximately constant. In the case of material like steel, the necking down has a material effect on the elongation; consequently, the difference in gaged length is more noticeable with pronounced local necking which occurs in the softer grades and especially in heat treated and alloy steels. With rectangular specimens, up to a certain point, the greater the ratio of width to thickness the higher the elongation. As regards other tensile properties, the strength, elastic limit, and reduction of area are not so greatly affected. The strength and elastic limit are increased by a sudden change of section, particularly where the specimen is short, such as a collar or shoulder without fillets or where a notch is cut in the piece. For a complete discussion treatises, such as those by Martens or Unwin, must be consulted.

The speed of testing, *i.e.*, the rate at which the machine is operated, principally affects the determination of the yield point. The speeds recommended by the A. S. T. M. are as follows:

Specified Minimum Tensile Strength of Material	Gage Length	Maximum Crosshead Speed for Testing Machine in Determining	
		Yield Point	Tensile Strength
Lb.—sq. in.	In.	In. per min.	In. per min.
80,000 or under	8	0.50	2.0
	2	2.00	6.0
Over 80,000	8	0.25	1.0
	2	0.50	2.0

After rupture the reduced dimensions, at the point of rupture, are measured for the purpose of determining the reduction of area; the two portions are then fitted accurately together and, from the increase in distance between the punch marks, the elongation, either actual or as a percentage, is calculated.

It is a well recognized fact that, for material of the same grade and treatment, as the strength increases the ductility decreases and *vice versa*. This is sometimes covered in specifications by the proportion or **inverse ratio** (which is approximately correct within certain limits) between them. Requirements according to this would be stated, for example, elongation, not less than $\frac{1,500,000}{T.S.}$; and reduction of area, not less than $\frac{2,400,000}{T.S.}$.

A device, known as a **weigh bar**, is sometimes employed where a completely equipped testing machine is not available. This is simply a bar of high elastic limit and large section which is calibrated as to extension (within its elastic limit) for different

weighed loads. The specimen to be tested is attached to one end and the free end of each attached to any machine capable of exerting tension. By measuring the extension on the weigh bar during the test a simple calculation will indicate the actual load applied.

Tensile properties may also be determined approximately by Brinell's ball-testing method (see below).

Compression tests may usually be made on the same type of vertical machine as used in tensile tests. As explained in Physical Properties the elastic limit is the true measure of strength of a ductile body owing to the flowing, with consequent increase of section, which results when this limit is exceeded. It is checked by a measuring device termed a **compressometer** similar to an extensometer. A **piezometer** is an instrument to determine directly the modulus of compression. Compression tests are also used to determine ductility in which case they consist in reducing a piece (either hot or cold) a certain proportion of its original height.

Hammer tests, or forging tests, are used to determine the malleability of metal; the sample is hammered (hot or cold) usually to a given fraction of the original thickness. In making a **scarfing test** one edge of a flat piece is hammered down at an angle, and no cracks must result. **Smithy tests** (Eng.) usually consist in heating a piece, splitting it a certain distance, and bending the ends outward into a ramshorn (**ramshorn test**); a hole may also be punched near the cut and drifted.

Bend (bending) tests are static tests to determine the ductility, and to a certain extent the toughness, of material, by bending a specimen over on itself, usually 180° but in some cases 90° , in the former case flat (for small and soft material) or in either case with a given curvature at the bent portion, frequently expressed as around a bar of stated diameter, D , or as a function of the thickness, t , of the piece, as $180^\circ D = 3t$. The specimen is required to meet this test without evidence of cracking on the outside of the bent portion (where the strain is greatest); in some cases, particularly relatively brittle or high elastic material such as springs, the test may be carried on until rupture occurs when the angle is measured by some form of protractor. A **nick bend test** is where a nick or notch is cut transversely in the specimen, usually on the outside of where the bend is to occur, sometimes on both sides or all around. This is used practically only in connection with fire box steel, when it is frequently referred to as **homogeneity test**. Bends may be of the following kinds:

1. **Cold bend:** specimen as manufactured with no subsequent treatment except shearing or machining.
2. **Hot bend:** Specimen heated to a cherry red, and tested at that temperature.
3. **Quench bend** (rarely called **temper test**): specimen heated to a cherry red and quenched in water before bending.

A test for the toughness and elasticity of wire, sometimes called **snarling**, consists in bending and twisting it backward and forward.

Transverse tests or **deflection tests** are usually employed in determining the elastic limit (and the transverse strength if the material breaks before bending too far) for such objects as leaf springs, carriage axles, etc. It consists in supporting the piece on bearings spaced a certain distance apart and applying the load at the middle; the stresses with corresponding strains (deflections) are then plotted, including any permanent set after each successive load has been applied and removed. A somewhat similar test, known as a **dead weight test** or **loading test**, is occasionally applied (e.g.) to rails; a full-size specimen is laid on supports a stated distance apart and has to sustain a given load a certain length of time without any permanent deflection after the load has been removed. "The **modulus of rupture** has a conventional meaning. It expresses in pounds per square inch the apparent maximum fiber stress, tension or compression, of a member transversely loaded, as it is just on the point of breaking; the stress being calculated by the common beam theory, with its three important assumptions which are known to be inaccurate above the elastic limit" (L. H. Fry).

Shearing tests consist in determining the stress required to shear or cut material, such as plates or bars; in some cases by applying shearing stresses to the rivets in riveted pieces. It is expressed per unit of area. **Punching tests** are another form of shearing tests, and usually consist in punching holes in a sample to determine the suitability of the material for this kind of work. It is rarely required to determine the actual resistance per unit of area. In connection with this a **drift test** is sometimes specified. This is performed by enlarging a punched hole a certain amount, without causing any cracks, by driving through it a tapered pin. A **torsion test** also involves shear. It consists in twisting the specimen, the actual load and the number of circular degrees being measured for the elastic limit and the ultimate strength respectively. The elastic limit may be checked by a **torsiometer** similar to an extensometer. The stress is a function of the cube of the diameter or thickness. In general results torsion tests agree closely with tensile tests although the actual respective figures may not be directly comparable except for standard test specimens.

For the latest information on detailed requirements and standard specifications the *Proceedings* and *Year Book* of the American Society for Testing Materials should be consulted.

Hardness Tests.—**Static indentation or pressing-in method.** **Brinell's ball-testing method** consists in measuring the indentation produced by forcing into the material a hardened steel ball of a definite size (usually 10 mm. in diameter) under a standard load (usually 500 Kg. for soft materials such as brass, and 3000 Kg. for hard materials such as steel). From the size of the impression the **hardness number**, H , can be calculated according to **Brinell's formula**:

$$H = \frac{2W}{\pi D (D - \sqrt{D^2 - d^2})}$$

W = load in Kg.; D = diameter of ball in mm.; d = diameter of impression in mm. **Benedick's formula**, for the same purpose is as follows:

$$H = \frac{L}{A} \sqrt[5]{\rho}$$

L = load in Kg.; A = superficial area of concave surface of indentation; ρ = radius of ball. In the table given below are the approximate relations between hardness number and tensile strength.

Guillery's method is similar to Brinell's, consisting in measuring the indentation produced by a small ball by the pressure exerted by Belleville springs under a determined deflection. **Foeppl's method** consists in testing the metal or substance with itself; two pieces are specially prepared and pressed together under a constant load, the indentation thus produced varying inversely as the hardness. **Ludwik's method** or cone test depends upon the impression produced by forcing in, under constant load a circular cone with 90° angular opening. The **Amsler-Laffon** machine employed a 90° rounded cone which is forced into the material under constant load and the depth of impression shown on a graduated scale by a needle indicator.

Dynamic Indentation or Driving-in Method.—**Shore's method** depends upon the use of an instrument known as a scleroscope which consists essentially of a small diamond-pointed hammer falling freely in a graduated glass tube from a constant height on the surface of the object, the hardness (or rather the elastic quality termed the **coefficient of restitution**) of which is measured by the height of the rebound. By multiplying the scleroscope number by 6 an approximate conversion to the Brinell number is secured; it must be borne in mind, however, that exactly the same qualities are not determined as one test is dynamic while the other is static. The **Keen impact ball tester** consists of a hardened ball secured at the end of a rod; this rod serves as a guide for a weight falling from a height of about 3 feet, the blow which it delivers serving to force the ball into the material upon which it rests. The amount of impression is then measured. The **Brinell meter** depends upon the comparison with a standard specimen by producing an impression by the blow from a hand hammer. The **Pellin hardness-testing machine** is a ball held in a weighted frame which is allowed to fall on the sample, and the diameter of the impression is measured. In **Frémont's method** a weight, with a specially shaped point, is allowed to fall on the object, and the indentation is measured. The **Ballantine method** is carried out with an instrument in which a cylinder of lead is supported on a cylindrical anvil, the lower end of which is pointed and rests upon the material to be tested. A weight or hammer is allowed to fall on the lead cylinder, and acts through it upon the anvil which is driven into the sample. The deformation of the lead is inversely as the hardness of the sample.

Abrasive Hardness or Surface Scratching.—**Moh's scale** was devised to determine the **relative hardness** of mineral substances, based on the fact that an object will scratch one of equal or less hardness, but not one which is harder (see page 480).

Table of Brinell Hardness Numbers and Estimated Tensile Strength for 3000 Kilogram Pressure on a 10 mm. Ball Testing Machine

Dia. of Impression in Mm.	Hardness Numerical.	Ultimate Pounds per Sq. In.	Dia. of Impression in Mm.	Hardness Numerical.	Ultimate Pounds per Sq. In.	Dia. of Impression in Mm.	Hardness Numerical.	Ultimate Pounds per Sq. In.	Dia. of Impression in Mm.	Hardness Numerical.	Ultimate Pounds per Sq. In.
2.00	946	465100	3.00	418	204100	4.00	228	112600	5.00	143	70200
2.05	898	442100	3.05	402	197300	4.05	223	109700	5.05	140	68700
2.10	857	421000	3.10	387	190800	4.10	217	106900	5.10	137	67200
2.15	817	402000	3.15	375	184600	4.15	212	104200	5.15	134	65800
2.20	782	383700	3.20	364	178800	4.20	207	101600	5.20	131	64500
2.25	744	366000	3.25	351	173200	4.25	202	99100	5.25	128	63100
2.30	713	350500	3.30	340	167800	4.30	196	96700	5.30	126	61800
2.35	683	335700	3.35	332	162700	4.35	192	94400	5.35	124	60600
2.40	652	321600	3.40	321	157800	4.40	187	92200	5.40	121	59400
2.45	627	308400	3.45	311	153100	4.45	183	90000	5.45	118	58200
2.50	600	295900	3.50	302	148600	4.50	179	87900	5.50	116	57000
2.55	578	284300	3.55	293	144300	4.55	174	85800	5.55	114	55900
2.60	555	273300	3.60	286	140200	4.60	170	83900	5.60	112	54800
2.65	532	262900	3.65	277	136200	4.65	166	82000	5.65	109	53700
2.70	512	253100	3.70	269	132400	4.70	163	80100	5.70	107	52700
2.75	495	243800	3.75	262	128800	4.75	159	78300	5.75	105	51700
2.80	477	235000	3.80	255	125300	4.80	156	76600	5.80	103	50700
2.85	460	226600	3.85	248	121900	4.85	153	74900	5.85	101	49700
2.90	444	218700	3.90	241	118700	4.90	149	73300	5.90	99	48800
2.95	430	211200	3.95	235	115500	4.95	146	71700	5.95	97	47900

Pressure = HARDNESS NUMBER
 Area of Impression = $\frac{\text{Pressure}}{1422.3}$ Factor to convert Kg. per sq. mm. to lbs. per sq. in.
 Tensile in Kg. per sq. mm. = coefficient .346 X Hardness number.
 V. Dept.

1. Talc.
2. Rock salt.
3. Calcite.
4. Fluorspar.
5. Apatite.
6. Orthoclase.
7. Quartz.
8. Topaz.
9. Corundum.
10. Diamond.

Behren's scale adapted for metals, and based on the use of sharp-pointed needles for testing, is as follows:

1.0,	Lead.
1.7,	Tin.
2.0,	Tin with iron.
1.5 to 2.2,	Hard lead.
2.5,	Zinc.
3.0,	Copper.
2.1,	Brass wire.
3.3,	Gun metal (bronze).
3.5,	Bronze with 12% tin.
3.7,	Bronze with 18% tin.
3.7 to 3.9,	Iron wire.
4.0,	Needles tempered yellow.
5.0,	Needles tempered blue.
5.0 to 5.5,	Sewing needles.
6.0,	Drill steel tempered yellow.
6.2 to 6.5,	Chrome steel.
7.0 to 7.3,	Ferro-chrome.

Certain of the materials, at least, are too variable to make this scale anything more than approximate.

Marten's test (**hardness tester**) depends upon the width of scratch produced by dragging across the surface of the material a diamond point under a definite load. **Turner's method** is similar to the above except it depends upon the weight necessary to produce a visible scratch; the instrument employed is termed a **sclerometer**. **Bauer's method** is based on the depth of penetration of a drill operating under constant conditions of speed and pressure. — **Keop's hardness test** is similar to Bauer's, an autographic record being taken of the progress of the drill. In **Jagger's method** an instrument called a **microsclerometer** is used. This is a small weighted drill provided with a diamond point, and the depth of the hole produced by drilling for a certain length of time (at constant speed) is measured. It is intended to be used in connection with a microscope for determining the relative hardness of the microscopic constituents of metals. **Wearing tests** may take the form of abrading a specimen under constant load by means of a grinding wheel or revolving disk covered with a suitable abrasive. Methods employed by **Saniter**, **Stanton** and **Norris** consist essentially in subjecting cylindrical specimens to a rubbing action by rotating them against other material.

Dynamic Tests.—Those in which the load is suddenly or repeatedly applied, as opposed to static tests where the load is gradually applied. They are usually divided into (a) **impact tests** where the test specimen is subjected to a blow, and (b) **endurance tests** where the stresses are repeatedly applied either in the same or in alternate directions. They are used to determine the **toughness** (or absence of brittleness) of material, particularly those going into moving parts which are subjected to such conditions in actual service. The tests may be carried out on full-size objects, such as car axles or pieces of rail, or on small sections cut out and especially prepared.

Impact Tests.—Also termed **shock tests**, **percussion tests**, **falling weight tests**, **drop tests**, **drop weight tests**, **hammer tests**, or **impact crushing tests**. Johnson says "The unit of measure in impact tests is the foot-pound (or the kilogrammeter). This energy cannot be measured in pounds, and no scheme of equivalents can be devised between the foot-pound units of an impact test and the pound units of a static test, although this has often been attempted. There is no relation between the resistance to shock and the resistance to a static load, since there is no relation between the total area of a stress diagram and its stress coordinate. The attempt which is often made, therefore, to equate these two kinds of resistance is as foolish as the ancient practice of estimating the discharge of stream, or aqueduct, or pipe, from its cross section alone." In bridge design, for example, the **coefficient of impact** is a number by which the calculated static stresses are multiplied in order to take care of the increase to be allowed for impact stresses. The specimen, either full-size or of reduced section, rests on supports a certain distance apart and the **hammer**, **tup** or **bob** strikes it midway. The specimen may be required to withstand one or more blows without rupture, or the energy (**striking** or **impact energy**) may purposely be made more than sufficient to effect rupture (**single-blow-test**), in which case the **residual energy** is measured, the difference representing the **absorbed energy**, indicating the energy of deformation, **work of deformation**, or **specific work of rupture**. Car axles are tested on a **drop test machine**, ordinarily resting on supports at a distance of 3 feet between centers, with a tup weighing 2240 pounds falling freely from a height which varies according to the size of the axle; they are turned 180° about their axis after the first, third, fifth, etc., blow, according to the number which must be withstood. Usually the **deflection** at the center, measured from a straight line between the journal collars, must not exceed a prescribed maximum after the first blow. Rails are tested in a similar manner, usually resting on their base; a deflection requirement is also customary. In some cases the ductility (**ductility test**) is determined by measuring the increase between marks previously placed on the base (or lower portion); a minimum percentage must be shown. Cast iron car wheels are sometimes tested on a **wheel breaker**, resting flange down on three supports spaced 120 degrees apart, the tup falling centrally on the hub, and a certain number of blows to be withstood

without rupture. A special form of impact test is what is known as **proof testing**. This consists in subjecting all the objects, before being accepted or placed in service, to a blow less than will produce any permanent distortion. This may take the form of a modified axle test or of allowing the object itself to drop from a specified height; it may also be struck with a hand hammer or sledge (**peening test**). The specimen is frequently cut away in some form of notch at the point where it is intended to break it. The resistance to rupture is therefore sometimes termed **notch toughness**. Owing to the variable results due to the different forms of notch and also the fact that it is very difficult to insure uniformity, a plain bar is preferred by many; McAdam, for example, recommends a plain bar to be sheared by the impact applied by a pendulum hammer (**impact shear test**); this introduces a single kind of stress instead of a combination, and in addition to avoiding slight variables in the notch is much simpler to carry out.

Of the tests producing rupture one of the best known is the **Charpy test**, which employs a machine of that name, also termed the **Charpy pendulum hammer**; the difference in swing (number of degrees), after passing the lowest point, when a specimen is broken from what would have occurred without, is the measure of the absorbed energy. The **Frémont machine** is similar in principle, the tup, however, falling vertically, and the residual energy being measured by means of a scale and indicator. Other similar tests of the **one-blow method** are those of **Russell, Izod, and Seaton**; tests of the **many-blow method** include those of **Breuil, Yarrow, Seaton and Jude, Brinell and Wahlberg, Ruelle, and Stanton**.

Endurance Tests.—Also termed **fatigue tests, vibratory tests or repetitive stressing**. In **Wöhler's** tests the specimen was not loaded beyond the elastic limit and the stresses might be applied all in one direction (from zero to a maximum, or from one load to a greater load), or first in one direction and then in the other (as from tension to compression). The number of repetitions or alternations of different stresses to produce rupture served to indicate the fatigue properties of the material in question. Where an infinite number of repetitions would be necessary with a certain stress, below that figure is sometimes termed the **Wöhler range** of entire resistance to fatigue. The specimens are usually not stressed beyond the elastic limit, although in some forms of test such is the case. The piece may be vibrated by a reciprocating or rotational movement. Machines and tests have been devised for alternate bending by **Stead, Sankey, and Amsler-Laffon**; for rotational stresses by **White and Souther**; for vibration by **Arnold**, etc.

Miscellaneous Methods.—**Ballistic tests**, also termed **fring tests and proof tests**, are employed in connection with armor plate and projectiles. The armor plate must withstand the **attack** of the prescribed number of standard projectiles, and the projectiles, depending upon their type, must meet various conditions, such as the penetration of a certain thickness of armor,

break up on detonation into a minimum number of fragments (**fragmentation test**) etc., in addition to resisting deformation while in the gun. It was at one time common practice to take a sample billet from each heat and roll it down into a round of about $\frac{3}{4}$ " in diameter, from which pieces were taken for tensile tests which were considered as indicative of the qualities of the other material produced. This was known as the **billet test**, but has been abandoned as not truly representative. A **comparator** is an instrument for determining the coefficient of expansion of solids by comparison with a standard. A **conductometer** is an instrument for determining conductivity for heat, electricity, etc. A **dilatometer** is an instrument to measure changes in volume on heating or cooling.

Ductility Tests.—In addition to those described elsewhere, the following might be mentioned. A British method is to specify the sum of the elongation (in percent) and the tensile strength (in gross tons) to be not less than a given value; for example, with a range in tensile strength of 35 to 40 tons the actual tensile strength plus the elongation (percent in 2") must be not less than 60. The **Tetmayer formula** (or a similar requirement) sometimes found in foreign specifications, is that the product of the elongation (in millimeters) in a length of 200 millimeters, and the tensile strength (in kilograms per square millimeter) must equal or exceed, say 750. A **ductilimeter** is the term sometimes applied to an instrument to measure ductility. A **dynamometer** is an instrument to measure the amount of work developed as in the case of an engine, motor, etc. For example, a form known as a **Prony brake (brake test)** to determine the horse power which an engine can develop consists in clamping a frictional brake to the fly wheel or shaft so tightly that it can barely revolve; the torque is counterbalanced by weights. **Keep's tests** were suggested by him as a method for a mechanical analysis of the properties of cast iron based on the variations in the amount of shrinkage caused by different amounts of silicon present. The **nick and break test (fracture test)** sometimes used for rails, consists in nicking and breaking a piece for the purpose of detecting any internal flaws or defects by a visual examination. The **oncosimeter** is a special form of instrument in which the force acting on a metal ball suspended in a molten metal by a spiral spring is measured; in this way it was shown that gray cast iron and bisumth expand on solidification, while copper, silver, lead, tin, and zinc contract (Desch). A test referred to as a **ringing test, resonance test, or sonority test**, consists in striking an object (sometimes while suspended) with a small hammer or piece of metal to determine by the sound produced whether any internal flaws or unsoundness exist. The **schiseophone** was a modification of Prof. Hughes' induction balance, designed for detecting flaws in rails, etc. A core is reciprocated longitudinally within a coil and caused to strike the object. A continuous current from a battery is sent through this coil, which is connected with one of the coils in the induction balance. The other coil on the balance is adjusted to reduce or abolish the sound in the

telephone. When the core strikes the object near a flaw, it is claimed that the difference in the quality of the sound is readily detected. A **shrinkage test** (as applied to rails) is a requirement that, after hot sawing, the shrinkage shall not exceed a specified amount varying with the ordered (cold) length and the weight or design of the section. The **spark test** is a method worked out by J. F. Keller for distinguishing different metals, particularly different types and grades of iron and steel, by the appearance and nature of the spark thrown off when a sample is held against a grinding wheel, or produced by similar means. The **stremmatograph** is an instrument devised by Dr. P. H. Dudley to measure the stresses and record the effect on the rails caused by a passing train. Cast iron is usually tested transversely with an **arbitration bar** (designed and advocated by the American Foundrymen's Association), $1\frac{1}{4}$ " in diameter and 15" long, which is cast from a sample of the metal in a special mold under prescribed conditions. In testing, the supports are 12" apart, the load applied at the middle, and the deflection at rupture (**cross breaking strength**) noted.

- Testing Machine.**—See page 469.
Tetarto Prismatic System.—Of crystallization: see page 120.
Tetmayer Formula.—See page 483.
Tetrad.—See page 86.
Tetragonal System.—Of crystallization: see page 120.
Tetratomic.—See page 87.
Tetravalent.—See page 86.
Texture.—See page 125.
Thalpotassimeter.—See page 210.
Theodossief Process.—See page 230.
Theoretical Chemistry.—See page 81.
Thermal Analysis.—See page 284.
Thermal Capacity.—See page 201.
Thermal Chemistry.—See page 82.
Thermal Conductivity.—See page 200.
Thermal Crack.—See Crack.
Thermal Equilibrium.—See page 327.
Thermal Metamorphism.—See pages 122 and 271.
Thermal Method.—Of determining critical points: see page 265.
Thermal Refining.—See page 213.
Thermal Resistance.—See page 200.
Thermal Stability.—See page 275.
Thermal Transformation.—See page 326.
Thermal Treatment.—Heat Treatment.
Thermal Unit.—See page 199.
Thermally Metastable State.—See page 281.
Thermit (Thermite); Process; Weld.—(1) For reducing metals: see Goldschmidt Process; (2) for producing sound ingots: see page 61; (3) for welding: see page 504.
Thermochemistry.—See page 82.
Thermo-couple.—See page 208.
Thermo-elastic Properties.—See page 330.
Thermoelectric Couple.—See page 208.

- Thermoelectric Method.**—For determining critical points: see page 266.
- Thermoelectric Pair.**—See page 208.
- Thermoelectric Pyrometer.**—See page 208.
- Thermoelectric Telescopes.**—See page 207.
- Thermo-element.**—See page 208.
- Thermogage, Morse.**—See page 207.
- Thermograph.**—See page 205.
- Thermolabile.**—See page 204.
- Thermolysis.**—See page 82.
- Thermo-magnetic Selector.**—See page 210.
- Thermo-metallurgy.**—See page 82.
- Thermometer.**—See page 205.
- Thermometric Conductivity.**—See page 200.
- Thermometric Heat.**—See page 199.
- Thermometric Scales.**—See page 204.
- Thermometrograph.**—See page 205.
- Thermometry.**—See page 205.
- Thermoneutrality.**—Law of: see page 201.
- Thermophone, Wiborgh's.**—See page 210.
- Thermopile.**—See page 207.
- Thermoradiometer.**—See page 205.
- Thermoscope.**—See page 205.
- Thermostable.**—See page 204.
- Thermo-tension.**—Subjecting red hot metal to high tensile stress which is maintained during cooling.
- Thicken.**—To expand the end of a tube which is to be threaded, by an amount equal to the depth of the thread.
- Thickness.**—(1) Of plates: gage; (2) of molten slags, etc.; the degree of viscosity or fluidity.
- Thiel Process.**—See page 388.
- Thin Lined Blast Furnace.**—See page 27.
- Thiosulphate Process.**—See page 96.
- Third Order Cells.**—See page 121.
- Thomas Converter.**—See page 24.
- Thomas or Thomas-Gilchrist Pig Iron.**—See pages 343 and 346.
- Thomas-Gilchrist Process.**—See page 15.
- Thomas (G. C.) Process.**—See page 73.
- Thomas (J. W.) Process.**—See page 319.
- Thomas (S. G.) Process.**—See page 15.
- Thompson Process.**—See page 118.
- Thomson Effect.**—See page 209.
- Thomson Process.**—See page 503.
- Thorn.**—See page 128.
- Three-high Mill.**—See page 408.
- Three-pass Stove.**—See page 34.
- Threw Pyrometer.**—See page 210.
- Throat.**—Of a blast furnace: see page 27.
- Thurston's Formulæ.**—For tensile strength: see page 339.
- Thundergust Forge (obs.).**—An irreverent term formerly applied to forges blown with a trompe.
- Thwing Pyrometer.**—See page 207.

- Tiemann's Formula.**—For quality: see page 341.
- Tilt Hammer.**—See Hammer.
- Tilt (Tilted) Steel.**—Steel hammered with a tilt hammer; the term is now restricted to blister steel which has been hammered.
- Tilter.**—See page 411.
- Tilting Converter.**—See page 17.
- Tilting Furnace.**—See page 312.
- Tilting Table.**—See page 408.
- Time.**—Influence of on strain beyond the elastic limit: see page 472.
- Timp.**—See page 32.
- Tin.**—Sn; at. wt., 119; melt. pt., 228° C. (442° F.); sp. gr., **crystal-line**, 7.2, **amorphous**, 5.8. It is not found in the free state. When pure it is a white, soft, ductile metal. It is not readily oxidized at ordinary temperatures and, for this reason, either alone or alloyed with lead, is used for coating sheets (see pages 429, 432). It combines with iron in all proportions, but these alloys are not of importance (see page 453), and ordinarily it occurs in steel only as an impurity.
- Tin Bar.**—See page 429.
- Tin Mill.**—See page 430.
- Tin (Tinned) Plate; Sheet.**—(1) General: see page 429; (2) manufacture of: see page 431.
- Tin Plate Bar.**—See page 429.
- Tin Plating.**—See page 371.
- Tin Pot; Tinning Pot.**—See page 431.
- Tin Steels.**—See page 453.
- Tinman's Pot; Wire.**—See page 432.
- Tinting.**—Heat tinting: see page 288.
- Tintometer.**—An instrument for matching colors, *e.g.*, in colorimetric determinations.
- Tipping Converter.**—See page 17.
- Tipping Furnace.**—See page 312.
- Titanate Ore; Titanic Iron Ore.**—See page 245.
- Titanium.**—Ti; at. wt., 48.1; melt. pt., 3000° C. (5432° F.); sp. gr., 3.54. It is never found uncombined. The pure metal is very hard to produce on account of its great affinity for oxygen and nitrogen, and is merely a chemical curiosity. It is obtained as an alloy with iron, called ferro-titanium (see page 355), and is used to a certain extent as an addition to steel; it alloys with iron in all proportions.
- Titanium Steels; Titanium-treated Steels.**—See page 453.
- Ton.**—Owing to the different kinds of ton it is always necessary to specify which one is intended, and it is well to give the equivalent in pounds avoirdupois as well as the name. The names and values are as follows: **short or net ton**, 2000 pounds; **long or gross ton**, 2240 pounds (this is the British standard, and is always meant when "ton" is referred to in British publications); a **special long ton** of 2268 pounds, sometimes used for sand cast pig iron, 1¼% above the ordinary long ton being added to represent approximately the adhering sand; **double gross ton** (obs.), 2464 pounds, a weight 10% above that of the ordinary long ton; **metric ton**, 1000 Kg., equivalent to 2205 pounds, nearly.

- Tonnage** (Eng.).—See page 472.
- Tool Steel**.—See page 445.
- Tool Temper**.—See Temper.
- Top**.—(1) Of a blast furnace: see page 27; (2) of an ingot or piece: see page 115.
- Top Casting**.—See page 57.
- Top Cut; Discard**.—See Discard.
- Top Heating; Insulation; Lag**.—Of ingots: see page 59.
- Top Pouring**.—See pages 57 and 299.
- Top Pouring Ladle**.—See Ladle.
- Top Replenishment**.—See page 59.
- Torpedo**.—In blast furnace practice: see page 35.
- Torrified**.—See page 73.
- Torsiometer**.—See page 477.
- Torsion**.—See page 330.
- Torsion Test**.—See page 477.
- Torsional Resilience**.—See page 331.
- Torsional Strength**.—See page 330.
- Total Carbon**.—See Carbon.
- Total Cementation**.—See page 67.
- Total Cementite**.—See page 273.
- Total Ferrite**.—See page 272.
- Total Heat**.—See page 202.
- Tough Fracture**.—See page 178.
- Tough Hardening**.—See page 232.
- Tough Hardness**.—See page 452.
- Toughened Cast Iron**.—See Semi-steel.
- Toughening**.—See pages 230 and 232.
- Toughness**.—See pages 331 and 481.
- Tourangin Process**.—See page 147.
- Track Scales**.—Heavy scales for weighing railroad cars.
- Traction Test**.—See page 469.
- Train**.—Of rolls: see pages 406 and 409.
- Transcarburization**.—See Carbon.
- Transcrystalline Deformation**.—See page 282.
- Transcrystalline Fracture**.—See page 178.
- Transcrystalline Rupture**.—See page 282.
- Transfer Caliper**.—See page 187.
- Transfer Process**.—See page 21.
- Transference**.—See page 81.
- Transference of Heat**.—Law of: see page 221.
- Transformation; Curve**.—See pages 81 and 326.
- Transformation Point**.—See page 264.
- Transformation Strains**.—See page 332.
- Transfusion**.—Repouring: see page 21.
- Transition**.—See pages 81 and 271.
- Transition Point**.—See page 264.
- Translation**.—See page 81.
- Translation Banding**.—See page 127.
- Transmutation**.—See page 81.
- Transpiration Pyrometer**.—See page 210.
- Transverse Deformation**.—See page 337.

- Transverse Rolling.**—See page 414.
- Transverse Rupture.**—See page 336.
- Transverse Seam.**—See Seam.
- Transverse Strain.**—See page 337.
- Transverse Strength.**—See page 330.
- Transverse Test.**—See page 477.
- Transverse Test Piece.**—See page 469.
- Treading; Treading Floor.**—In the manufacture of crucibles: see page 112.
- Treatment Crack.**—See page 222.
- Treatment for Grain Size and Carbon.**—See page 218.
- Trebles.**—Of sheets: see page 433.
- Tree-like Crystals.**—See page 122.
- Tressider Process.**—(1) Armor plate: see page 9; (2) heat treatment: see page 230.
- Triad.**—(1) In chemistry: see page 86; (2) in meteorites: see page 291.
- Trial Bar.**—See page 70.
- Triatomic.**—See page 87.
- Triaxial Diagram.**—See Curve.
- Tribasic.**—See page 87.
- Triblet (Eng.).**—(1) A smith's tool, being a round rod, slightly tapered, which is used as a mandrel around which rings and nuts are finished upon the anvil; (2) the steel core upon which tubes are drawn to produce a smooth interior surface of uniform diameter (Horner).
- Trick, Davis, Daniel, and Phillips Process.**—See page 380.
- Triclinic System.**—Of crystallization: see page 120.
- Triclinohedral System.**—Of crystallization: see page 120.
- Trimetric System.**—Of crystallization: see page 120.
- Trimorphism.**—See page 121.
- Trio Mill.**—See page 408.
- Trip Hammer.**—See Hammer.
- Tripartite Nature of Metals.**—See page 127.
- Triple-melting Process.**—See page 75.
- Triplex Process.**—Sometimes applied to a process involving refining in three stages as (a) acid Bessemer, (b) basic open hearth, and (c) basic electric.
- Trivalent.**—See page 86.
- Troilite.**—See page 292.
- Trolley.**—(1) A two-wheeled truck for carrying puddle balls, etc.; (2) on an electric crane, the part carrying the hoisting drum which runs back and forth.
- Troostite.**—See page 276.
- Troosto-Sorbite.**—See page 277.
- Troostitic Martensite.**—See page 276.
- Tropenas Converter; Process.**—See page 24.
- Trosca Process.**—See page 147.
- Trough (Eng.).**—Same as pot in the cementation process, *q.v.*
- True Calorie.**—See page 199.
- True Elastic Limit.**—See page 470.
- True Fusion.**—See page 201.

True Pearlite.—See page 273.

True Stress.—See page 332.

True Welding.—See page 501.

Trunnel Head.—See page 95.

Tschernoff's Point.—See page 265.

Tschernoff's Process.—See page 233.

Tuaran (obs.).—Tuyere.

Tub (obs.).—Ladle.

Tubes; Tubing.—Tubes or pipes are long hollow metallic cylinders. The technical distinction between the two is that tubes are rated according to the outside, and pipes according to the inside, diameter but, in general, the two terms are used interchangeably. **Cast iron pipe** is necessarily cast in molds, the center being cored out. **Welded and riveted pipes** are made from plates of steel or wrought iron called **skelp** which are rolled up longitudinally into shape and the edges welded or riveted together. **Close-jointed skelp** is the name sometimes given to a tube in which the edges of the skelp are brought close together, but are not fastened. If the skelp is bent into form spirally, depending upon the method of fastening the edges, it is known as **spirally welded or spirally riveted pipe**. In the welding, depending upon whether the edges simply come together, or overlap, **butt welded or lap welded pipe** is produced, the former being generally restricted to sizes up to about 3" in diameter, while the latter method is used for sizes up to 36". The line of the weld is frequently called the **seam**.

Butt Welding.—The process of butt welding consists in drawing the highly heated skelp through a die or bell having an opening of the exact size of the outside of the pipe, which serves to bend the skelp into form and at the same time produce the pressure necessary for effecting the weld. In modern practice tongs are thrust through the bell and grip the end of the skelp which has previously been cut to a tapered point, the other end of the tongs being attached to a buggy or carriage moved forward by an endless chain. The bell is kept in position by resting against a stop. In the old method, known as **tag butt welding**, in place of the tongs, a rod was welded directly to the end of the skelp, being subsequently cut off.

A **falling seam** is a depression on the top (outside) of the weld due to scant width of skelp; a **deep seam** is somewhat similar, but the depression occurs on both sides, due to round edges on the skelp.

Lap Welding.—In this method the edges of the skelp are usually slightly beveled or tapered (**scarfed**) so when they overlap there will not be too great an excess of metal. The skelp in this case is always bent (hot) to form in a separate operation called **piping** (rarely **skelping**). Formerly a machine called a **skelper** (from which the word **skelp** is derived) or **crocodile** was employed, consisting of a semi-circular trough on which the skelp was laid, a round-nosed plunger forcing it down. It was then removed and bent further into a circle. In modern practice this bending is done in a set of three bending rolls, one roll being placed between and slightly above two other

rolls, the height depending upon the diameter of the pipe. In welding, as one edge of the skelp is on top of the other, two rolls, with grooves corresponding to the exact diameter of the pipe, are provided for supplying the necessary pressure which is resisted on the inside of the pipe by a mandrel or ball having the exact diameter of the inside of the pipe, and held in place by a rod. Where the ball is on the same side as that on which the pipe enters the rolls, the operation is called **rolling off**; if on the opposite side, **rolling on**. For certain purposes, such as boiler tubes, where the pipe is to be subjected to high internal pressure, the whole welding operation may be repeated, the product then being known as **rewelded pipe**.

After welding, both butt and lap welded pipes are made perfectly round by passing them through a set of grooved rolls, called **sizing rolls**, and are then made straight by passing them through the **straightening rolls**. Tubes which are straightened hot, particularly the larger sizes, are usually put through **cross rolls**, consisting of two concave rolls, one above the other, and with their axes set at an acute angle. They both revolve in the same direction, which causes the pipe to rotate very rapidly and at the same time to move slowly forward. The pipes are then cooled on some form of cooling bed, cut to length, etc. Another form of straightening machine is like an ordinary gag press. There are two grooved rollers over which the pipe is run, and a third roller, spaced between the other two, is brought down on the top of the pipe to take out any curvature. A third type has one set of vertical and one set of horizontal grooved rollers, of about six each, and spaced the right distance apart for the given diameter of pipe.

Rified pipe is a kind recently introduced for use in the transmission of oil. It has spiral laminations rolled in it which give the oil a whirling motion, a certain amount of water which is present being thereby thrown to the periphery and lessening the friction. **Perrins process** for making welded tubes consists in first rolling puddled bars into a trough section, which are then piled together in tubular form, with the longitudinal abutting edges placed so as to break the joint, and the pile is then rolled into a tube.

Seamless or weldless tubes are always manufactured of steel on account of the great homogeneity necessary. They are generally made from solid round billets which are heated and then pierced by a mandrel (no longer drilled on account of the cost), after which they are rolled over mandrels to obtain the proper diameter and thickness of wall, much in the manner already described for lap welding, except that a number of passes are necessary. There are two methods of piercing: (a) in the **Mannesmann process** a pair of special conical rolls (**pilger rolls**), both of which revolve in the same direction, rotate the billet very rapidly and at the same time drive it slowly forward over a pointed mandrel situated between them. The action here is very peculiar, as the hole is not produced by the mandrel but by the rolls which, by exerting a pressure on the billet at two

diametrically opposed points, continuously changing, cause a central cavity to open up, the mandrel serving simply to open up the end and smooth the interior. This phenomenon is known as **internal rupture** and may also be produced by hammering. A different style of rolls to effect the same result has been designed

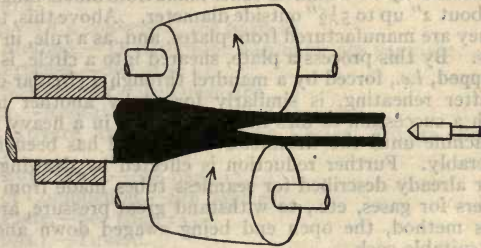


FIG. 64.—The Mannesmann process for rolling weldless steel tubes.

by R. C. Stiefel. (b) In the Erhardt process a round-nosed mandrel is forced longitudinally through a square billet enclosed in circular dies, the difference in cross-sectional area between the two giving the space necessary, for the metal displaced into the wall of the billet by the mandrel. Tubes so produced may be hot or cold drawn to final size, the principle being the same as in

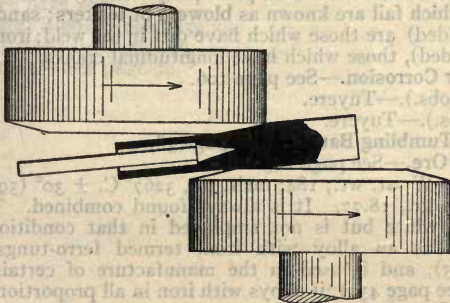


FIG. 65.—The Stiefel process for rolling weldless steel tubes.

wire drawing; but since a tube is hollow, it must be drawn over a mandrel to prevent it from being crushed. In cold drawing the tube is first pickled in a bath of dilute sulphuric acid, heated by steam, to remove all scale which if left would spoil the surface and scratch the dies. It is then rinsed in water and drawn without further treatment. Tallow and sawdust, or some other

form of lubricant, are used both outside and inside. The tube must be **annealed** and pickled after each drawing. For ordinary purposes two drawings are usually sufficient, but for very thin walls seven or eight may be required. With **cold drawing** the operation is rarely commenced before the walls have been reduced to $\frac{3}{8}$ " ; with hot drawing the thickness of the walls is not generally carried below $\frac{1}{4}$ ". Seamless tubes made from billets range in size from about 2" up to $5\frac{1}{2}$ " outside diameter. Above this, to about 20", they are manufactured from plates, and, as a rule, in shorter lengths. By this process a plate, sheared into a circle, is heated and **cupped**, *i.e.*, forced by a mandrel through a circular die, and then after reheating, is similarly forced by another mandrel through a succession of dies held in position in a heavy trough-like machine until the thickness of the wall has been reduced considerably. Further reduction is effected by drawing in the manner already described for seamless tubes made from billets. Cylinders for gases, etc., to withstand great pressure, are made by this method, the open end being swaged down and fitted with a suitable cock.

Robertson's process is a method for producing seamless tubes (somewhat similar to Erhardt's) by piercing longitudinally a blank fitting a die, a pressure plate being held against the far end to prevent the mandrel from tearing the piece. The further rolling is as usual.

The **Kellogg process** is also for producing seamless tubes, and consists in casting an ingot with a hollow center. This is put over a mandrel and rolled out until the wall is of the desired thickness.

Finished tubes are tested principally with hydraulic pressure. Those which fail are known as **blowers** or **leakers**; **sand blowers** (lap welded) are those which have dirt in the weld; **iron blowers** (lap welded), those which have longitudinal cracks.

Tubercular Corrosion.—See page 106.

Tue Iron (obs.).—Tuyere.

Tuiron (obs.).—Tuyere.

Tumbler; Tumbling Barrel.—See page 58.

Tungstate Ore.—See page 245.

Tungsten.—W; at. wt.; 184; melt. pt., 3267° C. $\pm 30^{\circ}$ (5913° F. $\pm 54^{\circ}$); sp. gr., 18.77. It is always found combined. The pure metal is white but is not employed in that condition. It is obtained as an alloy with iron, termed ferro-tungsten (see page 355), and is used in the manufacture of certain special steels (see page 450); it alloys with iron in all proportions.

Tungsten-Chrome Steels.—See page 450.

Tungsten Hardenite.—See page 275.

Tungsten Steels.—See page 450.

Tunnel Head.—See page 34.

Tunnel Kiln Process.—See page 44.

Tap.—(1) Of a hammer: see page 195; (2) of a drop test machine: see page 481.

Turbo Blowers.—See Blowing Engines.

Turgite.—See page 244.

- Turk Process.**—See page 420.
- Turn.**—A working period, also the men composing one shift. A plant running on **single turn** works for ten to twelve hours per day; **double turn**; two shifts of twelve hours each; **triple turn**: three shifts of eight hours each.
- Turn Down.**—(1) Of a converter: see page 17; (2) in rolling: see page 412.
- Turn Up.**—Of a converter: see page 20.
- Turner Method.**—To determine hardness: see page 480.
- Turner Process.**—See page 61.
- Turner Sclerometer.**—See page 480.
- Turnover.**—Repeater, in rolling: see page 416.
- Tuyere; Tuyere Arch; Tuyere Arch Cooler; Tuyere Block.**—See page 31.
- Tuyere Box; Brick.**—See page 17.
- Tuyere of Combustion.**—See page 24.
- Tuyere Plate.**—See page 135.
- Tweer (obs.).**—Tuyere.
- Twere (obs.).**—Tuyere.
- Twin; Axis; Crystal.**—See page 124.
- Twinning; Axis; Law.**—See page 124.
- Twinning Plane.**—See page 123.
- Twisted Guide.**—See page 412.
- Two-high Mill.**—See page 408.
- Two-pass Stove.**—See page 34.
- Twyer; Twyere (Eng.).**—Tuyere.
- Twynam Process.**—(1) Direct process: see page 147; (2) for steel: see page 319.
- Tying.**—See page 300.
- Typ; Plate; Stone.**—See page 32.
- Type.**—Of steel: see page 455.
- Tyrol Process.**—See page 79.

U

- U.**—Chemical symbol for uranium, *q.v.*
- U. S. Gage.**—(1) Standard for sheet and plate iron, and steel: see page 188; (2) for steel wire: see page 188.
- Uchatius Process.**—See page 113.
- Uehling Process.**—See page 388.
- Uhling-Steinbart Pyrometer.**—See page 209.
- Ultimate Analysis.**—See page 82.
- Ultimate Shortening.**—See page 336.
- Ultimate Strength; Stress.**—See page 335.
- Ultimate Structural Composition.**—See page 337.
- Ultramicroscopic.**—See page 284.
- Uncombined Carbon.**—See Carbon.
- Underburdened.**—Of a blast furnace: see page 34.
- Undercooling.**—See page 268.
- Undercut.**—Of patterns: see page 296.
- Understrained Ferrite.**—See page 216.
- Unequal Cooling.**—See page 222.
- Unequal Heating.**—See page 223.
- Uneven Fracture.**—See page 179.
- Unicellular Structure.**—See page 126.
- Uniform Load.**—See page 468.
- Uniformity.**—In heat treatment: see page 212.
- Unit Crystal.**—See page 122.
- Unit Stress.**—See page 333.
- United States Gage.**—(1) Standard for sheet and plate iron and steel: see page 188; (2) for steel wire: see page 188.
- Univalent.**—See page 86.
- Universal Mill.**—See pages 408 and 413.
- Unsatisfied.**—See Satisfied.
- Unsaturated Steel.**—See page 273.
- Unsegregated Pearlite.**—See page 276.
- Unstable Crystallographic Equilibrium.**—See page 217.
- Unstable Equilibrium.**—See page 326.
- Unstressed.**—See page 332.
- Uphead.**—See Upset.
- Upset.**—To enlarge the cross-section of a piece of metal at one end by striking or pressing that end; to uphead.
- Upper Freezing Point.**—See page 267.
- Uptake.**—(1) In an open hearth furnace: see page 310; (2) in a gas producer, the passage connecting the combustion chamber with the gas main.
- Upton's Equilibrium Diagram.**—See page 272.
- Uranium.**—U; at. wt., 138.5; melt. pt., 800° C. (1472° F.); sp. gr., 18.7. It is not found free in nature. When pure it is a heavy

white metal. It has recently had some application as an addition to steel (see Special Steels, p. 453).

Uranium Steels.—See page 453.

Uses (Eng.).—A rough block (reduced from an ingot) to be made into small forgings, or ready to be machined to final form.

Utricular.—See page 120.

V—(1) Volume; (2) chemical symbol for vanadium (V).
 of Binnell; see page 205.
 V-weld—see page 202.
 Vacuum Casting—see page 61.
 Vacuum Gases (Howe)—Those obtained on heating metal in
 vacuo.
 Vacuum Inverse—see page 21.
 Valence; Valency—see page 205.
 Valence Formula—see page 20.
 Valency Theory.—Of passivity; see page 204.
 Van Allen Process—see page 272.
 Van der Waals' Formula.—See Gas.
 Van Riet Process—see page 202.
 Vanadium.—V; at wt. 51.1; melt. pt. 1850° C. (3350° F.).
 It is a comparatively rare element and is always
 found combined. When pure it is a white metal having
 great affinity for oxygen and nitrogen. Owing to the discovery
 of large mineral deposits it has recently come into considerable
 use in the manufacture of special steels (see page 453); it alloys
 with iron in all proportions and is obtained commercially as
 ferro-vanadium (see page 250). The element was first isolated
 in 1830 by Axel Rönro who called it *erythronium*; its present name
 was given in 1830 by Selstrom.
 Vanadium Hardening—see page 272.
 Vanadium Steels—see page 453.
 Vanado-Ferite—see page 272.
 Vapor—see page 202.
 Vapor Pressure Pyrometer—see page 202.
 Vapor Pyrometer—see page 202.
 Vaporization—see page 202.
 Variable Pressure Thermometer—see page 202.
 Variable Volume Thermometer—see page 202.
 Variability, Degree of—see page 202.
 Vectorial Movement—see page 202.
 Vehler.—Of a paint; see page 202.
 Vain—see page 28.
 Vein Stuff (Lang K)—The kaolin or matrix of an ore.
 Velocity of Cementation—see page 67.
 Velocity of Transmutation—see page 202.
 Vent Hole; Vint—see page 202.
 Ventilation; Venting—see page 202.
 Vertical Heating Furnace—see page 184.
 Vertical Illumination—see page 202.

V

- V.**—(1) Volume; (2) chemical symbol for vanadium, *q.v.*; (3) point of Brinell: see page 265.
- V-weld.**—See page 502.
- Vacuum Casting.**—See page 62.
- Vacuum Gases (Howe).**—Those obtained on heating metal in vacuo.
- Vacuum Tuyere.**—See page 32.
- Valence; Valency.**—See page 86.
- Valence Formula.**—See page 86.
- Valency Theory.**—Of passivity: see page 364.
- Van Aller Process.**—See page 372.
- Van der Waal's Formula.**—See Gas.
- Van Riet Process.**—See page 60.
- Vanadium.**—V; at. wt., 51.2; melt. pt., 1680° C. (3056° F.); sp. gr., 6.025. It is a comparatively rare element and is always found combined. When pure it is a white metal having a great affinity for oxygen and nitrogen. Owing to the discovery of large mineral deposits, it has recently come into considerable use in the manufacture of special steels (see page 452); it alloys with iron in all proportions, and is obtained commercially as ferro-vanadium (see page 356). The element was first isolated in 1803 by Del Rio who called it **eurythronium**; its present name was given in 1830 by Sefstrom.
- Vanadium Hardenite.**—See page 275.
- Vanadium Steels.**—See page 452.
- Vanado-Ferrite.**—See page 272.
- Vapor.**—See page 202.
- Vapor Pressure Pyrometer.**—See page 210.
- Vapor Pyrometer.**—See page 209.
- Vaporization.**—See page 202.
- Variable Pressure Thermometer.**—See page 205.
- Variable Volume Thermometer.**—See page 205.
- Variability, Degree of.**—See page 327.
- Vectorial Movement.**—See page 281.
- Vehicle.**—Of a paint: see page 365.
- Vein.**—See page 58.
- Vein Stuff (Eng.).**—The gangue or matrix of an ore.
- Velocity of Cementation.**—See page 67.
- Velocity of Transformation.**—See page 265.
- Vent Hole; Wire.**—See page 298.
- Ventilation; Venting.**—See page 298.
- Vertical Heating Furnace.**—See page 184.
- Vertical Illumination.**—See page 285.

- Vertical Regenerators.—See page 312.
- Vertical Shear.—See page 336.
- Vertical Testing Machine.—See page 469.
- Vessel.—A Bessemer converter: see page 15.
- Vessel Patching.—See page 17.
- Vibration.—See page 333.
- Vibrator Machine.—See page 301.
- Vibratory Brittleness.—See Brittleness.
- Vibratory Test.—See page 482.
- Vical's Experiment.—See page 334.
- Vickers Process.—See page 118.
- Villon Process.—See page 374.
- Violent Aeration.—See page 107.
- Violent Cement.—See page 67.
- Violle's Actinometer.—See page 207.
- Violle Calorimetric Pyrometer.—See page 207.
- Viscous Materials.—See page 331.
- Visible Color.—See page 210.
- Visual Analysis.—See page 284.
- Visual Microscopy.—See page 284.
- Vitreous Amorphous Phase.—See page 281.
- Vitreous Fracture.—See page 179.
- Vitreous Fusion.—See page 201.
- Vitricarbo.—See page 398.
- Vitriform Fracture.—See page 179.
- Vitriol.—Oil of vitriol: commercial sulphuric acid.
- Vivianite.—See page 244.
- Void.—Pipe: see page 53.
- Volatile Matter.—See Fuel.
- Voltaic Contact.—That between unlike metals, causing an electrolytic action.
- Voltex Process.—See page 503.
- Volume Force.—See page 331.
- Volume Increase.—From quenching: see page 225.
- Volumenometric Thermometer.—See page 207.
- Volumetric Modulus of Elasticity.—See page 335.
- Volumetric Thermometer.—See page 207.
- Vom Baur Furnace.—See page 165.
- Von Maltitz Process.—See page 388.
- Von Nawrocki Process.—See page 64.
- Vug; Vug Crystals.—A cavity in a casting, etc., and crystals found in such cavities.

W

- W.**—(1) Chemical symbol for tungsten, *q.v.*; (2) point of Brinell: see page 265.
- W Structure.**—See page 291.
- Wabbling.**—See page 407.
- Wagner Process.**—See page 371.
- Waidner and Burgess Pyrometer.**—See page 208.
- Walker Process.**—See page 371.
- Wall.**—One of the sides of a furnace; in a circular furnace, the vertical portion.
- Wall (Arthur) Process.**—See page 73.
- Walled Cell.**—See page 121.
- Wallerant's Process.**—See page 232.
- Walloon Processes.**—See page 75.
- Walrand Converter.**—See page 24.
- Walrand-Delattre Converter.**—See page 24.
- Walrand and Delattre Process.**—See page 23.
- Walrand and Legenisel Process.**—See page 23.
- Walrand Process.**—See pages 23 and 388.
- Wanner Optical Pyrometer.**—See page 207.
- Ward Process.**—See page 370.
- Warm Blast.**—See Blast.
- Warm Blast Charcoal Iron.**—See page 350.
- Warner Process.**—(1) Basic Bessemer process: see page 23; (2) for desulphurizing: see page 388.
- Warped.**—See page 56.
- Wash.**—(1) Wearing of molds: see page 57; (2) coating for molds: see page 298.
- Wash Heat.**—A heat which causes the scale on the surface of a piece of iron or steel to melt and run off; also called a **cinder heat**: (2) used in the sense of reheating merely the outside of a piece where it has become slightly chilled from rolling or forging, the interior being still sufficiently hot; (3) in open hearth practice; see page 313.
- Wash Metal.**—See page 384.
- Wash Out Heat.**—See page 313.
- Wash Pot.**—See page 298.
- Wash Up.**—See page 298.
- Wash-welding Temperature.**—See page 116.
- Washburn and Moen Gage.**—See page 188.
- Washed Metal; Pig.**—See pages 346 and 384.
- Washer.**—See Ore.
- Washing.**—(1) Of gas: see page 33; (2) see Wash Heat; (3) of ore, *q.v.*

- Washing Process.**—Pig washing process: see page 383.
- Wassell Process.**—See page 420.
- Wassereisen (obs.).**—See Hydrosiderum.
- Waste Gases.**—See page 202.
- Waste-heat Oven.**—See page 96.
- Waste Liquor.**—See Pickling.
- Waste Wax Process.**—See page 301.
- Waster.**—An article rejected on account of imperfections developed in the course of manufacture; scrap. This term is applied more especially to defective sheets and tin plates.
- Water.**— H_2O ; it occurs in practically every non-metallic substance unless it is specially removed by drying (**desiccation**), and is then often termed **moisture**. It may, so to speak, be simply mixed, so that heating to a temperature slightly above its boiling point will expel it: in this case it is called **hygroscopic moisture** (rarely **hygrometric water**) or **mechanically combined water**. The action whereby a solid substance parts with its moisture upon exposure to ordinary air is termed **efflorescence** (the substance is said to **effloresce**); where additional moisture is taken up it is known as **deliquescence** (the substance is said to **deliquesce**). Where the water is more closely bound and appears to enter into a weak chemical combination, so that a temperature considerably above its boiling point is necessary to expel it, it is termed **combined water**, **water of crystallization**, or **water of combination**; an example of this is copper sulphate which is generally seen in the form of beautiful blue crystals having the formula $CuSO_4 \cdot 7H_2O$; upon drying at a fairly high temperature, the water is driven off and a white powder results.
- Water Annealing.**—See page 231.
- Water Breast.**—See page 31.
- Water Coating.**—See page 507.
- Water of Combination.**—See Water.
- Water of Crystallization.**—See Water.
- Water Cooled; Cooling.**—See page 227.
- Water Core.**—See page 299.
- Water Crack.**—See Crack.
- Water Dipping.**—See page 227.
- Water Equivalent.**—See page 201.
- Water Finish.**—The finish or appearance of machined metal obtained when a small stream of water trickles upon the cutting tool.
- Water Gas.**—A fuel gas produced by the decomposition of steam with incandescent carbon. The fuel is maintained in a thick bed in an apparatus called a **water gas producer** (rarely simply **gas producer**), and the process consists of two periods; during the first period (sometimes called **blowing up** or **blowing hot**) air is blown through the fuel until it becomes incandescent, the gases formed being allowed to escape; in the second period (**steaming** or **blowing cold**) the air is turned off and steam is blown through the fuel, the gas so formed being led to the gas receiver: this is kept up until the fuel is so much cooled that the reaction becomes very imperfect. The theoretical compo-

sition of the gas is 50% each of hydrogen and carbon monoxide. Ledebur gives the following as the usual range by volume:

Hydrogen.....	44.0 to 53.0%
Carbon monoxide.....	45.0 to 40.0
Methane.....	4.0 to 0.0
Carbon dioxide.....	1.5 to 6.0
Nitrogen.....	8.0 to 1.0

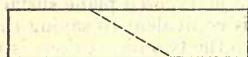
- Water Hardening.**—See page 227.
- Water Hardening High Speed Tool Steels.**—See page 448.
- Water Helve.**—See Hammer.
- Water Jacket.**—A metallic casing through which water circulates to keep the interior of a furnace wall from being corroded or burned away, *i.e.*, to keep it “cool.”
- Water Oil Gas.**—See Oil Gas.
- Water Pot.**—See page 298.
- Water Pyrometer.**—See page 207.
- Water Quenching.**—See page 227.
- Water Seal Producer.**—See Producer.
- Water Tempering.**—See page 227.
- Water Toughening.**—See pages 227 and 445.
- Watery Fusion.**—See page 201.
- Watson (J. J. W.) Process.**—See page 73.
- Watts Process.**—See page 166.
- Wave.**—See Flute.
- Weak.**—Brittle, *q.v.*
- Weak Iron.**—White, brittle pig iron.
- Wearing Tests.**—See page 480.
- Weathering.**—Exposure to the atmosphere; used in the case of ores which are exposed for a considerable period (months or years) to assist in their disintegration and in removing or oxidizing impurities.
- Webster's Formula.**—For tensile strength: see page 339.
- Wedging Down.**—Of top-poured iron ingot molds; capped with sand and an iron plate held in place by a wedge driven under a bar passing through rings in the top of the mold.
- Wedgwood's Contraction Pyroscope.**—See page 209.
- Weigelin Process.**—See page 369.
- Weigh Bar.**—See page 475.
- Weight Percent.**—See page 83.
- Weiss Process.**—See page 44.
- Weld.**—See page 501.
- Weld Iron.**—A term suggested for wrought iron but seldom used.
- Weld Metal.**—A term suggested by Von Ehrenwerth for iron products produced in a pasty (containing slag) condition.
- Weld Steel.**—Iron containing sufficient carbon to be capable of hardening greatly by sudden cooling, and in addition slag bearing, because made by welding together pasty particles of metal in a bath of slag, as in puddling, and not later freed from that slag by melting. The term is rarely used (I. A. T. M.).
- Welded Joint.**—See page 501.
- Welded Pipe.**—See page 489.

Welding.—(a) Strictly a method of uniting two pieces of wrought iron or steel by heating them to a temperature, moderately close to their melting point (but without actual fusion), at which they become pasty, and forcing them into intimate contact whereby molecular cohesion takes place, producing a weld or welded joint. (b) In recent years methods are included which employ actual melting either of a substance which acts as a solder or of a portion of one or both of the pieces which are to be united. Stead describes (a) or **true welding** as "the crystallizing into union of two metallic surfaces when they are brought together under suitable conditions. That such is the case is proved by microscopic examination, for on polishing and etching sections of the united metals, the crystals along the junction are found to be common to each of the original pieces of metal. In perfect welding there is no visible joint, for the line or plane of junction is occupied by crystals, portions of which belong to one piece of metal and portions of the same crystals to the other. When the boundaries of the crystals are coincident with the juxtaposed plane surfaces it is evidence of non-welding, which is equivalent to saying that 'unless the crystals become common to the two pieces there is no welding'" (Stead's Law of Welding).

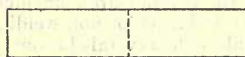
The temperature necessary for ordinary welding is a good white heat (**welding heat or temperature**), say 1250 to 1350° C. (2280 to 2460° F.) for soft steel, and in some cases slightly higher for wrought iron. As this makes the grain very coarse, hammering or some other form of work is usually necessary to refine it; annealing or some form of heat treatment alone may in some cases be sufficient (see Heat Treatment, page 231). **Hammered weld** is the term sometimes used for such welds particularly to distinguish them from those (chiefly electrical or thermit welds) which are simply pressed together at a high temperature and may, in consequence, have a coarse grain from not having been worked down to a low temperature. By the **Komm method** of welding the union of the two pieces is produced within the fire where the two conically pointed ends are in contact. The crust of cinders is removed by blows applied to the butts which project from the hearth, and since the two surfaces which are thus kept pure cling to one another at once and unite, there is no opportunity for a renewed oxidation. Rods which are welded in this way do not separate under alternating torsional bending along the faces welded, but they break across the axis of the rod, just like rods which have not been welded (Bermann). At the moment of welding it is essential to have the surfaces clean, *i.e.*, free from scale or dirt, to remove which a **flux** is commonly used, ordinarily sand for steel and borax for wrought iron. The term **welding cinder** is sometimes employed for one which is easily fusible and, while protecting the surfaces from oxidation, will run out readily when they are pressed together. It has been recommended to have the surfaces convex to each other so they will at first touch on a line near the middle and the liquid slag will be forced out as the weld is formed instead of being inclosed as might easily be the case if the surfaces were concave. The flux is sometimes formed

into a thin plate (**welding plate**) which is placed between the two surfaces, and in this case is frequently of a special composition. **W. B. Middleton** dips the pieces to be welded into a solution of sodium silicate, after which they are heated and welded in the usual manner.

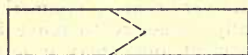
The strength of a weld (*i.e.*, of the material at the joint) is almost never equal to that of the original section, although in some cases, particularly with wrought iron, it may approach it very closely. **Defective welds** may be caused by (*a*) heating too high: burning; (*b*) heating too low: molecular cohesion not effected; (*c*) not working sufficiently at the weld, back from the weld, or both: brittle; (*d*) surfaces not clean; (*e*) sulphur too high; (*f*) carbon too high. It should be appreciated that one of these conditions may directly affect another; for example, if the carbon is higher than usual the temperature cannot be so high without danger of burning, but if too low good cohesion will not be se-



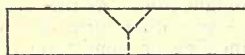
Lap or Scarf Weld



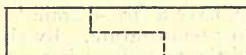
Butt or Jump Weld



V-Weld



V-Weld with Binder



Split Weld

FIG. 66.—Types of weld.

cured. It is also of interest that experiments with relatively high sulphur steel developed the fact that the temperature had to be lower (or shorter time of heating under the same conditions) than with low sulphur stock; the welds produced in this way were entirely satisfactory. There are a number of types of weld which are sufficiently explained by Fig. 66.

V-welds and V-welds with binder are sometimes called respectively **bird's-mouth welds**, and **glut welds**. **Cross welding**, employed in the manufacture of extra-long lengths of tubes, consists in welding two pieces of skelp together at the ends before bending and welding the edges. The line of the weld is called the **joint** or sometimes the **shut** or, particularly in the case of welded tubes, the **seam**. A **cold shut** is where the hammering has not been carried far enough to obliterate the line or joint between the

two pieces: the weld is not smooth but otherwise may be all right.

An experiment to show that welding may occur at a temperature only slightly above the upper critical point is known as **Coffin's weld** or **joint**. It consists in taking a small bar of tool steel, breaking it to obtain a fresh fracture (two pieces may also be machined to produce clean surfaces fitting accurately), which are then fitted together. They are wrapped in platinum foil to prevent oxidation, and are heated with an ordinary Bunsen burner (or otherwise) when the pieces will unite more or less completely, unassisted by any hammering.

In ordinary (or "old-fashioned") welding the pieces are generally heated in a coke fire or in some form of regular heating furnace. An oxyhydrogen flame (**oxyhydrogen welding**) is sometimes employed, which is the principle of **Garut's process**, and more recently considerable application has been made of an oxyacetylene flame (**oxyacetylene welding**), both of these methods being chiefly applicable to small or thin pieces such as sheets. Owing to the extremely high temperatures produced such welds are sometimes referred to as **hot flame welds**; the temperatures are so high that frequently (and by intention) actual fusion occurs. **Oxyhydrogen** and **oxyacetylene cutting** are simply a further application of this possibility by melting away the metal in order to remove portions of an object; with a substance containing carbon (any form of wrought iron, cast iron or steel) after a point of incandescence is reached it is sufficient to shut off the hydrogen or acetylene, as the case may be, and the oxygen under heavy pressure will burn and fuse the metal in the immediate vicinity, which is blown away. By employing a fine jet a very narrow cut may be effected.

The necessary heat may also be supplied electrically (**electric welding**): (a) with an arc (**arc welding**) in which the pieces are heated by direct contact or by radiation; (b) by the resistance of the pieces themselves to the passage of the current (**incandescent welding** or **resistance welding**); and (c) by **electro-percussive methods**. Electric welding was first introduced by **Elihu Thomson** in 1886, his process of incandescent welding consisting in passing a heavy alternating current through the pieces to be welded, the increased resistance at their point of contact (**contact welding**) giving the necessary temperature at the joint. Other contact systems were devised by **Pontelec**, **Helsby**, and **Lagrange-Hoho**. In **Bernardos' process** an arc is formed between a carbon rod (positive pole) and the metal (negative pole). Between the pieces to be welded are placed small pieces of metal, such as turnings, which melt and unite the pieces by soldering rather than by true welding. Bernardos also suggested the application of a magnet to deflect the arc between two electrodes, forming an **electric blast**. This method (**voltex process**) was perfected in the **Zerener process**. Somewhat similar to Bernardos' earlier method was that of **N. Slaviankoff** for repairing broken pieces of machinery, etc. The piece to be repaired is attached directly to one pole of a dynamo, and small pieces of metal are melted by

the electric arc in a special tool attached to the other pole and fall on the object in a molten state.

Spot welding is the fusing or welding together of relatively thin sections by means of a single-phase alternating current, with the electrode making a heavy contact pressure on the area being welded. It is adapted especially to sheet metal work ranging from the welding of fish plates to tram rails, to the lightest of sections such as the sticking of handles to oil cans and kitchen ware. The electrical contacts cover a small area similar to that of a rivet, and the points pinch the two pieces together like a vise. A heavy current is then sent through this area and in a few minutes produces a welding heat. It can be made to take the place of riveting, requires no punching and is much quicker. It can be applied to almost all kinds of metals and alloys except that cast iron cannot be welded to cast iron. It is also possible to heat and head rivets when set in the holes, and to produce soft spots in hardened sheets (*Iron Trade Review*, Oct. 19, 1916, 781).

Electro-percussive welding (also called **percussive electric welding**) is a recent development of electrical welding originated by L. W. Chubb. The process is based on the principle of simultaneous condenser discharge and percussive engagement. In the first apparatus the wires to be welded together, placed in the grips of two hinged arms, were connected to the terminals of a charged electrolytic condenser. When the arms were released the wires came into contact and immediately discharged the explosive condenser, the force of impact welding the ends together. In an improved apparatus, similar in construction to a pile driver, the **forge effect** and velocity are capable of independent variation. It is claimed that the generation of heat is so localized, so sudden and so intense, that there is no time for unequal heat conduction through the shanks of the wires, and the ends will be melted and even vaporized whether the melting point of the metal is high or low. For this reason various metals and alloys can be welded together independently of their electrical resistance, melting point, or heat conductance (*Journ. Inst. Metals*, 1915, II, 247).

Thermit welds are those where (a) the temperature is secured by contact with the slag produced from thermit applied around the joint and may in cases be high enough to cause actual or partial fusion; or (b) where the molten metal produced from thermit is used directly to form the joint. The **Stroh steel hardening process** is stated to consist in depositing a layer of alloy steel to secure a better wearing surface and may be of a depth as required, uniting with the part so treated (*Iron Age*, May 2, 1912, 1080). The **Simpson weld**, intended as a method where high-speed tool steel is to be united to a soft steel backing for armor plate, etc., consists in the application of a section of copper between the two sheets of steel; a mixture of charcoal, brown sugar, and water is used as a flux and upon being subjected to a temperature of 2000° F. (1095° C.) the copper combines with the steel and forms a perfect weld (*Iron Trade Rev.*, Aug. 17, 1911, 286).

Soldering consists in joining two metals or alloys together by means of a more soluble alloy (solder) or one to which they will more readily unite than with each other. **Ordinary** or **soft solder**, used for uniting non-ferrous metals such as lead, or principally sheets of iron or steel, consists of approximately 2 parts of lead and 1 part of tin. **Wiping** (of joints) is a term used principally in plumbing work where the solder in a pasty, semi-molten condition is worked and pressed into the desired shape around a joint. **Hard solder** consists of a mixture of copper and zinc, usually about half and half, sometimes with a little tin added, and is used for **brazing** or joining where greater strength is required than by soldering but not so great as by welding. **Autogenous welding** or **soldering** is really a form of soldering where two pieces of the same metal or alloy are united by limited fusion of the pieces themselves without the addition of some other substance (except a flux). The autogenous welding of lead pipe is sometimes called **lead burning**.

Welding Cinder.—See page 501.

Welding Flux.—See page 501.

Welding Furnace.—(1) A furnace in which pieces are heated for welding; (2) a puddling furnace (obs.).

Welding Heat.—See page 501.

Welding Plate.—See page 502.

Welding Process.—Of coating: see page 372.

Welding Seam.—See page 502.

Welding Temperature.—See page 501.

Weldless Tube.—See page 490.

Well.—Hearth of a blast furnace: see page 27.

Wellman and Schwab Process.—See page 388.

Welt.—The covering strip used in butt riveting (Horner).

Wenstrom Mill.—See page 420.

West Coast Hematite.—See page 344.

West Sintering Process.—See page 45.

Westman Process.—See page 148.

Westphalia Gage.—See page 188.

Wet Analysis.—See page 82.

Wet Assaying.—See page 82.

Wet Blacking.—See page 298.

Wet Bottom.—See pages 253 and 377.

Wet Brush.—See page 298.

Wet Cleaning.—Of gas: see page 33.

Wet Drawing.—See page 508.

Wet Process.—See page 82.

Wet Puddling.—See page 374.

Wet Slag.—See Slag.

Wet Washing.—Of gas: see page 33.

Weyl's Method.—Of etching: see page 288.

Weyrauch's Formula.—For tensile strength: see page 339.

Wheel Breaker.—See page 481.

Wheel Burns.—See page 110.

Wheel Swarf (Eng.).—A mixture of silicious particles and partially rusted steel obtained from the grindstones in cutlery grinding; it

is used in cementation furnaces as a lute to make the pots airtight.

- Wheeler Process.**—See page 64.
- Wheeling Theory.**—Of slip: see page 284.
- Whiskers.**—Of coke: see page 96.
- White Amorphous Sulphur.**—See Sulphur.
- White Annealing.**—See page 431.
- White Calorimeter.**—See page 201.
- White Cast Iron.**—See page 342.
- White Clay.**—See page 302.
- White Crucible Process.**—See page 114.
- White Edged Plate.**—See page 432.
- White Ghost Lines.**—See page 289.
- White Heart Casting; Malleable.**—See page 258.
- White Heat.**—Color temperature: see page 210.
- White Iron.**—(1) Grade of pig iron: see page 342; (2) tin plate: see page 433.
- White Iron Pyrites.**—See page 245.
- White Ironstone.**—See page 244.
- White Metal.**—See page 383.
- White Pickling.**—See page 431.
- White Pig.**—See page 342.
- White Pot.**—(1) Kind of crucible: see page 111; (2) in the manufacture of tin plate: see page 431.
- White Refined Cast Iron.**—See page 383.
- White-Souther Machine.**—See page 482.
- Whiteley Process.**—See page 65.
- Whiteley's Reagent.**—For etching: see page 287.
- Whitesmith.**—See page 433.
- Whitworth Armor Plate.**—See page 9.
- Whitworth Process.**—For fluid compression: see page 63.
- Wiborgh Air Pyrometer.**—See page 207.
- Wiborgh's Thermophone.**—See page 210.
- Wicket.**—The small hole in the door of an open hearth or other form of furnace through which the interior can be inspected without raising the door.
- Widmanstätten (Widmanstätten) Lines; Structure.**—See page 291.
- Wild.**—Of metal, usually steel, when overoxidized, causing it to spit and fly. Spitting in the ladle is usually caused by a reaction between the metal and the cinder; in the molds, by the violent escape of gases while the metal is in a pasty condition. The opposite condition is **dead**.
- Wild Process.**—See page 64.
- Wile Furnace.**—See page 165.
- Willans Process.**—See page 388.
- Williams Mill.**—See page 420.
- Williams Process.**—See page 63.
- Willis Process.**—See page 372.
- Wills Converter.**—See page 25.
- Wilson Process.**—For armor plate: see page 9; (2) direct process: see page 148.
- Wind Box.**—See page 17.

Wind Furnace.—See page 183.

Winiwarter Process.—See page 370.

Winslow Squeezer.—See page 377.

Wiper.—In wire manufacture: see page 509.

Wiping.—Kind of soldering: see page 505.

Wire.—On tinned sheets: see page 432.

Wire.—(1) The name given to small metal filaments (usually round) produced in pieces of considerable length by **drawing**, *i.e.*, successively reducing (and thereby extending) the section by repeatedly pulling it cold (**cold drawing**) through tapered holes in a die or **draw plate** (**block, die plate**). Drawing is necessary as it is impracticable to roll such small sections commercially. (2) Wire is also the name given to rounds for helical springs (particularly for railway work).

Billets are first reduced, in a rolling mill, to **wire rods** (rounds) about 0.2" to 0.3" in diameter, which are coiled up into **bundles**. These bundles are placed in a **pickling bath** of dilute sulphuric acid, heated by steam, to remove the scale, and are then transferred to the **rinsing bath** to remove the greater part of the acid, after which they are put on a revolving frame and sprayed with water still further to remove the acid; this causes a certain amount of rust to form on the surface, which acts later as a slight lubricant and is known as a **rust coating, water coating, or sull**.

The last traces of acid are eliminated by treatment in the **lime bath** (**liming**), after which the bundles are taken to the **dry house** where they are dried (**baked**) at a low temperature in a furnace called the **baker**. This treatment expels most of the occluded hydrogen (due to the action of the acid) whose presence causes brittleness (**acid brittleness**). If the wire is to be **bright finished** (*i.e.*, unannealed), it is transferred from the rinsing bath immediately to the lime bath. Instead of cleaning wire with acid, it is sometimes put into a **scouring barrel**, in which it is rotated with some cleaning material.

The **draw plate** is either of chilled cast iron or of steel. According to Lewis (*Iron Trade Review*, Oct. 9, 1913) the former is most largely used in this country, and is prepared by reaming out the hole which, when worn, must be enlarged to the next size. The latter, generally used in Europe, is made of the best grade of tool steel (high carbon), and when worn is upset to a smaller size by gently hammering around the hole and then reaming out again to the original size; as this cold upsetting hardens the metal, it is carefully annealed from time to time. Some steel dies are also quenched to contract the hole. The term **hole** or **draw hole** (through which the wire passes for reduction) signifies the entire aperture. This is somewhat enlarged at the two surfaces of the plate, and the part of smallest diameter where the drawing is principally accomplished is distinguished as the **gage hole**. Usually all the holes in one plate are of the same size and the wire is passed through successive plates, each hole serving for one (sometimes two) bundle. After use the plates are annealed (as the metal around the holes has been hardened), the holes reduced

by hammering and then opened up to the exact size by punching (**pricking**). The plates used for the first few reductions are sometimes referred to as the **roughing blocks**, **ripping blocks**, or **rippers**, those for the last, as **finishing blocks**.

Drawing is performed on the **draw bench**, which comprises the draw plate and a power reel for pulling the wire through. To start the wire through the hole, it must be pointed either with a small hammer, or by a pair of small rollers with grooves of different sizes, given a rocking movement (like an alligator shears) by an eccentric. The wire is then pulled through by a pair of tongs (**grippers** or **nippers**) attached to a crank shaft, giving a reciprocating (back and forth) movement, until there is a sufficient length to attach it to the power reel. The term **ratch** is used for the pull of the wire through the die at one operation where a straight pull and not a reel is used. The plate is sometimes tilted backward at a slight angle to **kill** the wire, *i.e.*, prevent the tendency to spring out into an unmanageably large coil on removal from the reel. To reduce the friction in drawing, the wire must be coated with some substance which acts as a lubricant. In **dry drawing**, grease is employed: it is piled against the back of the draw plate around the hole, and one application serves for a number of reductions. In **wet drawing**, the wire is given a **lees coating** by passing it through **lees liquor** composed of water and some kind of flour, sometimes fermented and sometimes mixing with milk of lime. A **copper coating (lacquer)** is obtained by treating the wire with a weak acidulated solution of copper sulphate, and then usually passing it through lees liquor before drawing. After this treatment it is known as **lacquered**, **straw-tinted**, or **coppered wire**; this method is sometimes called the **liquor-bright process**. If the finished wire is to be coppered, it must receive an additional treatment.

Multiple drawing is where the wire is drawn through a number of dies simultaneously, being reeled up only after passing through the last, instead of after each plate. In this case, to avoid breaking, it is necessary to provide a power reel between each pair of holes, around which the wire is given a couple of turns. Passing the wire through the various dies and around the reels, ready for drawing, is called **stringing up**. After about 8 to 10 **holes** (hole in this sense means pass or reduction) the wire is so much hardened that it must be reannealed, etc., before drawing can be continued. This fine wire is sometimes **batted**, *i.e.*, beaten with wooden sticks while being washed after pickling.

Plain drawn wire (bench hardened wire) is wire in the condition in which it leaves the last hole, without any further treatment. **Plain annealed wire** is where it is annealed in closed iron pots to render it soft and pliable. **Galvanized wire** is annealed and then coated with zinc (spelter). In galvanizing, the wire is passed (*a*) through a lead bath to anneal it; (*b*) through a weak pickling solution to remove the scale formed; (*c*) through a rinsing bath; and (*d*) through the molten spelter contained in the

galvanizing pan. The excess of zinc is removed by drawing it through plugs of asbestos, called **wipers**. The wire is kept below the surface of the zinc by passing it under heavy toothed bars, called **sinkers**. In modern practice a number of wires or strands are treated simultaneously, the whole series of operations being continuous, and one power reel serving to pull each strand through (**Bedson's continuous galvanizing process**). **Bright annealed wire** is where the annealing is carefully conducted in closed pots to keep surface oxidation at a minimum; attempts have also been made to prevent oxidation entirely by means of a reducing or neutral atmosphere.

After having been drawn down several numbers, *i. e.*, reduced by passing through several successively smaller holes, the wire becomes brittle from the cold working and to permit of further reduction is given a **process annealing** or **works annealing**; this consists in heating to a temperature, which may be below the critical, say 1100° F. (595° C.), and holding a certain length of time (**Tinsley**) followed by slow cooling. **Dead soft annealing**, as the name indicates, is where extra precautions are observed to make the wire specially soft for subsequent severe bending or cold working processes. **Improved or patented wire** is where medium carbon wire (about 0.35 to 0.85% carbon) is heated above the critical point and cooled rapidly through the critical range, the operation usually being continuous, the wire passing through the heated tubes of a furnace and cooled by being brought into the air or into a bath of molten lead, comparatively cool but seldom below 700° F. (370° C.). Patenting serves to increase the ductility and permit of greater subsequent drawing down than is the case with annealing. Higher carbon wire (say 0.65 to 1% carbon) is usually treated by quenching and tempering (**Tinsley, Am. I. & S. Inst., 1914**).

Tinman's wire is a soft bright drawn wire used in the manufacture of various tin plate goods. **Plow steel wire** is made from a fine grade of high-carbon, crucible steel, and is so called because it was originally used for dragging steam plows. **Gun screw wire** is a name sometimes employed for wire made from a high grade of refined wrought iron. **B., B. B., E. B. B.** (best, best best, extra best best) wire, or **four-sided charcoal wire** were grades in England, used for telegraphic work, made of fagots composed of puddled billets in the center, and four flats outside, of (a) best best puddled iron, (b) or top and bottom of charcoal iron with sides of best best puddled iron or (c) charcoal iron all around, respectively. **Bimetallic wire** is usually a combination of steel center with copper outside ("copper clad"—see **Protection**, page 372). **Stranded wire** is another name for wire rope or cable.

Wire Drawing.—See page 64.

Wire-edged.—Usually a defect; of material having a rough untrimmed edge.

Wire Gage.—See page 188.

Wire Glass.—Also called **armored glass**; sheets of glass cast around a wire netting which holds the glass together in case it becomes cracked or broken.

Wire Iron.—See page 378.

Wire Rod.—See page 507.

Wire Rod Mill.—See page 417.

Witherow Converter.—See page 25.

Wittgenstein Mill.—See page 434.

Wittnufftt Converter.—See page 25.

Wittorff's Equilibrium Diagram.—See page 272.

Wobble; Wobbler.—See page 407.

Wöhler's Law.—See page 333.

Wöhler Range; Test.—See page 482.

Wolf Furnace; Oven.—See page 147.

Wolframium.—A trade name for a special alloy of aluminum containing a small percentage of tungsten.

Wolfram Steels.—See page 450.

Wolframite.—See page 245.

Wood.—As a fuel, this is used in metallurgy practically only for drying purposes. It consists naturally of nearly equal parts of cellulose and water. A sample of air-dried wood showed:

Carbon.....	40.0%
Hydrogen.....	4.8
Oxygen.....	32.8
Nitrogen.....	0.8
Ash.....	1.6
Moisture.....	20.0

Wood Coal (Eng.).—An old name for charcoal.

Wood Process.—See page 369.

Wootz.—Or **Indian steel**; it is manufactured from wrought iron made in a native furnace (India) in the following way (Harbord and Hall): "Small crucibles of refractory clay are used, in each of which about a pound of metal is placed, with a certain proportion of finely chopped wood. The crucibles are then covered with one or two green leaves and wetted clay, and placed in the sun to dry. When the plugs have hardened, twenty to twenty-four of the crucibles are built in an arched form, on the bottom of a small blast furnace, blown by bellows, and strongly heated for two or three hours. The furnace is then allowed to cool, the crucibles taken out and broken, the steel having melted down to a rounded button at the bottom of each pot. Probably in order that it may be completely melted the steel is overcarburized, and before drawing out into bars the buttons are heated for several hours in a charcoal fire, urged by bellows, to a temperature not much below their melting point, and turned over before the blast, so that the metal may be partially decarburized."

Work.—The mechanical treatment which a piece receives in the process of manufacture.

Work Cold.—Of a blast furnace: see page 35.

Work of Deformation.—See page 481.

Work Hardness.—See page 331.

Work the Holes.—To have charge of a crucible furnace.

Work Hot.—Of a blast furnace: see page 35.

Working.—(1) The condition of an operation or process, *e.g.*, “How is the heat working?”; (2) to stir an open hearth heat with a rod, or to add ore, to assist in the oxidation of the carbon and impurities; (3) to corrode, as when a heat is working on the bottom or lining of a furnace; (4) operating a mine.

Working Anvil Block.—See Hammer.

Working Load; Strength.—See page 468.

Wring Fit.—Of a bar, etc.; which fits a coupling or other piece so accurately that, while it cannot be readily slid or pushed on, it can be wrung or twisted on (Howe).

Works Annealing.—See page 509.

Wrought Iron.—Also called malleable iron in England; iron low in carbon produced in a pasty condition (owing to the temperature employed being too low to render it fluid), in consequence of which a small percentage of slag is mechanically intermingled with it. The percentage of carbon is usually under 0.15%, and that of the other constituents (not including the slag) under 0.25%. It can be forged or rolled, and welded, but is not appreciably hardened by rapid cooling (quenching). It is made by the puddling, a direct, or a charcoal hearth process.

Wrought Steel.—(1) Wrought iron containing sufficient carbon so it may be hardened by quenching; (2) rarely, steel which has been worked, more especially hammered.

Wulf Oven.—See page 147.

Württemberg Process.—See page 319.

Wuth Process.—See page 319.

Y

- Yb.**—Chemical symbol for ytterbium: see page 84.
- Yt.**—Chemical symbol for yttrium: see page 84.
- Yarrow Test.**—See page 482.
- Yates Process.**—See page 148.
- Yatsevitch's Reagent.**—For etching: see page 287.
- Yellow Prussiate of Potash.**—Commercial potassium ferrocyanide, $K_2Fe(CN)_4$.
- Yellow Pyrites.**—See page 245.
- Yellow Temper.**—Oxide color: see page 230.
- Yield Point.**—(1) General: see pages 334 and 470; (2) by scribe or scriber method: see page 470.
- Yield Stress.**—See page 471.
- Yielding Guard.**—See page 415.
- Young Blowing.**—In Bessemer practice: see page 21.
- Young Iron.**—See page 376.
- Young's Modulus.**—see page 334.

Z

Zn.—Chemical symbol for zinc, *q.v.*

Zr.—Chemical symbol for Zirconium: see page 84.

Zenzen Converter.—See page 25.

Zerener Process.—See page 503.

Zero Calorie.—See page 199.

Zero Point.—See Curve.

Zinc.—Zn; at. wt., 65.5; melt. pt., 420° C. (786° F.); boil. pt., 918° C. (1684° F.); sp. gr., 7.14. It is rarely if ever found in the uncombined condition. When pure it is a crystalline, bluish white metal, only slightly tarnished on exposure to air, and, for this reason, used as a protective coating, the process being known as galvanizing (see pages 370, 431). It alloys with iron in all proportions, but is rarely found in iron except as an impurity. **Cadmia**, also called **philosopher's wool**, is a deposit of oxide of zinc found in the upper part of a blast furnace in which ores containing traces of zinc are smelted.

Zinc Ashes.—The oxidized zinc removed from the surface of a galvanizing bath.

Zinc Dust.—Oxide of zinc produced when zinc is distilled; used in sherardizing: see page 371.

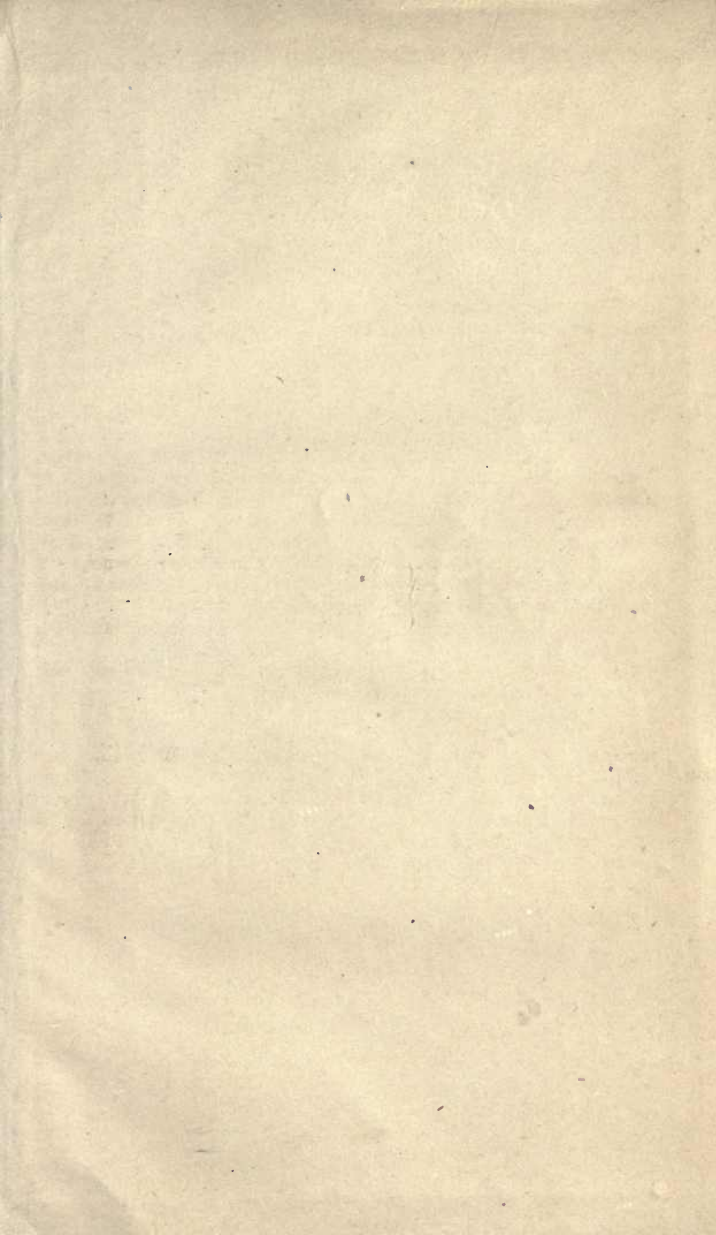
Zinc Etching.—See page 287.

Zinc Plating.—See page 390.

Zinceisen.—Zinc (from a galvanizing bath) of inferior quality, due to the presence of iron.

Zincing (rare).—Zinc plating or galvanizing: see page 370.

Zone.—(1) In cementing: see page 68; (2) of carbon deposition in blast furnace practice: see page 36; (3) of complete fusion: see page 36; (4) of heat interception: see page 36; (5) of incipient fusion: see page 36; (6) of slag formation: see page 36.



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