IRON

IRON AND STEEL MANUFACTURE

BY THE SAME AUTHOR.

PRACTICAL METALLURGY AND ASSAYING.

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IRON AND STEEL MANUFACTURE

A TEXT-BOOK FOR BEGINNERS

BY

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London:
MACMILLAN AND CO.
AND NEW YORK
1889

PREFACE.

THE object of the present work is to impart to beginners a knowledge of the fundamental principles of the various processes employed in the Manufacture of Iron and Steel, together with an account of the valuable properties of these metals, so far as they can be treated in an elementary manner.

The book is not intended to supersede any of the larger manuals on the subject, but rather to prepare the student for a more advanced course of study. It also is hoped that manufacturers and workmen connected with trades in which iron and steel are used may find some of the contents of value to them.

A chapter has been added dealing specially with chemical principles and changes for the assistance of students having but a limited knowledge of chemistry.

Pupils preparing for the ordinary grade examinations of the City and Guilds of London Institute will find the questions at the end of each chapter specially useful.

The author desires to acknowledge his indebtedness to the works of Percy, Gruner, Kerl, Phillips, Bell, Greenwood, Bauerman, and others; to the authors of various papers read before the Iron and Steel Institute; and to Mr. Arthur Adams for his kindness in reading the proof sheets.

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July, 1889.

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IRON AND STEEL MANUFACTURE.

CHAPTER I

INTRODUCTION.

IRON, although very widely diffused throughout the earth's crust, is seldom found in the free state. This circumstance, together with the great dissimilarity between the metal and the minerals in which it occurs, may account for the fact of its nature and properties remaining comparatively unknown until the later period of the world's history, which has been termed the "Iron Age." People unacquainted with the extraction of iron from common ironstone would be unlikely to discern any relationship between that substance and metallic iron or steel, and although the purer varieties of magnetite and hæmatite may be easily reduced when in contact with burning fuel, considerable skill is required to form and fashion it into useful articles.

Of all the metals, iron is the one most eminently adapted to the wants and requirements of industry, being, as Horner says, "not only the soul of every other manufacture, but the mainspring perhaps of civilised society." It is not only extremely valuable in its commercially pure state, but when in combination with other elements, forms compounds having an endless variety of applications.

It is not known who first discovered iron, but

tradition attributes it to the accidental burning of a wood in Greece. Or, in the process of charcoal burning for metallurgical or other purposes, if the soil contained a mass of meteoric iron, or an easily reducible oxide, a mass of iron might have been obtained.

The earliest contrivance for smelting iron ore in a systematic manner would probably be a kind of rude hearth, similar to the low conical furnace employed by the natives of South Africa at the present time. This, or a similar arrangement would very likely be built on the windward side of a hill, so as to obtain a natural draught. An important improvement was the addition of the foot-blast, such as that still used in Ceylon and India. Simple leather-bellows are inflated by strings pulled by the hand, and worked by the pressure of men's feet for the exhaust. During the fourth century A.D. single-acting bellows with valves were introduced into Gaul by the Romans. These were afterwards superseded by double-acting bellows.

Another primitive contrivance, known as the Catalan-forge, blown by water-blast, was the only arrangement for supplying Europe with iron for several hundred years; and in the United States of America many thousands of tons are annually produced by a similar forge known as a "bloomery." In later times the walls of the smelting furnace were made higher, consequent on the use of more refractory ores. A lateral opening was made in the lower part for the withdrawal of the bloom below, instead of from above, as in the Catalan-forge. Such a furnace was termed the "stückofen" or high-bloomery. This, and the later form of the "blauofen" were the prototypes of the modern blast furnace, being worked with compressed air. With such arrangements there would be no difficulty in combining the iron with sufficient carbon, etc., to form cast-iron. As the varieties of iron known as malleable-iron, steel, and pig- or cast-iron differ essentially in the amounts of carbon contained, it would

be easy to produce either by properly proportioning the ore, fuel, air, etc.

Iron making on a large scale was introduced into Britain by the Romans, especially in those parts most conveniently situated for purposes of exportation. It is a remarkable circumstance, that in several districts where the existence of extensive iron-beds had not been dreamt of by Englishmen until within the last fifty years, such as those of North Yorkshire and Northamptonshire, the remains of ancient workings recently discovered show that the Roman colonists were acquainted with them. For centuries after the Roman occupation the art was almost lost, for in the time of Edward the Third the metal was so rare, that the pots, and spits, and frying pans were classed amongst his Majesty's jewels. In 1354 it was enacted that no iron, wrought or unwrought, should be exported under heavy penalties. In the sixteenth century a revival appears to have taken place in iron manufacture. The smelting of iron, entirely with wood fuel, caused such an enormous consumption of timber, that an Act was passed in 1581 to check its use within a radius of 20 miles of London.

Early in the seventeenth century we find recorded the first attempts to smelt iron with coal, and about the year 1620 Dud Dudley successfully accomplished this most desirable result, but the secret died with him, and it was not till the early part of the eighteenth century that the method was permanently established. Even at the middle of that century the home manufacture had so fallen off, that four-fifths of the iron used in this country was imported from Sweden. At what period the blast-furnace was established is unknown, but it was probably used as early as the fifteenth century in conjunction with the "finery" for producing malleable iron.

In 1784 Cort introduced his method of refining pig-iron in the puddling-furnace, and rolling the puddled balls

into bars by means of grooved-rolls. This gradually superseded almost all the older methods.

In 1828 James Neilson recommended the use of the hot-blast, in direct opposition to the views of the most eminent metallurgists of the day. Four years after its introduction at the Clyde works, their weekly output was doubled without the consumption of extra fuel, the air being heated to 300° C.

In 1855 a total revolution occurred in the iron trade by the valuable invention of the Bessemer process, an invention, which, as Sir L. Bell says, "will probably for some time, if not permanently, remain as a culminating point in the progress of the manufacture of iron." For some time the invention seemed likely to fail, until Mr. R. F. Mushet proposed to add a manganese compound at the completion of the blow, thus bringing about complete success.

Subsequently, Messrs. Siemens conceived the notion of constructing a furnace in which an intense temperature could be produced, with the aid of heat from the combustion of gaseous fuel. These renowned metallurgists have given to the world an invention, invaluable as a means of producing temperatures hitherto undreamt of, which ranks equal in importance with that of Bessemer. In fact Siemens and Bessemer may truly be said to have inaugurated a new era, termed the "Age of Steel."

The next great advance, made by the collection and utilisation of the waste gases of the blast-furnace, by a Frenchman at Ebbw Vale in South Wales, was so successful, that in a few years it was almost universally adopted, with a saving of a million and a half tons of coal per annum. This utilisation of the waste gases led Mr. Cowper to adopt the regenerative principle of Siemens in stoves for heating the blast, thus placing at the disposal of ironmasters much higher temperatures than before.

Lastly, of quite recent date, Messrs. Thomas & Gilchrist

have adopted the principle of a basic lining for the Bessemer converter, whereby common pig-iron—containing a considerable quantity of phosphorus—may be employed for making good steel. The success of the process has led many experimenters to test the suitability of basic linings for the Siemens furnace, and excellent results have been obtained, so that the dephosphorisation of pig-iron, both in the Bessemer-vessel and in the open-hearth, must now be recognised as an accomplished fact.

CHAPTER II.

Definition of Metallurgical Terms. Refractory Materials. Fuel.

Ore.—An ore is a naturally occurring substance containing a metal, chiefly in the forms of oxide, sulphide, and carbonate. These compounds are generally associated with earthy matter, termed gangue, which may often be separated by mechanical means, such as crushing, washing, and sorting. Some metals are found in nature in the metallic state, when they are said to occur "native."

Calcination and roasting.—When an ore or other substance is subjected to a temperature, insufficient to melt it, but sufficient to expel volatile matter, and render the body more porous and more fit for the subsequent smelting, it is said to be "calcined." When the main object of the process is to oxidise the substance, the operation is termed "roasting."

Slag.—The fusible compound formed by the union of metallic oxides with silica is termed a "silicate," in which other bodies are often dissolved. When such a "silicate" is a waste product of an operation it is termed a "slag." It may be glassy, crystalline, or stony. Rapid cooling tends to produce a glassy slag, while slow

cooling induces the crystalline form. The presence of much lime and other earths renders a slag stone-like in character.

Flux.—A flux is a substance added to ores, or other metalliferous substances, for the purpose of uniting with the foreign matter and forming a fusible slag. The kind of flux added will vary with the nature of the bodies to be removed; thus, a siliceous gangue requires a basic flux, and a basic gangue a siliceous one.

Smelting.—This term in its broadest sense is applied to the whole of the processes by which a metal is extracted from its ores with the aid of heat.

Welding.—When two pieces of metal are joined together by pressure to form one compact mass, they are said to be welded. This union is effected at different temperatures, according to the character of the metal, thus—iron requires a white-heat, but steel must be welded at a lower temperature. It is necessary that the metals should be in a soft condition, with clean surfaces, and that the metal should possess considerable malleability and tenacity; for this reason cast-iron cannot be welded.

Occlusion.—Metals, when melted in contact with air or other gases, absorb them more or less, and retain a portion after solidification; the portion thus retained is said to be occluded.

Cementation.—When a metal is heated in contact with a powder, which modifies its nature and composition, without melting, the process is termed cementation, and the powder employed is termed the cement. Iron is heated in this way with carbon to form steel; this is a "carburising" cementation. When cast-iron is heated with oxide of iron, the oxygen of the latter so modifies the character of the iron that it becomes malleable; this is an "oxidising" cementation.

Fining and refining.—The term "fining" is applied to the operation of purifying pig-iron, either in the

puddling-furnace or in the old charcoal-finery. The term "refining" is applied to a preliminary process originally used to partially purify pig-iron, and convert it into white iron, before fining it.

Hot-short and cold-short.—When a metal cannot be hammered or rolled at or above a low red-heat, without cracking, it is termed "red-short." On the other hand, a metal, which cannot similarly be worked below a low red-heat, is said to be "cold-short."

Metal.—This term is applied to a certain number of the chemical elements which have well defined characters in common, such as metallic lustre, conductivity, and high specific gravity. The influence of heat upon metals is very varied; some melt at a low temperature, others require a red-heat, a strong-red, or a white-heat respectively, to melt them. The following table by Pouillet will explain the temperatures corresponding to different colours:—

Incipient red-heat	corresponds to	525° C.	977° F.
Dull-red	,,	700	1292
Incipient cherry-red	,,	800	1472
Cherry-red	,,	900	1652
Clear cherry-red	,,	1000	1832
Deep-orange	,,	1100	2012
Clear-orange	,,	1200	2192
White	,,	1300	2372
Bright-white	,,	1400	2552
Dazzling-white	,,	1500	2732

Metals expand when heated and contract on cooling, and within certain limits, the expansion is proportional to the range of temperature. Certain anomalies however exist, thus—molten pig-iron expands at the moment of becoming solid, and solidified bismuth occupies a larger space than bismuth in the liquid state. One of the most distinctive features of a metal is an internal mobility, in virtue of which, its shape may be altered by pressure with-

out disruption of the mass. This property is possessed by metals in various degrees, so that the "malleability" or power of being extended by pressure without cracking, and "ductility," or the capability of being permanently elongated by a tensile stress combined with lateral pressure, are by no means equal in extent; nor is the order of their malleability the same as of their ductility, for the former depends on the softness and tenacity, while the latter is much more dependent on tenacity. By "tenacity" or tensile strength is understood the resistance a body offers to an attempt to pull its particles asunder when a stretching force is applied. The tenacity is generally diminished by a rise in temperature, while the reverse is often the case with regard to malleability and ductility. Some metals have a feeble tenacity, and are then said to be brittle. When a body resists rupture by a bending or twisting force, it is said to be "tough." Elasticity is a property of bodies, in virtue of which they tend to recover their size and shape after being subjected to a disturbing force. There is a limit in every solid body, beyond which, it will not return to its original form on the withdrawal of the force; this is termed *the limit of perfect elasticity.* "Hardness," which is measured by resistance to a compressive force, like all the other physical properties of a metal, is modified by the presence of impurities, so that in many cases softness is a test of purity. All malleable metals become hardened by pressure, and often require annealing during the process of manufacture. The fractured surface of metals is often characteristic, being spoken of as fibrous, crystalline, granular, columnar, and conchoidal, thus—wrought-iron is fibrous, zinc is crystalline, steel is granular, tin is columnar, and hard steel is conchoidal. Crystalline structure is often accompanied by brittleness, and fibrous structure by high tenacity. Most metals are much heavier than water, and the ratio which expresses the number of times a body is heavier than an

equal volume of water is termed its "specific gravity." The "specific heat," or the capacity of a body for heat, extends over a wide range with regard to metals; iron for example being $\frac{1}{10}$th that of water, while lead is less than $\frac{1}{30}$. The oxides of metals are usually basic in character, but this property is only relative, as an oxide which is basic in one compound may become acid when allied with a stronger base.

Alloys.—By uniting two or more metals in various proportions an almost infinite variety of combinations may be obtained, possessing to a greater or less extent the properties of their constituents; these are termed "alloys." The effect of this is, generally, to increase the hardness, alter the specific gravity, and otherwise modify the character of the components. The melting point of an alloy is usually less than the mean of the constituents, and sometimes below that of either.

Refractory Materials.

In any hearth or furnace where a high temperature is desired, it is necessary that it should be lined inside with a material capable of withstanding the heat, and scorifying action of the matter operated upon, without melting. Refractory materials are either used in the natural state, such as silica, alumina, lime, magnesia, oxides of iron and fire-clay; or they are made to undergo a certain preparation. In some cases the materials are moulded to the internal shape of the furnace. If they are not of a plastic nature, such as lime and magnesia, tar or some other binding material is added, to give the necessary plasticity. Fire-bricks are generally made of fire-clay mixed with burnt-clay and white sand, which prevent the bricks cracking, and diminish the fusibility. The composition differs with the purposes for which the refractory materials are designed. In some cases they are required to withstand

a high and prolonged temperature without softening; in others they are required to withstand great pressure; in others to resist the corrosive action of metallic oxides; and in others to withstand great and sudden changes of temperature.

Crucibles are open-mouthed vessels in which metals and other bodies may be strongly heated with safety. They are made of mixtures of clays in the raw and in the burnt state, or the same mixed with coke dust and graphite, the most refractory being those made with clays containing the largest amount of silica, and the smallest quantity of lime and oxide of iron. When graphite is used, with sufficient clay to impart the requisite plasticity, they are termed black-lead or plumbago pots. Good plumbago crucibles resist sudden changes of temperature, and may be used several times, until they are worn too thin to bear the weight of the metal. The crucibles used for making steel at Sheffield are made of a mixture of Burton and Stannington clays, mixed with burnt clay and a little coke-dust.

Refractory materials are either acid, such as ganister and Dinas clay; neutral, such as kaolin (fire-clay); or basic, such as dolomite, bauxite, alumina, etc. A substance is termed acid, neutral, or basic, when the acid is greater, equal to, or less in equivalence than the base. (See p. 21.)

Ganister is a highly siliceous substance, with sufficient plasticity to enable it to be used for lining a furnace, such as the Bessemer converter.

Dinas clay is more siliceous than ganister and highly refractory. It is devoid of plasticity, so that it requires a little clay to be mixed with it, in order to mould it into bricks, which are termed silica-bricks.

Fire-clay is essentially a hydrated silicate of alumina, which resists a high temperature without softening; all other bodies that may be present may be considered as impurities, which generally tend to make it more fusible,

especially potash and soda. Its plasticity or power of being moulded into different shapes is owing to its chemically combined water.

Dolomite ($CaCO_3 + MgCO_3$) is a double carbonate of lime and magnesia. When it is strongly heated, carbonic acid is expelled, leaving caustic lime and magnesia ($CaO + MgO$). If this double oxide be exposed to air, it re-absorbs carbonic acid and water. This substance is used for lining furnaces which require a "basic" fettling.

Bauxite and Belfast ore.—Bauxite is a basic substance generally containing but little silica, found in the south of France. It is highly refractory and requires the addition of a little clay to render it plastic. Belfast aluminous-ore is similar to Bauxite.

ANALYSES OF REFRACTORY SUBSTANCES.

		Ganister.	Dinas clay.	Fire-clay.	Bauxite.	Belfast ore.
Silica, - - - - -	SiO_2	89·5	98·3	63·30	2·8	9·87
Alumina, - - - -	Al_2O_3	4·8	·7	23·30	57·4	34·57
Ferrous oxide, - -	FeO	2·8	·2	1·80	—	5·08
Ferric oxide, - -	Fe_2O_3	—	—	—	25·5	27·93
Lime, - - - - -	CaO	·4	·2	·73	·2	·91
Magnesia, - - -	MgO	·2	—	—	—	·62
Potash, - - - -	K_2O	·1	·1	—	—	—
Titanium oxide, -	TiO_2	—	—	—	3·1	3·51
Water and Volatile matter,	—	2·2	·5	10·87	11·0	17·51

FUEL.

By this term is meant—substances that may be burned in air, giving heat capable of being applied to economic purposes. The two chief elements employed are carbon and hydrogen, the latter in fuels being always asso-

The bodies used as fuel are—wood, peat, coal, petroleum, and natural gas. From some of these are obtained prepared fuels, such as charcoal, coke, etc.

Charcoal is prepared by heating wood to a temperature of about 400° C. in a covered pile, or in a closed vessel, so as to admit only a limited supply of air. This is the purest form of solid fuel.

Coke is made in a similar way to charcoal in piles, in kilns, and in ovens. The bee-hive-oven Fig. 1 is a somewhat circular chamber of brickwork, with an arched roof, having a chimney opening at the top for the escape of the products of combustion and vapours. The cavity is about 9 feet to 10 feet in diameter, and 4 feet to 5 feet high. The charge is introduced through a doorway in front, about $2\frac{1}{2}$ feet square, through which the charge is also withdrawn. These ovens are generally built in two rows back to back, with a charge of three tons in each, which reaches up to the springing of the dome of the roof. When the charging is completed, the doorway is loosely filled up with bricks, through the openings of which the air can pass. In some ovens an iron door is used. Supposing the oven to be hot from a previous charge, in three hours the lower holes are closed, and in twenty-four hours the upper ones are closed. The oven is now allowed to remain twelve hours with the chimney open. When the flame ceases, the damper is closed, and the oven allowed forty-eight hours to cool. The charge is then withdrawn by means of a large shovel suspended by a crane, and the hot coke quenched with water.

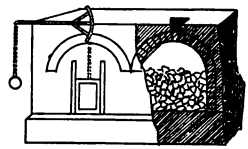

Fig. 1.

Pyrometers.—The heat of a furnace is measured by an instrument called a "pyrometer." A good pyrometer must be capable of giving a constant indication for the same temperature, and must not

change with use. Various methods are employed for this purpose.

The temperature of the hot-blast, used for the blast-furnace, is generally determined by its power of fusing certain metals whose melting points are known. Tunner uses different alloys of silver and platinum for measuring the temperature of a furnace. Pouillet exposes a ball of copper or of platinum of given weight to the heat of the furnace, and then rapidly transfers it through a clay tube to a vessel containing a known weight of water, at a known temperature. From the increase in temperature of the water the temperature of the furnace is calculated. The mode of calculation is as follows :—

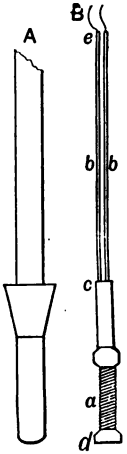

Fig. 2.

$$T = \frac{W \times (t' - t)}{w \times s};$$

T is the temperature, $t' - t$ the rise in tem perature of water, W the weight of water, w the weight of ball, and s its specific heat. To this result must be added the observed temperature of the water. Daniell estimated high temperatures by means of a rod of platinum placed in a plumbago tube. The inner end of the platinum was fixed, while the outer end pressed against a lever serving as an index. He assumed that the expansion was proportional to the temperature. Siemens' electric resistance pyrometer is far superior to the foregoing arrangements and is represented in part in Fig. 2. It consists of a platinum spiral (a) of known resistance, wound on a cylinder of fire-clay, and enclosed in a casing of platinum or copper according to the temperature to be measured. The two cnds of the coil are connected by thick platinum wires with two thick copper wires, at the part which is less strongly heated. These wires are insulated by

pipeclay tubes (*bb*) and communicate with the measuring instrument by which the resistance is measured. The electric resistance of platinum is increased fourfold by a rise in temperature from 0° to 1650° C. The portion (*c d*) which is exposed to the highest temperature of the furnace is encased in wrought iron or platinum, and the outer portion (*c e*) is enclosed in an iron tube. The outer tube is shown in Fig 2A, and the resistance arrangement in Fig. 2B.

QUESTIONS.

1. What is an ore? In what condition are iron ores for example usually found?
2. What do you understand by the term "dressing" as applied to ores? Mention cases in which this is unnecessary.
3. What object is gained by submitting an ore to calcination or roasting?
4. What is a slag; how is it formed; and for what purpose is it produced?
5. What is a flux? By what principles would you be guided in the choice of a flux?
6. What conditions are necessary to produce a good weld? Why will not pig-iron weld?
7. What do you understand by the term "cementation" as applied to iron and steel?
8. Explain the terms "fining" and "refining" and mention operations to which your answer is applicable.
9. What is meant by the terms "red-short" and "cold-short" when applied to malleable iron, and to what causes are those properties commonly attributed?
10. What are the most characteristic properties of a metal? What do you understand by the term "metal"?
11. Explain the terms "malleability," "ductility," and "tenacity" as applied to metals.
12. What do you understand by a "tough" metal?
13. Define the terms "elasticity" and "limit of elasticity."
14. Name the different kinds of fracture in metals and give an example of each kind.

15. What do you understand by a refractory substance? Give a few examples.

16. What is a crucible? Of what materials are crucibles made?

17. What is fire-clay? How does it differ from sand?

18. What is the nature of the substance called "ganister" and for what purposes is it used?

19. What is Dinas clay? How is it made into bricks?

20. What is dolomite, and for what purposes is it employed in steel making?

21. What kind of a substance is Bauxite? Under what circumstances would you use it as a furnace-lining?

22. What is charcoal, coke, and anthracite?

23. What is the use of a pyrometer? Describe any useful pyrometer with which you are acquainted.

CHAPTER III.

Chemical Principles and Changes.

THE present chapter is intended for the non-chemical student, so as to impart a better conception of the chemical changes involved in the various operations connected with iron and steel manufacture.

Chemists have found that all bodies, whether in the form of a solid, a liquid, or a gas, are either simple substances or can be resolved into simple substances, termed "elements." These elements are represented by symbols, which are usually the initial letter or letters of their names. Different elements combine together in definite proportions forming an endless variety of substances, termed "compounds."

Elements are classified into "metals" and "non-metals," the former being distinguished by well marked properties, which are absent in the latter. The ultimate particles or "atoms" which compose any element differ in weight

from the atoms of any other element, and the relative weight compared with hydrogen is termed the "atomic weight." The following elements are referred to in the present work.

Metal.	Symbol.	Atomic weight.	Non-Metal.	Symbol.	Atomic weight.
Aluminium,	Al	27·4	Carbon,	C	12
Arsenic,	As	75	Hydrogen,	H	1
Calcium,	Ca	40	Nitrogen,	N	14
Chromium,	Cr	52	Oxygen,	O	16
Copper,	Cu	63	Phosphorus,	P	31
Iron (Ferrum),	Fe	56	Silicon,	Si	28
Magnesium,	Mg	24	Sulphur,	S	32
Manganese,	Mn	55			
Titanium,	Ti	50			
Tungsten or Wolfram,	W	184			

Compounds are formed, as already stated, by the combination of different elements, thus; FeO represents oxide of iron, and MnO oxide of manganese. In many cases two elements unite in more than one proportion, such as FeO, Fe_2O_3, Fe_3O_4, each of which requires a distinguishing name. There are several systems of nomenclature, but the simplest—for compounds containing two elements—is that of writing the name of the metal first, and the non-metal or least metallic element afterwards, giving it the termination "ide." When two non-metals combine, the one which is most unlike a metal is written second. Sometimes Greek prefixes are used for the element of the second position, such as mono, di, tri, tetr, etc., to indicate the number of atoms present.

Another system is to make the metal terminate in "ic" or "ous." That compound which contains the greater proportion of the non-metallic constituent is distinguished by the suffix "ic" and that containing the lesser in "ous." The following list will illustrate these points.

Name.	Name.	Name.	Formula.
Iron oxide,	Ferrous oxide,	Iron protoxide,	FeO.
Iron trioxide,	Ferric oxide,	Iron sesquioxide,	Fe_2O_3.
Iron tetroxide,	Triferric tetroxide,	Black oxide of iron,	Fe_3O_4.
Manganese oxide,	Manganous oxide,	Manganese protoxide,	MnO.
Manganese dioxide,	Manganic oxide,	Manganese peroxide,	MnO_2.
Aluminium oxide,	Aluminic oxide,	Alumina,	Al_2O_3.
Calcium oxide,	Calcic oxide,	Lime,	CaO.
Magnesium oxide,	Magnesic oxide,	Magnesia,	MgO.
Titanium dioxide,	——	Titanic acid,	TiO_2.
Carbon monoxide,	Carbonic oxide,	——	CO.
Carbon dioxide,	——	Carbonic acid,	CO_2.
Silicon dioxide,	Silicic oxide,	Silica,	SiO_2.
Phosphorus pentoxide,	Phosphoric oxide,	Phosphoric acid,	P_2O_5.
Sulphur dioxide,	Sulphurous oxide,	Sulphurous acid,	SO_2.
Sulphur trioxide,	Sulphuric oxide,	Sulphuric acid,	SO_3.

When three elements—one being a metal and another oxygen—are combined together, the name of the second is made to end in "ate." In the following list a few compounds are given to illustrate this, but it should be observed that the order of placing the symbols is immaterial. In works on metallurgy the arrangement of formulæ in the last column is most common.

Name.	Name.	Formulæ.
Iron silicate,	Ferrous silicate,	$FeSiO_3$ or $FeO.SiO_2$.
,, ,,	,, ,,	Fe_2SiO_4 or $2FeO.SiO_2$.
Iron sulphate,	Ferrous sulphate,	$FeSO_4$ or $FeO.SO_3$.
Calcium silicate,	Silicate of lime,	$CaSiO_3$ or $CaO.SiO_2$.
Aluminium silicate,	Silicate of alumina,	$Al_4Si_3O_{12}$ or $2Al_2O_3.3SiO_2$
Calcium carbonate,	Carbonate of lime (Limestone),	$CaCO_3$ or $CaO.CO_2$.
Iron carbonate,	Ferrous carbonate,	$FeCO_3$ or $FeO.CO_2$.

Equations.—When two or more elements unite to form a compound, or two compounds unite to form a more complex compound, the change may be represented by a chemical equation, thus;—

3Fe	+	4O	=	Fe_3O_4.
Iron.		Oxygen.		Iron tetroxide.
3×56		4×16		$168 + 64$

FeO	+	SiO_2	=	$FeO.SiO_2$.
Ferrous oxide.		Silica.		Ferrous silicate.
$56 + 16$		$28 + 32$		$72 + 60$

Any chemical change may be so represented, the bodies taking part in the change being placed on the left hand side of the sign of equality "=", and the bodies formed after the change, on the right hand side.

The quantities involved in any such change can be seen at a glance, since the symbol of an element represents a definite weight, given in the table, p. 17, as the atomic or combining weight. Thus, in the first equation 3×56 parts of iron unite with 4×16 parts of oxygen to form $168 + 64 = 232$ parts of the black oxide of iron.

When a chemical change occurs, the production or absorption of heat is the result, the former by the union of elements or compounds, the latter by the forcible separa-

tion of the constituents of a compound. When the temperature produced is considerable, it is usual to speak of it as combustion; thus, carbon combines with oxygen to produce carbonic acid and generates intense heat.

$$\underset{\text{Carbon.}}{C} + \underset{\text{Oxygen.}}{2O} = \underset{\text{Carbonic acid.}}{CO_2}$$

In common language it is said to burn, and the burning of fuel is simply the result of chemical combination.

When substances combine with oxygen they are said to be "oxidised," and the substance which imparts the oxygen is termed an oxidising agent. Conversely, substances which remove oxygen from a body are termed reducing agents. The following lists give some examples of both kinds.

Oxidising Agents.	*Reducing Agents.*
Oxygen (O).	Carbon (C).
Air (O and N).	Carbonic oxide (CO).
Iron tetroxide (Fe_3O_4).	Hydrogen (H).
Iron trioxide (Fe_2O_3).	Compounds of carbon and hydrogen, such as coal-gas.
Slags containing the above or similar oxides.	All fuels.
Carbonic acid (CO_2).	Sometimes metals.
Water (H_2O).	

Examples of Oxidation.

$$\underset{\text{Ferrous oxide.}}{3\,FeO} + \underset{\text{Oxygen.}}{O} = \underset{\text{Iron tetroxide.}}{Fe_3O_4}$$

$$\underset{\text{Tap-cinder.}}{2(2FeO.SiO_2)} \quad \underset{\text{Oxygen.}}{O} = \underset{\text{Bull dog.}}{Fe_2O_3} + \underset{\text{Bull-dog slag.}}{2(FeO.SiO_2)}$$

$$\underset{\text{Iron carbonate.}}{3FeCO_3} + \underset{\text{Oxygen.}}{O} = \underset{\text{Iron tetroxide.}}{Fe_3O_4} + \underset{\text{Carbonic acid.}}{3CO_2}$$

$$\underset{\text{Ferrous oxide.}}{3FeO} + \underset{\text{Carbonic acid.}}{CO_2} = \underset{\text{Iron tetroxide.}}{Fe_3O_4} + \underset{\text{Carbonic oxide.}}{CO}$$

Examples of Reduction.

$$\underset{\text{Ferric oxide.}}{Fe_2O_3} + \underset{\text{Hydrogen.}}{6H} = \underset{\text{Iron.}}{2Fe} + \underset{\text{Water.}}{3H_2O}$$

$$\underset{\text{Ferric oxide.}}{Fe_2O_3} + \underset{\text{Carbon.}}{3C} = \underset{\text{Iron.}}{2Fe} + \underset{\text{Carbonic oxide.}}{3CO}$$

$$\underset{\text{Ferric oxide.}}{Fe_2O_3} + \underset{\text{Carbonic oxide.}}{3CO} = \underset{\text{Iron.}}{2Fe} + \underset{\text{Carbonic acid.}}{3CO_2}$$

$$\underset{\text{Ferric oxide.}}{Fe_2O_3} + \underset{\text{Carbonic oxide.}}{CO} = \underset{\text{Ferrous oxide.}}{2FeO} + \underset{\text{Carbonic acid.}}{CO_2}$$

It will be obvious that in the cases of oxidation and reduction, the change may be partial or complete. Thus, iron is completely oxidised when converted into Fe_2O_3, and oxide of iron is completely reduced when all the iron is brought to the metallic state.

The following is a short description of the chief substances mentioned in the present chapter and which are subsequently alluded to.

Oxygen (O).—This is the most abundant element, forming probably one half the solid mass of the earth, $\frac{8}{9}$ths of all water, and about 21 per cent. by volume of the air. It is necessary for life and all ordinary processes of combustion. In the air it is a gas, but in its compounds it is chiefly a solid or a liquid. Its oxidising action has been already mentioned. It is the chief supporter of combustion, that is, it forms the active medium in which bodies burn.

Oxides, as the compounds of oxygen with other elements are termed, are divided into two groups:—1°. Those which have an acid character, chiefly oxides of the non-metals, and often termed acids, such as carbonic acid CO_2 and silica SiO_2. 2°. Those of a basic character, chiefly oxides of the metals, which are termed bases. These two classes are opposite in character, and when united in equivalent proportions, neutralise each other, forming what are termed "neutral" bodies, which do not possess the characteristic properties of either kind. Thus

silica SiO_2 will neutralise oxide of iron FeO, forming a silicate which is neither acid or basic. If any compound contain an excess of acid or base, it is classified either as an acid or as a basic substance, according to the kind which predominates. Thus, $3FeO . SiO_2$ is a basic silicate, and $FeO.SiO_2$ an acid silicate, because in the former there is more FeO than is required to neutralise the acid SiO_2, and in the latter less than is necessary for this purpose.

Hydrogen (H) is chiefly found in nature in combination with oxygen, forming water (H_2O), which contains $\frac{1}{9}$th its weight of hydrogen. It differs from other non-metals in not uniting with metals to form compounds, but metals such as palladium and iron absorb it in large quantities, when it is said to be occluded. It burns in air or in pure oxygen, forming water, and evolving great heat: $2H + O = H_2O$.

It is a constituent of wood, peat, coal and coal-gas, part of it probably existing as water; and in combination with carbon it forms what are termed hydro-carbons, such as marsh-gas CH_4, and olefiant-gas C_2H_4. When the latter are burnt the hydrogen forms water, thus:

CH_4	+	$4O$	=	CO_2	+	$2H_2O$	
Marsh-gas.		Oxygen.		Carbonic acid.		Water.	
C_2H_4	+	$6O$	=	$2CO_2$	+	$2H_2O$	
Olefiant-gas.		Oxygen.		Carbonic acid.		Water.	

In some furnaces and gas-producers, steam is introduced along with air to increase the volume of combustible gases, but only a very limited amount of steam can be used for this purpose (see p. 96).

Nitrogen (N) forms about 79 per cent by volume of the air, its chief function being to modify the active properties of oxygen. It neither burns nor supports combustion, so that the nitrogen which enters a furnace, for the most part, comes out unchanged, thus robbing it of a large amount of heat without contributing any itself.

Air is simply a mixture of oxygen and nitrogen along

with small quantities of water and carbonic acid. Omitting the latter, its composition may be taken as:—

	By Volume.	By Weight.
N	79	77
O	21	23
	100	100

A ton of air thus contains about 515 lbs. of oxygen. Air resembles oxygen in its properties, but is less active on account of the inactive nitrogen.

Silicon (Si).—This non-metal is a greyish-black substance. It is generally present in iron, and supposed to exist, like carbon, in the "free" and in the "combined" state. It is of little importance as an element, but in combination it forms about $\frac{1}{4}$th of the earth's crust. It burns in oxygen, forming silica, thus:

$$\underset{\text{Silicon.}}{Si} + \underset{\text{Oxygen.}}{2O} = \underset{\text{Silica.}}{SiO_2}$$

Silica (SiO_2) plays a prominent part in the manufacture of iron and steel, being the chief slag-forming substance. It exists largely as sand, and in combination with "bases" termed silicates. The various slags are chiefly combinations of SiO_2 with alumina Al_2O_3, lime CaO, ferrous oxide FeO, manganese oxide MnO, etc., which fuse at high temperatures. Uncombined silica is practically infusible.

Carbon (C).—This non-metal is an essential constituent of all living matter, and of all ordinary fuels, such as coal. It exists in the free state as the diamond, and as graphite or black-lead. In the latter form it is used in the manufacture of crucibles, etc., because of its infusibility and its non-tendency to form fusible slags with acid or basic substances. It will burn away in contact with air, but will not melt or vapourise. It exists in pig-iron and steel in the free and in the

combined state. Part of the free carbon of pig-iron sometimes rises to the surface of the molten mass when allowed to stand, and is known as "kish." Charcoal and coke are almost entirely composed of carbon, with a little earthy matter, which is left as ash when the carbon is burnt. Either form of carbon will burn in oxygen, forming oxides. When carbon is strongly heated in the presence of steam the latter is decomposed and the carbon oxidised thus:

$$\underset{\text{Carbon.}}{C} + \underset{\text{Water.}}{H_2O} = \underset{\text{Hydrogen.}}{H_2} + \underset{\text{Carbonic oxide.}}{CO}$$

$$\underset{\text{Carbon.}}{3C} + \underset{\text{Water.}}{2H_2O} = \underset{\text{Marsh-gas.}}{CH_4} + \underset{\text{Carbonic oxide.}}{2CO}$$

Carbon dioxide or carbonic acid (CO_2) is a gas, about 1½ times the weight of air, and is formed when carbon is burned in oxygen or in a free supply of air, thus:

$$\underset{\text{Carbon.}}{C} + \underset{\text{Oxygen.}}{2O} = \underset{\text{Carbonic acid.}}{CO_2}$$

Also when carbonic oxide is burned in air or oxygen, thus:

$$\underset{\text{Carbonic oxide.}}{CO} + \underset{\text{Oxygen.}}{O} = \underset{\text{Carbonic acid.}}{CO_2}.$$

If carbon dioxide is brought in contact with red-hot carbon, it takes up some of the latter, forming twice its volume of carbonic oxide CO, thus:

$$\underset{\text{Carbonic acid.}}{CO_2} + \underset{\text{Carbon.}}{C} = \underset{\text{Carbonic oxide.}}{2CO}.$$

In this case carbonic acid is oxidising. CO_2 is not poisonous, but it will not support life or combustion.

Carbon monoxide or carbonic oxide (CO) is a colourless gas, about the same weight as air, extremely poisonous, and burns in air or oxygen with a blue flame, producing carbonic acid, and evolving considerable heat. The gas formed in gas-producers is chiefly carbonic oxide.

It is a powerful reducing agent, probably the chief agent in reducing oxide of iron in the blast-furnace, thus :

$$\underset{\text{Ferric oxide.}}{Fe_2O_3} + \underset{\text{Carbonic oxide.}}{3CO} = \underset{\text{Carbonic acid.}}{3CO_2} + \underset{\text{Iron.}}{2Fe}.$$

At high temperatures CO is decomposed (dissociated), especially in the presence of other bodies, such as iron, which combine with carbon.

$$\underset{\text{Carbonic oxide.}}{2CO} = \underset{\text{Carbon.}}{C} + \underset{\text{Carbonic acid.}}{CO_2}$$

This is probably the case in the blast-furnace, and in the cementation process for steel.

Phosphorus (P).—This non-metal is generally a waxy-looking crystalline solid, which readily melts and vapourises. It is highly inflammable in air, forming a white cloud of phosphorus pentoxide P_2O_5, also called phosphoric acid. It combines with oxygen in two proportions, forming oxides of phosphorus. One of these oxides unites with bases to form compounds termed phosphates. It probably exists in iron and steel as an element, but in slags as a phosphate. Thus : phosphate of iron ($3FeO.P_2O_5$) is found in tap-cinder, and phosphate of lime ($4CaO.P_2O_5$) in basic slag.

Phosphates are decomposed by silica at high temperatures, because under these conditions SiO_2 is non-volatile, thus :

$$\underset{\text{Iron phosphate.}}{3FeO.P_2O_5} + \underset{\text{Silica.}}{SiO_2} = \underset{\text{Iron silicate.}}{3FeO.SiO_2} + \underset{\text{Phosphoric acid.}}{P_2O_5}.$$

Phosphoric acid is reduced by carbon or even by iron, the phosphorus uniting with the iron, thus :

$$\underset{\text{Phosphoric acid.}}{P_2O_5} + \underset{\text{Carbon.}}{5C} = \underset{\text{Carbonic oxide.}}{5CO} + \underset{\text{Phosphorus.}}{2P}.$$

Sulphur (S) is a non-metal, and solid at ordinary temperatures. It readily melts and vapourises, and unites with metals forming sulphides, such as ferrous

sulphide FeS. With oxygen it forms oxides, viz., sulphur dioxide SO_2, and sulphur trioxide SO_3.

Manganese (Mn) is a metal somewhat resembling iron, and unites with oxygen in several proportions, but its oxides are more difficult to reduce than those of iron, in consequence of the greater affinity of manganese for oxygen. For this reason, manganese, when present with iron, tends to prevent iron from being oxidised, as in the case of puddling.

Chromium (Cr) is a metal somewhat similar in its character and properties to manganese.

Aluminium (Al) is a white metal, soft, malleable, and ductile, and does not oxidise in air. It only forms one oxide, alumina Al_2O_3.

Calcium (Ca) is a metal with so strong an affinity for oxygen that it is seldom obtained in the uncombined state. As calcium oxide or lime CaO it forms the base in limestone $CaO.CO_2$, and with silica it forms a variety of silicates, such as $CaO.SiO_2$, etc.

Fusion and solution.—When a body is melted by heat, it is said to undergo "fusion"; but when a body is absorbed by a liquid, it is said to be dissolved, and the liquid is then termed a solution. Thus, iron in the state of fusion will dissolve carbon, and when the solution solidifies the carbon may be retained, when it is said to be in the "combined" form; or the carbon may separate in crystals of "graphite," which is also termed free carbon. The condition in which a body separates from its solution depends upon the rate of cooling; the more gradual the change from the liquid to the solid state, the more perfect will the separation be. Liquids not only dissolve solids but also gases, thus; Bessemer steel absorbs air and other gases, some of which are expelled on cooling, some are retained and are said to be occluded, whilst some act chemically on the steel, and alter its properties. Metals in a spongy state also possess the power of occluding gases under

certain circumstances, sometimes to a remarkable extent. (See p. 6.)

QUESTIONS.

1. Define the terms "atom," "element," "compound," "metal," and "non-metal."
2. What do you understand by the atomic weight of an element?
3. How is an element and a compound usually represented?
4. Upon what principles is the naming of chemical compounds based? Write the names for FeO, Al_2O_3, and MnO_2.
5. What do you understand by a chemical equation? What advantage is gained by its use?
6. What is the general result of chemical action?
7. Define the terms oxidation and reduction, and give examples of each.
8. What is an oxide? Give examples.
9. Clearly explain the difference between an acid- and a basic-substance.
10. Describe the properties of the gases hydrogen and nitrogen.
11. What is the difference in character and properties between silicon and silica? What is a silicate?
12. Describe the different forms of carbon. What are the general effects of carbon on iron?
13. What is the chief difference between carbonic acid and carbonic oxide from a metallurgical point of view?
14. What is the difference between phosphorus and phosphoric acid? What is a phosphate?

CHAPTER IV.

ORES OF IRON, COMPOUNDS, ETC.

Native iron.—Iron in the metallic state is of very rare occurrence, which may be accounted for by its great

affinity for oxygen and other non-metals. Large masses of iron, known as meteorites, are occasionally found in different parts of the world; they are easily distinguished from the masses of terrestrial origin, as they invariably contain nickel (which very rarely occurs in ordinary iron ores) and the metal is usually found in a mass containing crystals. The mass is nearly always covered on the surface with a thin coating of oxide, which protects the metal from oxidation. Berzelius gives the analysis of a mass from Siberia weighing 1600 lbs., and of one from Bohemia weighing 103 lbs. Stromeyer analysed an enormous mass found near Treves which weighed 3300 lbs.

Locality.	Bohemia.	Siberia.	Treves.
Analyst.	Berzelius.		Stromeyer.
Iron,	93·78	88·04	81·8
Nickel,	3·81	10·73	11·9
Cobalt,	·21	·46	1·0
Copper,	—	·07	—
Manganese,	—	·13	0·2
Magnesium,	—	·05	—
Carbon,	—	·04	—
Sulphur,	—	—	5·1
Insoluble Matter,	2·20	·48	—
	100·00	100·00	100·00

Iron occurs in a great variety of minerals, but the oxides and carbonates are almost the only forms utilised by the smelter.

Magnetite or magnetic iron ore.—When pure it contains 72·41 per cent. of iron, and is represented by the formula Fe_3O_4. It is sometimes crystalline, but more

generally massive. It is black or dark brown in colour, brittle, magnetic, and leaves a black streak when drawn across a plate of unglazed porcelain; it has a specific gravity of about 5·2. It occurs in granite, gneiss, clay-slate, hornblende, chlorite, and occasionally in limestone. Nearly all the Swedish iron is obtained from this ore, which also occurs in great abundance in the island of Elba and in the United States of America.

Franklinite.—This ore is similar in colour to magnetite, but less magnetic, occurring in crystals and massive. It gives a dark reddish brown streak, and has a specific gravity of about 5·1. It consists of ferrous and ferric oxides, manganous and manganic oxides, and oxide of zinc. It is chiefly found in New Jersey, and is used as a source of zinc, and spiegel-eisen.

Hæmatite.—Composition Fe_2O_3, containing 70 per cent. of iron when pure. It exists in crystals, in fibrous, columnar, kidney-shaped, granular, and compact forms. Its colour varies from dark iron-grey in the crystallised, to deep red in the compact varieties. Its specific gravity is as high as 5·3 when in crystals, and as low as 4·2 in earthy varieties. Special names are given to different forms, thus :—Specular ore, as in the brilliant crystalline species of Elba and Brazil. Micaceous ore, as in the scaly varieties of South Devon. Kidney ore, as that from Cumberland. Red ochre is a compact earthy variety, often containing clay. Puddlers' ore is a compact, unctuous form from Cleveland, and used for lining puddling furnaces. Spanish or Bilbao ore is a siliceous hæmatite containing manganese, and noted for its purity, hence its use in the open-hearth steel process.

Ilmenite or titaniferous iron ore.—This is a dead black mineral, generally found massive, consisting of ferrous and ferric oxides, titanic oxide and magnesia. It gives a brownish streak, and its specific gravity varies from 4·5 to 5. It may be typically represented by the formula $FeO.TiO_2 + MgO.TiO_2$.

Turgite.—This is an ore resembling hæmatite in colour and streak, but is hydrated, consisting of 94·7 per cent. ferric oxide, and 5·3 per cent. water. Formula $2Fe_2O_3$, H_2O. It occurs both compact and fibrous. Its specific gravity varies from 4·2 to 4·7.

Brown hæmatite.—This class, which contains several varieties, is distinguished by its brown or yellowish-brown colour, its brown streak, and a considerable proportion of water. It is chemically a hydrated ferric oxide. The different forms are :—Göthite, Fe_2O_3, H_2O; brown iron ore or limonite, pea ore, yellow ochre, and bog ore, $2Fe_2O_3$, $3H_2O$. Its specific gravity varies from 3·6 to 4·4. Oolitic deposits, like those of Northamptonshire, frequently contain phosphorus from the fossil remains of organic matter.

Siderite or spathic iron ore.—This is a carbonate of iron $FeCO_3$. The purer varieties occur in crystalline forms, the more impure and most abundant occur in beds of considerable thickness, or in detached nodules in the clay and shales of the coal measures. This class is the chief source of British iron. Manganese is often present in spathic ore, in some cases to the extent of 50 per cent. The pig-iron obtained from rich manganese ores is termed spiegel-eisen. Siderite contains 48·27 per cent. of iron, the crystals have a pearly lustre of a yellowish-brown or grey colour, owing to a surface coating of hydrated oxide. The streak is white, representing the true colour of the mineral. Clay-ironstone is a compact earthy variety containing clay, and of a brown colour. Black-band is a carbonate, mixed with carbonaceous matter, frequently in laminæ, amounting in some varieties to 20 and even 30 per cent. These ores are often very impure, containing carbonates of lime, magnesia, and manganese; clay, potash, phosphoric and sulphuric acids, iron and copper pyrites, along with water and organic matter.

The following table shows the composition of different ores of iron :—

Name.	Magnetic Iron Ore.	Red Hæmatite.	Brown Iron Ore.	Spathic Ore.	Clay Ironstones.		Cleveland Ore.
Locality.	Dannemora.	Ulverstone.	Dean Forest.	Brendon, Somersetshire.	Blackband, Lowmoor	Dudley.	Eston.
Ferric oxide (Fe_2O_3)	27·55	93·23	90·05	·81	1·45	·40	3·60
Ferrous ,, (FeO),	58·03	—	—	43·04	36·14	45·86	39·92
Manganese oxide (MnO),	·10	·23	·08	12·64	1·38	·96	·95
Alumina (Al_2O_3),	·29	·63	·14	·01	6·74	5·56	7·86
Lime (CaO),	·38	·05	·06	·28	2·70	1·37	7·44
Magnesia (MgO),	·61	—	·20	3·63	2·17	1·85	3·82
Potash (K_2O),	—	—	—	—	·65	—	·27
Silica (SiO_2),	12·54	4·90	·92	·07	17·37	10·68	8·76
Carbon dioxide (CO_2),	·12	—	—	38·86	26·57	31·02	22·85
Phosphorus pentoxide (P_2O_5),	—	—	·09	—	·34	·21	1·86
Sulphuric acid (SO_3)	—	·09	—	—	—	—	—
Sulphur,	·04	—	—	—	—	—	·11
Iron pyrites (FeS_2),	—	·03	—	—	·10	·10	—
Water,	·11	·56	8·22	·18	1·77	1·08	2·56
Organic matter,	—	—	—	—	2·40	·90	—

Iron pyrites.—This mineral is very abundant in nature, and is only used as a source of iron after the sulphur has been removed in the manufacture of sulphuric acid, when the resulting oxide is known as "blue billy." The chemical formula is FeS_2. Some varieties are bronze-yellow in appearance, others are nearly white, with a metallic lustre; the streak is brownish black, and the specific gravity varies from 4·8 to 5·1.

British ores.—The chief ores of Britain are spathic

ores and hæmatites, although magnetites and pyrites are present, the latter to a considerable extent in some localities. Clay-ironstone occurs abundantly in Staffordshire, Yorkshire, Derbyshire, Warwickshire, Shropshire, North and South Wales, and Scotland; black-band, in Lanarkshire, Linlithgowshire, North Staffordshire, and South Wales; red hæmatite, in North Lancashire, Cumberland, and North Wales; brown hæmatite, in Gloucestershire, Glamorganshire, Northamptonshire, Leicestershire, Lincolnshire, Buckinghamshire, and Oxfordshire. Of the above ores, hæmatite is valuable for producing pig-iron for the Bessemer process, on account of its freedom from phosphorus and sulphur. It is also used as the cement in producing malleable cast iron, and as a fettling for puddling-furnaces, etc.

Chemical relations of iron.—Pure iron is not a commercial article except as a medicine, but it may be obtained in several ways. 1°. By reducing pure ferric oxide in a porcelain tube by means of a current of hydrogen gas at 700° C.; the iron is obtained in the form of a dark powder, which when somewhat heated, fires spontaneously in contact with air, forming Fe_2O_3. When the reduction is effected at a much higher temperature, a spongy mass of a silvery-grey colour is obtained. 2°. By strongly heating the purest variety of iron wire with a little pure oxide of iron, covering the mixture with powdered glass free from lead, and exposing the whole to a high temperature in a covered clay crucible. The small portion of carbon present in the wire is removed in reducing the oxide, while the other impurities pass into the slag. 3°. By electrolytic decomposition of a solution of pure ferrous chloride or sulphate, a mass of silvery-white, soft, malleable iron is obtained, which, after annealing, has a specific gravity of 7·81.

Iron may be exposed to dry air for an indefinite period without alteration, but in the presence of moisture a

layer of rust (Fe_2O_3, $3H_2O$) is formed. The oxidation is accelerated by the presence of carbonic acid, which is always present in the air, a carbonate of iron being formed. This rapidly absorbs a further portion of water and oxygen from the air, and in this way the rusting is slowly conveyed to the centre of the mass of iron. The layer of oxide or carbonate is electro-negative with regard to iron, so that a galvanic action is set up, causing decomposition of the water. This electrical condition still further augments the liability of iron to rust.

When iron is strongly heated in contact with air or oxygen, its surface becomes rapidly coated with a scale of black oxide Fe_3O_4, which peels off when the iron is struck with a hammer.

Iron is readily attacked by hydrochloric- or dilute sulphuric acid, hydrogen gas being evolved, and chloride or sulphate of iron being formed. If concentrated sulphuric acid be employed, the metal is oxidised at the expense of the acid, and sulphurous acid is evolved. If a clean strip of iron be immersed in fuming nitric acid the iron is not attacked, and is said to remain passive; if the temperature be raised, or the iron be touched with a copper wire, dissolution immediately begins. Ordinary nitric acid attacks iron vigorously, especially if slightly diluted, nitrate of iron being formed. Iron may be rendered passive to nitric acid by removing it from the liquid, exposing it to the atmosphere, and then re-immersing in the acid. The symbol for iron is Fe, and its atomic weight 56.

Iron and oxygen.—There are three oxides of iron of metallurgical importance—ferrous oxide FeO, ferric or red oxide Fe_2O_3, and magnetic or black oxide Fe_3O_4. Ferrous oxide is a black unstable compound, which rapidly oxidises in contact with air, and unites with acids to form ferrous salts. This oxide is the principal base in all slags produced in refining pig-iron, such as tap-cinder, $2FeO.SiO_2$. In combination with carbonic acid

it forms that most important class of iron ores termed "spathic."

Ferric oxide occurs in nature as hæmatite, and in the hydrated state as brown hæmatite. It may be artificially prepared by strongly heating ferrous sulphate, which is decomposed, yielding Fe_2O_3. It is a very stable compound at ordinary temperatures, but at a white heat it gives up oxygen, forming Fe_3O_4.

Magnetic oxide.—As mentioned previously, this compound is very abundant in nature, forming the richest ores of iron, and from which some of the purest iron is obtained. It is artificially prepared when iron is strongly heated in air or oxygen, as in the formation of smithy-scale. This oxide is also formed when iron is heated in contact with superheated steam, thus forming a protective coating. This is the principle of Prof. Barff's process.

Iron and sulphur.—A compound of iron and sulphur occurs in nature as pyrites. These elements readily unite when heated together, forming ferrous sulphide FeS. Sulphur, even in small quantities, has a very injurious effect on wrought iron, making it red-short, although the metal may be readily worked in the cold. With cast-iron a small quantity of sulphur is an advantage, making it stronger, more easily fusible, and more liquid when poured. Sulphur in pig-iron tends to the production of the white variety; the surface and fractured portions often exhibit black patches, which are characteristic of sulphur in iron. Sulphide of iron when heated with carbon is but little affected, but it is decomposed at a high temperature by oxidising substances. When this sulphide is heated with ferrous sulphate in suitable proportions, the whole of the sulphur is removed as SO_2, leaving ferric oxide Fe_2O_3.

Iron and phosphorus.—These bodies readily unite when phosphorus is dropped into red-hot iron, forming a phosphide of iron, which, according to Percy, has the formula $Fe_{12}P$. When oxide of iron is reduced in

the presence of an earthy phosphate, phosphorus is separated, and unites with the iron. ·3 per cent. of phosphorus in wrought iron makes it harder and somewhat diminishes its tenacity. ·5 per cent. makes it cold-short, but not red-short. 1 per cent. makes it very brittle. The effect of phosphorus on iron is, to impart a coarsely crystalline structure, diminish its strength, increase its fusibility, and make it cold-short. The presence of phosphorus in cast-iron diminishes its strength, but on account of its imparting fluidity to the metal, its presence is beneficial in making fine castings.

Iron and arsenic.—The effect of arsenic on iron is much the same as that of sulphur, a very small amount will make the metal red-short. Several compounds of iron and arsenic are known, varying from grey to white in colour. Arsenic is not a frequent impurity in iron.

Iron and silicon.—A compound of silicon and iron, known as silicon-iron, highly crystalline, and of a silvery-white colour, is now an article of commerce, and is used for producing soundness in steel castings. It is obtained by reducing silica with carbon in the presence of iron. If iron be heated alone with silica no action takes place. The effect of silicon on cast-iron is to set the combined carbon free, so that, as a rule, the greyer the pig, the higher the amount of silicon present. Silicon makes iron hard, more easily fusible and brittle.

Ferrous oxide and silica unite in various proportions forming silicates. The slag produced in purifying iron is chiefly a basic silicate, $2FeO.SiO_2$, containing about 70 per cent of ferrous oxide, melting at a white heat, and becoming very liquid. When this silicate is heated with access of air for some time, and then the temperature considerably increased, a fusible silicate liquates out, known as "bull-dog slag," leaving behind a very refractory substance, chiefly ferric oxide Fe_2O_3, termed "bull-dog," which is used for lining puddling-furnaces. The above oxide does not unite with silica when heated, but if

carbon or a reducing agent be present, it may be reduced to ferrous oxide, FeO, which then unites with the silica.

Iron and carbon.—Carbon unites with iron in various proportions up to about 4½ per cent., forming the different varieties of steel and pig-iron. When manganese is present a larger proportion of carbon may be taken up. The difference between malleable-iron, steel, and pig-iron is chiefly dependent on the relative amounts of carbon in combination with the iron. The more the carbon, the harder and more fusible the metal becomes, and this effect is considerably increased by the presence of other bodies, such as phosphorus, sulphur, etc. Combination takes place when iron is heated in contact with gaseous fuel, such as carbonic oxide, cyanogen, and hydrocarbons; or by a prolonged exposure to a high temperature in contact with solid carbon, such an operation being termed cementation. When the carbon present in iron reaches ·15 per cent, the iron is sensibly harder: this may be considered the greatest amount of carbon which can be present in malleable iron without diminishing its softness and malleability. Steel may be considered as iron containing from ·15 to 1·8 per cent. carbon. When the proportion of carbon is low the metal is termed "mild-steel" or ingot-iron, and in like manner those with the higher proportions of carbon are termed "hard-steels." Carbon exists in pig-iron in two states—free and combined. When the carbon is chiefly in the combined form, the iron is "white." On the other hand, when the carbon is free, being diffused through the iron in crystalline scales, the iron is called "grey"; but neither variety is entirely free from graphite or combined carbon respectively. In some varieties the carbon is partly combined and partly free, which gives to the fractured surface of the metal a speckled appearance, consisting of grey spots, enclosed by reticulating lines of white: it is then termed "mottled iron."

The amount of carbon in the combined form may be

readily determined by Eggertz' method, which depends on the fact that, when iron or steel is dissolved in nitric acid, the intensity of the colour of the solution will be proportional to the amount of carbon originally present in the combined form. The graphite not being affected by nitric acid, will remain in the insoluble residue.

Grey pig-iron may be converted into white, by melting and sudden cooling, the iron being considerably hardened by this means. This principle is applied in chill-casting. *Vice versa*, white iron is changed to grey by melting and slow cooling. From the above remarks it will be observed that grey pig-iron is much softer than white, and the hardness of hardened steel may be due to the carbon passing into the combined form, while annealing restores it to the graphitic condition.

Alloys of Iron.

Gold alloys with iron making it harder and more fusible. Platinum, when present in iron to the extent of 1 per cent., makes it fine grained, the alloy being tenacious, tough, and ductile. The presence of a little iron in brass and bronze increases their strength. Copper in iron is somewhat injurious making it hard, so that any notable quantity of copper in pig-iron renders it unfit for making the best classes of wrought iron. Zinc alloys with iron to the extent of 7 per cent., which is used for alloying with brass in the production of delta-metal, Aich's metal, sterro-metal, etc. Zinc forms a surface alloy with iron in galvanising. A similar use is made of tin in the process of tinning iron plates, which coating is both ornamental, and protects the iron from oxidation. An alloy of 10 parts iron with 80 parts tin is said to be preferable to pure tin in tinning copper vessels. 7 parts of antimony to 1 part iron (termed martial regulus) is used for producing casts of medallions,

and similar objects. Antimony when present in iron to the extent of ·2 per cent. makes it both hot- and cold-short. Nickel and cobalt alloy with iron without seriously affecting its malleability, as is shown by the workable nature of meteoric iron. Chromium makes iron white, hard, brittle, and less fusible. Oxide of tungsten, in the presence of iron and carbon at a high temperature, is reduced, the tungsten alloying with the iron and forming a very hard, fine-grained, white alloy. Titanium occurs in pig-iron smelted from titaniferous ores, but passes out in refining.

Manganese frequently occurs in iron ores, and is partially reduced along with the iron. When present to the extent of from 5 to 20 per cent., it causes the production of white pig-iron in a highly crystalline condition, containing a large amount of carbon wholly in chemical combination. This is termed "spiegel-eisen." When the manganese exceeds the above amount, the distinctive crystalline plates are no longer apparent. Alloys containing up to 87 per cent. of manganese are now manufactured for use in steel making, being distinguished by the name of "ferro-manganese." These alloys are hard, crystalline and brittle.

QUESTIONS.

1. Describe the various kinds of iron ore that are used for iron smelting.
2. Enumerate the chief British iron ores, giving their chemical composition and the localities where they are found in quantity.
3. For what special purposes are any of these ores particularly suitable or unsuitable, on account of their physical properties or chemical composition?
4. If you wished to obtain a sample of pure iron, how would you proceed?
5. When iron is strongly heated in air it is oxidised. What is the difference in the change when iron is exposed to moist air without heating?

6. What is the action of nitric, hydrochloric, and sulphuric acids respectively on iron?
7. Name the three principal oxides of iron, and briefly explain how they differ from each other.
8. What is the effect of sulphur on iron? How do you suppose sulphur gets into iron during smelting?
9. What is the influence of phosphorus on iron? For what reason is phosphorus sometimes added to iron?
10. Name any useful compound of iron and silicon, and state for what purpose it is used.
11. What do you understand by the terms "bull-dog" and "bull-dog slag"?
12. What are the chief peculiarities of cast-iron, wrought-iron, and steel?
13. What are the differences between white and grey pig-iron, and what are the causes of these differences?
14. What is "spiegel-eisen" and how does it differ from "ferro-manganese"?
15. What is the effect of a prolonged heating of malleable-iron to redness in contact with charcoal?

CHAPTER V.

MALLEABLE IRON. DIRECT METHODS OF EXTRACTION.

Properties of iron.—Malleable iron is of a greyish-white colour, having a granular, crystalline, or fibrous fracture, according to the mode of treatment. When rolled or hammered hot the iron becomes fibrous, but continued cold hammering induces a crystalline or granular structure, making it hard and brittle. The nature of the fractured surface varies also with the manner in which the iron has been broken, for specimens broken by progressively increasing stresses are invariably fibrous, whilst the same specimen broken by a sudden blow will be crystalline. The presence of impurities generally tends

to impart a granular or crystalline fracture, and makes the iron less malleable. When impurities, such as sulphur and arsenic, render the metal unworkable at a red-heat, it is said to be hot- or red-short. On the other hand, some substances, such as phosphorus, cause iron to crack when hammered cold, it is then termed cold-short. The specific gravity of iron is about 7·7, and when the metal is compressed at a high temperature, the density is increased; but in wire-drawing and cold-rolling the metal elongates more than its transverse section diminishes, and the density is diminished, but its tenacity is increased. Its fusing point is said to be about 2000° C.; but before melting it assumes a pasty state, when two pieces may be joined together by welding. To ensure a good weld the surfaces must be clean, and the metal at a white heat. In order to dissolve any scale the smith adds a little sand, which unites with the oxide and forms a fusible silicate. The presence of any foreign bodies, such as carbon, silicon, sulphur, phosphorus, copper, oxygen, etc., increases the difficulty of welding. Iron possesses considerable malleability, ductility, and tenacity. Its tensile strength ranges from 17 to 25 tons per square inch, but this, like all the other physical properties, is modified by the presence of impurities, which tend to make it harder, more fusible, and brittle. When iron is heated to dazzling whiteness, it burns, forming the black oxide Fe_3O_4, the iron becoming friable and brittle, and is then termed "burnt-iron." Iron may be magnetised by bringing it in contact with, or near to a magnet, but it loses its magnetism when the exciting magnet is withdrawn. Its specific heat is ·1137, and its conductivity about 120, silver being taken as 1000. Its electric resistance is 5·8 times that of pure copper. When iron is exposed to moist air it readily rusts or oxidises, so that it is often coated with some substance to prevent this action, such as tinning, galvanising, and painting. Prof. Barff preserves iron from rusting by

exposing it at a red-heat to superheated steam, which imparts to it a coating of the black oxide Fe_3O_4.

Scheme for Iron and Steel Processes.

Two distinct methods are employed for smelting iron ores, known respectively as the "direct" and "indirect" methods: the former, which is the older and little used at the present time, having been superseded by the latter or more modern method. The various processes are represented in a general manner in the accompanying scheme Fig. 3.

In the *direct method*, the ore is reduced to iron or steel, in arrangements such as the Catalan-forge and Siemens'-rotator, then hammered, re-heated, and finished with the hammer or rolls. In the *indirect method*, the ore is calcined, and afterwards reduced in a blast-furnace, the iron then being run into pig-moulds; the pig-iron so obtained is afterwards refined (or puddled direct), puddled, hammered, rolled, re-heated, and finished in the rolls for bar-iron. If steel is desired, the bars are heated with carbon in the cementation furnace, then melted in crucibles for cast steel.

In the old method, the finery and open-fire were used instead of the puddling and re-heating furnaces.

Pig-iron is treated in the Bessemer-converter for the production of Bessemer-steel; in the Siemens' furnace for Siemens-steel; and melted in the cupola for foundry purposes. The bloom of iron produced in the rotatory-furnace may be made into steel by treating it in the Siemens' open-hearth furnace.

Direct Methods of Making Malleable Iron.

When malleable iron is extracted from the ore in one operation the process is said to be "direct." Many

SCHEME FOR IRON AND STEEL PROCESSES.

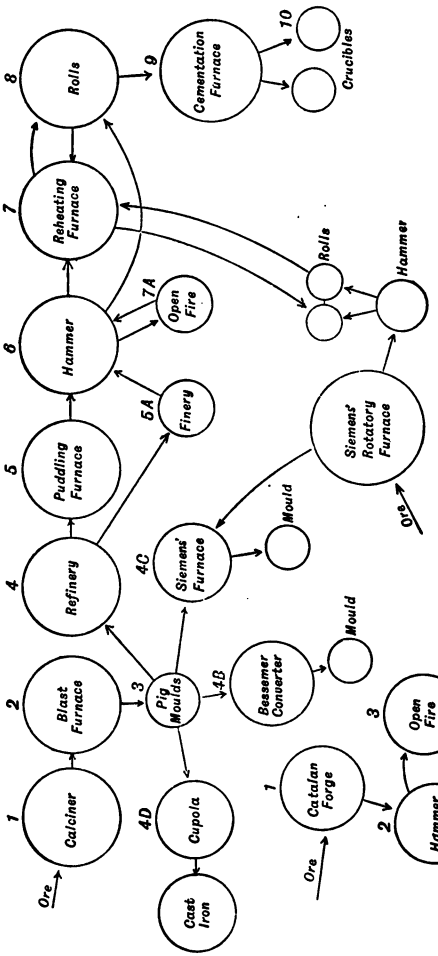

Fig. 3.

attempts have been made in recent years to revive the ancient principle of direct extraction, but the blast-furnace has been brought to such a pitch of excellence as regards economy of materials, and perfection of its reducing action, as to outstrip all rivals.

In reducing the ore directly, two things have to be taken into account: 1st, the easy oxidation of iron by carbonic acid and water, at the temperature at which ferrous oxide is reduced to the metallic state by carbon, carbonic oxide, or hydrogen; 2nd, the facility with which iron at a red-heat combines with carbon. Now if gaseous fuel be employed as a source of heat and reducing energy, carbonic acid and water will be produced, and a large excess of unburnt gas would be required to neutralise the oxidising tendency of these bodies, and this excess would require to be increased with the temperature. Sir L. Bell states that at a temperature near whiteness, iron will be oxidised, if carbonic acid and carbonic oxide are present in equal proportions, and that when the volume of carbonic acid CO_2, to carbonic oxide CO, is as 11 to 100, the reduction of protoxide of iron is no longer possible. In other words, gas ceases to be useful as a reducing agent, when it contains one tenth its volume of burnt gas. This enormous volume of unburnt gas not only represents a great waste of fuel, but also a great quantity of heat is absorbed in raising it to the requisite temperature, which can only be done by strongly heating the whole of the gas previous to its partial combustion. In the blast-furnace the combustion of solid carbon to carbonic oxide produces the requisite temperature, without producing an oxidising atmosphere, which makes that furnace unequalled for reducing energy.

With regard to the second difficulty, viz., the readiness with which iron combines with carbon at a red-heat. If solid carbon be employed to reduce oxide of iron, then only the exact quantity of carbon for such reduction must be added, in order to avoid carbonisation of the iron,

and the operation must be performed in a closed vessel, heated from the outside. But for this purpose the ore must be broken small, the flux and fuel well mixed with it, and the temperature maintained for a long time, with a considerable expenditure of fuel.

In all direct processes malleable iron can only be produced, by sacrificing a considerable portion of the iron, which passes into the slag, and this loss is in inverse ratio to the amount of carbon taken up by the iron. On the other hand, the blast-furnace allows of the most perfect utilisation of the fuel, and the slags produced therein are practically free from iron. Moreover, the pig-iron produced can be converted into malleable iron or steel in the Bessemer-converter, without an additional expenditure of fuel.

Catalan process.—This primitive method of making iron is now practically obsolete, only being retained in remote districts where there is an abundant supply of wood fuel and rich ores, as in the Pyrenees. It consists of a hearth made of sandstone, and lined with charcoal Fig. 4. The back and opposite walls are faced with iron, and of the remaining sides, one is of rough masonry, and the other, which forms the working side of the furnace, consists of two iron plates, the lower one having a hole for tapping the slag. The top of this plate serves as a fulcrum for the workman's tools. The twyer is made of sheet copper, and generally inclines at an angle of from 30 to 40 degrees, according to the degree of carbonisation desired. The blast is supplied by a blowing apparatus called a trompe Fig. 5. The water falling down the pipe A, drags air through the inclined openings BB. This mixture of air and water falling into the cistern is divided into two streams, the air rising and passing forward into the twyer, the water running out of the cistern at C.

Fig. 4.

Hæmatites are smelted directly, but carbonates are first calcined. The ore in small pieces is charged in with charcoal, several lumps of charcoal being placed near the twyer. The heat is gradually raised until a pasty mass is formed, which is then pushed towards the twyer. After two hours the full blast is turned on and the slag tapped off. The slag is fluid and formed at the expense of the iron; it is a silicate of iron $2FeO, SiO_2$, containing lime, magnesia, and oxide of manganese, which composition is favourable for the transference into the slag of any phosphorus that may be present. When the whole of the ore is reduced, the blast is stopped, and the spongy masses of iron worked into a lump or bloom with iron tools; it is then carried to the shingling hammer and shingled, in order to squeeze out the slag and consolidate the porous mass of iron. It is then re-heated in a similar fire and the iron finished under the hammer. If the operation is prolonged by arranging the twyer at a less inclination than in the above case the iron combines with carbon and forms steel. The conditions governing the formation of slag in this hearth are similar to those of the puddling-furnace, and different to those in the blast-furnace; the former being oxidising in its action, the latter reducing.

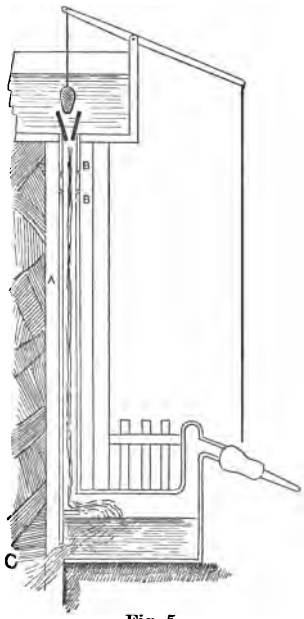

Fig. 5.

The chemical changes occurring in the Catalan process may be briefly stated thus—The air introduced by the twyers, being brought in contact with red-hot charcoal, causes a brisk combustion, with the formation of carbonic acid CO_2. This gas on ascending through other highly-heated charcoal is reduced to carbonic oxide CO. The latter being a reducing agent acts on the ferric oxide Fe_2O_3, which is partly reduced to the metallic state, and partly to ferrous oxide FeO, which unites with silica and other foreign matters to form the fusible slag mentioned above.

American bloomery, Jersey-, and Champlain forge.—This simple method, largely employed in the United States and Canada, is a modified form of the Catalan-process, and is conducted in much the same manner, except that the ore is in a finer state of division, and the furnace is worked continuously.

The furnaces are built in rows on either side of a wall, each measuring about 28 by 30 inches in area by 25 feet in height above the twyers, and 14 inches below them. The sides are formed with cast-iron plates, and the bottom of beaten earth or cinders. In some cases a hollow iron bottom, cooled by water, is used. A water-box 12 inches by 8 inches is let into the twyer plate, and the water, after cooling the twyer, passes through the bottom plate. The twyers are arranged so that the blast strikes the middle of the hearth. In front of the forge, at 16 inches above the bottom, is a flat iron hearth 18 inches wide, and in the side plate beneath it is a tap-hole for withdrawing the slag. The blast is used at a pressure of $1\frac{1}{2}$ to $1\frac{3}{4}$ lbs. per square inch, and heated to 300° C. by passing through cast-iron pipes in chambers fixed above the hearth.

The fire being made up, the forge is heaped up with charcoal, and crushed ore is scattered over the fuel. The ore is gradually reduced, without melting, as it descends, and the reduced grains collect into an irre-

gular mass at the bottom of the hearth. The earthy matters at the same time separate as slag. Fresh supplies of ore and fuel are added from time to time, and in about three hours a mass, weighing 300 lbs., termed a "bloom," is lifted and held before the twyers for a few minutes, then carried to the hammer and shingled. It is then reheated and fashioned into bars. Sir L. Bell says that such a process can only be conducted where high prices, fostered by protective duties, prevail, and where it would be inexpedient to incur the large outlay involved in the erection of modern ironworks.

The Chenot process was introduced about the year 1855, and was considered a great metallurgical discovery, but after a few years working it was abandoned, except in one locality in Spain, where its continuance depended on the possession of a quantity of charcoal screenings which would otherwise have been wasted.

The furnaces are rectangular retorts built in pairs—4 feet 6 inches long, 1 foot 8 inches wide, and 33 feet high. Beneath each retort is a rectangular tube of the same section, into which the metallic sponge is discharged. The total height of retort and tube is 50 feet. At the junction of the two parts are arranged four fireplaces, the flames from which circulate round both furnaces by a series of channels, which unite near the top and pass into a common flue. This mode of heating is very imperfect, as more heat is lost outside than passes into the retort. Four tons of fuel are required for the production of 1 ton of merchant-bars, and about 45 per cent. of the iron is lost. The retorts are charged with ore, broken small, and mixed with charcoal. The reduction extends over three days, producing a spongy mass of metallic iron, which requires three days to cool out of contact with air, to prevent rapid oxidation. The sponge obtained is made into steel by melting in crucibles with carbon; or balled in a charcoal hearth,

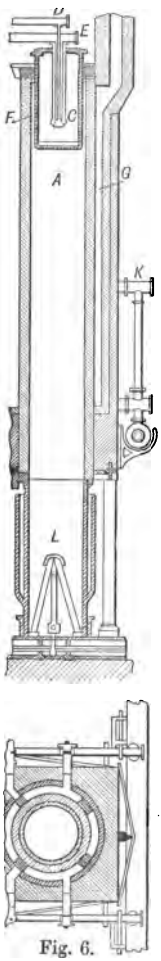

Fig. 6.

then hammered, piled, re-heated, and rolled into bars of wrought iron.

Blair's process.—In 1873 Mr. Blair in America introduced the Chenot process on an improved plan, but the furnace was irregular in its action, and the production small compared with that of the blast-furnace. The retorts are cylinders 3 to 4 feet in diameter, and 40 feet high. The great difficulty was to cause the heat to penetrate successfully to the centre. In order to effect this, Blair placed in the top of each retort a concentric cylinder, and through its axis a double blowpipe, by means of which a current of gas and air was forced in, producing by its combustion sufficient heat to make the ore and charcoal, charged into the annular space round the cylinder, red-hot.

Fig. 6 represents in section and plan one of a group of three furnaces. A is the retort, C the cylinder, D the gas-pipe, E the air-pipe, F the charging-space, G the annular space for combustion of the gas, K the gas-main, which introduces the gas at two different levels. This gas was originally obtained from the reduction of the ore, but its amount being found insufficient, a special gas-producer was afterwards provided. The cylinder L beneath the reduction chamber receives the sponge of iron, and is kept hermetically closed while the iron cools, as in the Chenot furnace. The wrought iron walls are double, in order to allow a current of water to circulate through them.

Siemens' direct process.—This is one of the most recent attempts to extract iron in an economical manner from the ore in one operation, but it suffers under the disadvantages of all direct methods, as explained on page 43.

The furnace (Fig. 7) consists of a cylindrical rotating

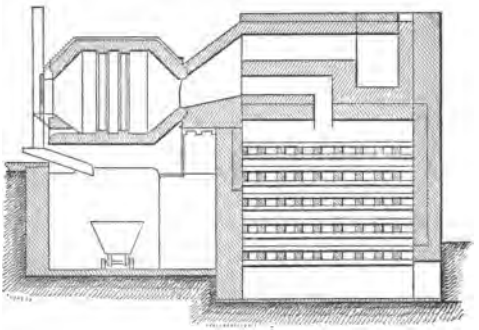

Fig. 7.

chamber, 8 feet in diameter and about 9 feet long, and rests on four anti-friction rollers. The inside is lined with bauxite, which consists of alumina, ferric oxide, water, and a little silica. From this substance, when mixed with 3 per cent. clay and 6 per cent. plumbago, bricks are made. The working door is at one end, and beneath this is a tap-hole for slag. The furnace is heated with gas supplied from a gas-producer, the air being heated by passing through one of a pair of regenerators. Ore, in small pieces, is charged into the hot furnace with lime, and the cylinder rotated. When red-hot, about 20 per cent. of small coal is added as the reducing agent, and the velocity increased. The carbon and hydrogen of the coal, together with the carbonic oxide of the gas, react on the oxide of iron, removing its oxygen and liberating metallic iron, the particles of which gradually

cohere to form a spongy mass, called a bloom. The lime and the basic lining of the furnace unite with the siliceous matters to form a slag, which, in consequence of its basic character, is highly favourable to the taking up of any phosphorus that may be present in the ore. When the reduction is complete, the slag is tapped off; then a quick rotation is imparted to collect the iron into three or more balls, which is effected by means of ribs projecting from the lining. The balls are then shingled, re-heated, and finished in the usual way. If steel is desired, 10 per cent. of spiegel-eisen is added after tapping off the slag. The charge is then melted and cast into moulds. In some cases the balls are treated for steel in the open-hearth furnace. The advantages claimed for this method are—economy of time, saving of fuel, and purity of the iron, since the metal is not brought in contact with solid fuel, as in the blast-furnace, except the coal added as a reducing agent.

In a newer form of the rotator the length is 10 feet 6 inches, and the same in diameter. At the back of the rotating chamber is fixed a water-jacket to keep the ring at the back cool. In order to maintain the circulation of water, and also to turn the charges over as the vessel revolves, four water pipes pass beneath the lining from back to front of the rotator, connected alternately with a valve at the front end, and the water-jacket at the back. Each pipe has two bends or knees, the lining on which stands above the general level of the furnace-lining. These knees serve to divide the bloom of iron at the conclusion into three balls.

QUESTIONS.

1. What is meant by the term "malleable iron"? State its chief physical properties.
2. How may iron be protected from rust? Describe the method invented by Professor Barff.

3. What do you understand by the "direct" method of extracting malleable-iron?

4. Under what disadvantages do all direct methods suffer with regard to economy of production?

5. Very pure iron may be obtained by direct methods; would the iron be equally pure if obtained from a coke blast-furnace and afterwards treated by puddling? Give reasons for your answer.

6. How would you extract the iron from a rich ore in a fine state of division?

7. When an ore consisting wholly of ferrous carbonate is heated to strong redness in a vessel from which atmospheric air is excluded, and the substance of which has no action on the ore, what chemical change occurs?

8. When iron is extracted in the malleable state from phosphoric ore in the Catalan forge, what becomes of the phosphorus?

9. What difficulties are met with in attempts to reduce iron ore by gas alone, without the admixture of solid fuel?

10. Describe Siemens' direct process of producing malleable iron, and roughly sketch the furnace employed.

11. Describe the production of iron in the American bloomery.

CHAPTER VI.

PIG-IRON. PREPARATION OF ORES.

Pig- or cast-iron.—In the indirect method of producing malleable iron, a crude product consisting of iron, carbon, silicon, phosphorus, sulphur, manganese, and very frequently other elements, such as copper, arsenic, titanium, chromium, etc., is first obtained; it is termed "pig-iron," and is D-shaped in section, being 3 or 4 inches square and about 3 feet long. Pig-iron is arranged into a variety of classes, according to the colour, texture, size of the crystalline plates, and general char-

acter of the fractured surface. That containing the largest grain and largest crystals of graphite is known as No. 1, the numbers increasing as the lustre and size of the grain diminish. When the metal ceases to be grey the numbers are not used, the iron being designated as mottled, either strong or weak, and white, in which, when manganese is present in quantity, the crystals are large and lustrous and the iron intensely hard; such a pig is termed spiegel-eisen. The lower numbers of grey iron are called foundry-pigs, being used for castings. The higher numbers are termed forge-pigs, being chiefly used for the production of wrought iron. Two other varieties are also made, which, owing to their comparative freedom from sulphur and phosphorus, are used for making Bessemer-steel, and are termed Nos. 1 and 2 Bessemer-pigs.

Grey iron requires a higher temperature to melt it than white iron, but becomes very liquid, and expands on becoming solid, which admirably adapts it for casting. White iron becomes less perfectly fluid, and passes through an intermediate pasty stage before becoming liquid, and the same during solidification after fusion. It contracts considerably after becoming solid. Grey iron is produced at a higher temperature in the blast-furnace than white, which tends to make it more impure. It sometimes happens that both kinds are contained in the hearth of a blast-furnace at the same time, the white being the heavier goes to the bottom, and when the furnace is tapped flows out first in a sluggish stream, emitting brilliant sparks; the grey iron following runs perfectly fluid without sparks.

Common white iron is produced when the furnace is charged with a heavy burden of cinders, *i.e.* slag from other processes mixed with ore, and is then termed "cinder-pig," as distinguished from metal produced from ore alone, which is termed "all-mine-pig." Cinder-pig is dull in colour, and presents a rough honeycombed appearance on the surface; it is very hard and brittle. White iron is also produced when easily reducible ores are

employed, so that the charge can be reduced and melted rapidly, and the melted metal remains a shorter time in contact with the highly heated carbon. In such a case a greater proportion of ore to fuel is employed, and consequently a lower temperature obtained. The production of grey iron requires a temperature far beyond that of mere fusion, causing the reduction also of other oxides, such as silica, besides those of iron. Such a condition is brought about by working with light burdens, that is, excess of fuel, and using very hot blast. Other things being equal, the iron will be grey if the slag is refractory, for the particles of carburetted metal cannot coalesce, until the foreign matter has united with the flux to form a fusible slag, hence they remain longer subjected to the action of carbon and silicon, which latter element induces greyness in pig-iron. The following analyses show the composition of (I.) grey, (II.) white, (III.) spiegel-eisen, (IV.) mottled pig-iron:—

	I.	II.	III.	IV.
Iron,	94·56	94·08	88·84	94·56
Graphite,	3·10	·10	·12	1·50
Combined carbon,	·04	3·00	3·17	1·64
Manganese,	·50	1·37	7·39	·50
Other constituents,	1·80	1·45	·48	1·80
	100	100	100	100

Preparation of Iron Ores for Smelting.

Iron ores are sometimes subjected to preliminary operations preparatory to the smelting process, according to their nature and to the facility of obtaining supplies. In parts of the world where good ores are abundant, such as in England, mechanical treatment of poor ores, such as washing, dressing, etc., offers no advantages. On some parts of the Continent where the opposite condition holds, poor ores are sifted, crushed or stamped, and

washed, the object being to wash away by a stream of water the lighter impurities, such as sand, from the ore.

Weathering.—In some cases, such as the clay-iron-stones of the coal measures and ores containing pyrites, exposure to the atmosphere for a lengthened period causes oxidation and disintegration of the shale and pyrites, whereby the former can be readily separated, and the latter are partially oxidised and washed away by rain. Soluble matter may be still further removed by frequently watering the heaps during dry weather.

For regularity of result in smelting, it is advisable to have the lumps of ore, fuel, and flux reduced to a uniform size according to the capacity of the furnace, and the greater or less ease with which the ore is reduced. In the large Cleveland furnaces blocks of ore 4 to 6 inches in diameter are employed, while the hard magnetic ores of Sweden are reduced to $\frac{3}{4}$ or 1 inch cubes. Large pieces allow of a freer passage of the gases; small pieces pack closer and offer greater resistance to the blast, but a greater surface is exposed to the reducing gases. The crushing is affected by lever machines, such as Blake's rock-crusher; by tilt, or other hammers; and by rollers.

Calcination.—This operation is resorted to in the case of all iron ores, except massive red hæmatite and certain magnetites. The effect of this is to decompose any pyrites, with the partial volatilisation of the sulphur, to eliminate carbonic acid, water, and other volatile matter, and to convert ferrous into ferric and magnetic oxides, which greatly reduces the liability to form slag with silica. Moreover the ore is rendered more porous, and more readily susceptible to the action of reducing agents. The loss of weight by calcination is from 25 to 50 per cent.

Calcination is performed in heaps, in stalls, and in kilns. The first method is adopted in localities where fuel is cheap, and space abundant. The ground is first covered with a layer of coal a few inches thick, then

a layer of iron ore 12 inches thick; this is succeeded by fresh layers of coal and ore, the whole heap being from 3 to 9 feet high. Fire is then applied at the base, and the combustion gradually extends to the whole mass, 3 cwts. of coal being required for 1 ton of calcined ore. Black-band ironstone often contains sufficient carbon to effect the calcination without additional fuel, except the layer of small coal at the base.

Calcination is conducted in some districts in stalls, each of which consists of three vertical walls enclosing a space into which the ore is placed. Draught-holes are left at suitable intervals for the passage of the air. This forms a kind of rough kiln. Calcining in kilns is much preferable to the preceding method, as the fuel is more perfectly utilised and a more uniform product is obtained. In South Wales the kiln Fig. 8 is in the form of an inverted truncated cone in section, 15 to 18 feet high, 20 feet long, 8 to 9 feet wide at top and 2 feet wide at the base. Two arched passages,

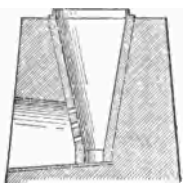

Fig. 8.

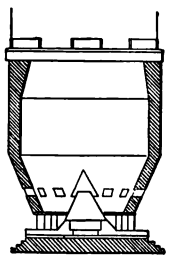

Fig. 9.

splayed outwards, are left at the base for withdrawing the charge. At a height of a few feet above the top is a railroad supported on pillars, over which the loaded wagons pass, and deliver their contents into the kiln in alternate layers of ore and fuel.

One of the best forms of kiln is that of Gjers Fig. 9,

largely used in the Cleveland district. The body is of fire-brick cased with wrought iron plates. The diameter at base is about 14 feet, at the boshes about 20 feet, and at top about 18 feet. The bottom of the brickwork rests on cast-iron plates, and the whole is supported on cast-iron pillars. In the centre of the base of the kiln is a cone about 8 feet high, and the same in diameter at the base. The total height of the kiln is about 30 feet, and the capacity about 6000 cubic feet. From two to three days are required for the calcination, with the consumption of 1 cwt. of coal per ton of ore. When the operation is complete, the ore is discharged at the bottom between the pillars, being directed outwards by the cone. The calcination is carried on continuously.

Fig. 10 represents a Swedish kiln about 20 feet high, employing the waste gases of the blast-furnace as a source of heat, instead of solid fuel. The combustion is effected by means of a blast of air introduced through the twyer (*a*), which communicates with the annular space (*b*), from which the air penetrates into the furnace by a number of small openings. The gas is conveyed by the pipes (*dd*), and enters the furnace by the channels (*c*). Above these are other channels (*ee*) which are kept closed; these are used for introducing bars to break up any lumps that may have caked together, or to admit additional air if necessary. The calcined ore is

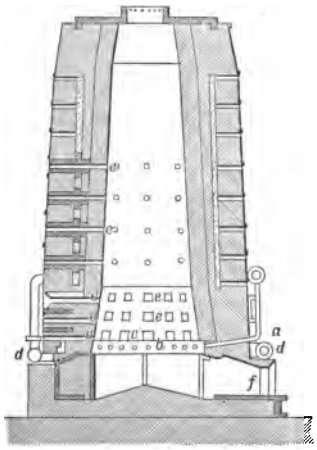

Fig. 10.

discharged through five radial openings (*f*). The charging is performed at the top, which is surmounted by a chimney for regulating the draught. Hoffmann's calciner is designed to utilise the whole of the heat generated by the combustion of the fuel, thereby effecting a considerable saving. It differs from a barrel furnace with regard to the direction of the gaseous current, and the stationary condition of the solid matter. The combustion is conducted in a horizontal direction in the same order as the gas. Figs. 11 and 12 represent a circular furnace of this kind in plan and section. The calcining space is circular, and is roughly divided into sixteen compartments (MM) by means of projections raised towards the roof. The whole circular space is divided by means of a wrought iron door (*p*). In Fig. 11 this

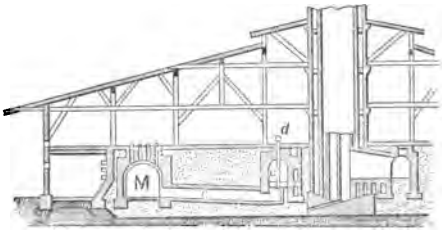

Fig. 11.

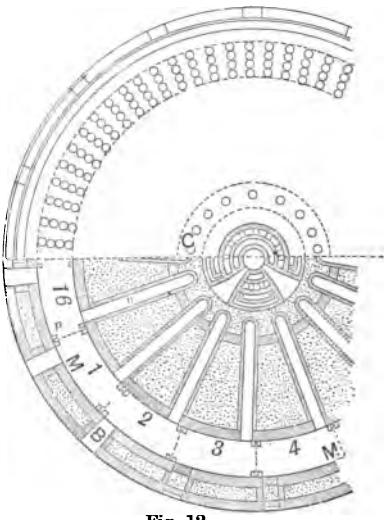

Fig. 12.

door divides No. 16 from No. 1 compartment. A lateral opening or doorway (B) is also provided for each chamber, for the purpose of discharging the calcined ore, but it is bricked up during the operation, only two being open at a time—one being charged and the other being discharged. The air for combustion is drawn through these doorways, and passes in the direction of the chambers 3, 4, 5, 6, etc. Each compartment communicates with the central gallery (C), and thus with the chimney by means of inclined flues (*n*), each of which is provided with a damper (*d*); all these are kept closed, except that connected with No. 16. Along this flue the products of combustion finally pass into an interior circular space (*c*), termed the smoke-flue, which communicates with the chimney. The outer wall is double, about 3 feet thick, the two portions being separated by a space filled with sand, in order to close up any cracks produced by heat in the brick-work.

The cold air, as before mentioned, passes into the calciner at Nos. 1 and 2, then circulates through 3, 4, and 5, containing ore already calcined, the air being heated at its expense. The air then arrives at No. 6 where the ore is red-hot. The fire commences here and occupies No. 7 and part of No. 8. This is the zone of greatest heat. The gases then traverse the remaining chambers, giving up their heat to the matter being calcined.

The fuel is charged in small quantities through openings in the roof, when it inflames immediately, and burns without smoke, because of the high temperature of the air employed for its combustion, and the incandescent space into which it arrives. The same openings are only used for charging every 24 hours, a fresh range being opened every 4 hours, working in the direction of the general current. Every 24 hours the operation in one chamber is completed. Then the iron partition (*p*) is transferred from No. 1 to No. 2, the doorway of No. 1 closed and that of No. 3 opened. The damper of No. 16 is then closed

and that of No. 1 opened. Now the contents of No. 3 are discharged and the chamber No. 2 re-filled. The operation is thus continuous, and only stopped in the case of serious repairs. This furnace is chiefly used for baking bricks and burning limestone. An oval form is also employed in some works.

QUESTIONS.

1. What impurities does pig-iron usually contain?
2. Describe the classification of pig-iron based on the character of its texture as exhibited at a fractured surface.
3. What are the leading differences between forge- and foundry-pigs, and why are they requisite?
4. Under what furnace conditions are white, grey, and mottled pig-iron respectively produced?
5. What relations have been observed between the character of the slag and the nature of the iron produced in a blast furnace?
6. What purpose is served in calcining iron ores? Describe some method of calcination with which you are familiar.
7. Describe Gjers' calciner for iron ores.
8. Describe the Swedish kiln employing waste gases as a source of heat.
9. Describe Hoffmann's circular calciner and the method of calcination conducted therein.

CHAPTER VII.

INDIRECT METHOD OF EXTRACTION.

Reduction in the blast-furnace.—The calcined ore is put into the blast-furnace with coal, coke, or charcoal, and a suitable flux, which is usually limestone. The heat is well utilised, and the reduction more perfect than in any other form of furnace. In the blast-furnace there are

two currents travelling in opposite directions, and constantly acting on each other—a "gaseous" ascending current and a "solid" descending one. The former travels at the rate of about three feet per second, the latter at the rate of 3 feet per hour. The effect of the blast on the carbon of the fuel is to produce carbonic acid CO_2 at the level of the twyers, with evolution of great heat. This gas ascends, and is reduced by carbon at a very short distance from the twyers, thus,

$$CO_2 + C = 2CO.$$

This carbonic oxide is the principal reducing agent in the blast-furnace, the oxide of iron being reduced to the metallic state as a spongy mass, thus—

$$Fe_2O_3 + 3CO = 3CO_2 + 2Fe.$$

At the same time the flux and earthy matter of the ore unite to form slag, which descends with the iron; the latter in contact with highly heated carbon is carburised, then melts and collects in the hearth, where, in combination with other substances, such as silicon, phosphorus, sulphur, and manganese, which have also been reduced, it constitutes pig-iron. On the top of the molten iron floats the liquid slag. The temperature and pressure have a great influence on the reducing action, and as the temperature increases with the temperature and pressure of the blast, it follows that as the reducing energy becomes greater the metal is more impure. When very pure iron is desired rich hæmatite and cold-blast are used, with charcoal as fuel. Great advantage is gained by the use of hot air, as less carbon is required for reduction and fusion. It is also useful to remedy defects, and to regulate the passage of materials in the furnace. If the fusion or reduction is at fault the temperature of the blast is raised, or more carbon is added. The former acts instantly, while the latter often takes several hours to remedy the defect.

The quality of the pig-iron produced from a given

furnace will depend on the temperature, the nature of the charge, and the mode of working. With easily reducible ores and heavy burdens—that is with a large proportion of ore to fuel—the iron will be white, since the metal is kept only the minimum time in contact with incandescent carbon. With a high temperature and a light burden the pig-iron is more siliceous and grey. The same things influence the character of the slag. Blast-furnace slags are mainly double silicates of lime and alumina, and may be represented by the formula

$$3(CaO.SiO_2) + Al_2O_3.3SiO_2$$

or

$$6(2CaO.SiO_2) + 2Al_2O_3.3SiO_2.$$

The former is the kind of slag obtained from charcoal-furnaces, and the latter from furnaces using coke or coal. In both cases the lime is replaced more or less by magnesia, oxide of iron, and oxide of manganese; while the silica is sometimes replaced to a small extent by alumina. The colour varies from white to grey, sometimes with varying shades of yellow, green, blue, and black, according to the metallic oxides present. Generally a white or grey slag accompanies grey iron, and a dark coloured slag, white iron. The former slag often contains excess of lime, which diminishes its fusibility; the latter is more fusible and contains oxide of iron, which, when present in quantity, makes a very liquid "scouring" slag, *i.e.* one attacking the lining of the furnace. The "scouring" slag sometimes contains as much as 20 per cent. of iron. When forge or mill cinders are added to the charge, the resulting metal is called cinder-pig-iron, and the change produced by the reduction of such slags may be represented by the following equation—

$$3(2FeO.\,SiO_2) + 4C = (2FeO.\,3SiO_2) + 4CO + 4Fe.$$

When phosphoric acid P_2O_5 is present in the blast-furnace, it is reduced, and the phosphorus passes into the iron, which can be prevented by allowing much

oxide of iron to pass into the slag. Blast-furnace slag has been utilised for building purposes, and for making slag wool.

The temperature and condition of the charge in different parts of a blast-furnace are represented by the aid of Fig. 13, prepared by Sir L. Bell. The zone (*a*) contains the raw materials: in (*b*) the ore is partially reduced by carbon; and in (*c*), which is at a dull red-heat, the limestone added as a flux is decomposed into lime CaO, and carbonic acid CO_2, which is liberated, thus:—

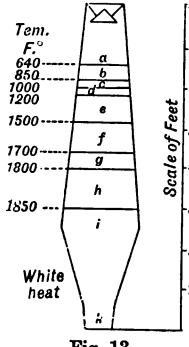

Fig. 13.

$$CaCO_3 = CaO + CO_2.$$

In the zone (*e*) carbonic acid CO_2 oxidises carbon from the fuel forming carbonic oxide CO; and in (*f*) which is at a bright red-heat, the reduced iron takes up carbon, forming pig-iron. This action is continued in the lower zones, in which foreign oxides, such as silica and phosphoric acid, are also reduced; the silicon, phosphorus, etc., uniting with the iron. In the zone (*i*) the temperature is very high, the iron is thoroughly fused, as well as the slag formed by the union of the flux with the earthy matter. In the zone (*k*) the temperature attains to intense whiteness; here the molten materials separate according to their specific gravities, the iron falling to the bottom, and the lighter slag floating on the top.

The fluxes employed in iron smelting vary with the nature of the ore to be treated. In some rare cases the ores are self fluxing, containing acid and basic constituents in the requisite proportion to form slag. This may be also effected by using a mixture of ores of dissimilar composition, such as siliceous- and calcareous hæmatites, or both with clay-ironstone. More generally a non-

ferruginous flux is added, and although it increases the weight of material to be operated upon, it is more easily obtained.

For ironstone containing clay, which is very frequently the case, limestone is the flux used. Rich hæmatites, such as those of Cumberland and Lancashire, require clay as well as limestone. Of late years, a brown hæmatite containing much free alumina called "Belfast Aluminous-Ore" has been used in preference to clay. Some smelters recommend the use of quick lime instead of limestone, producing an economy of fuel, since the absorption of heat by the expulsion of carbonic acid in the case of the raw carbonate, as well as the carbon removed by the conversion of carbonic acid into carbonic oxide, is avoided; but it is necessary to use the lime soon after burning, otherwise it takes up carbonic acid and moisture again from the air. When the ore is a carbonate, containing metals in the protoxide condition, the flux required is silica, added in quantity sufficient to form a silicate, in which the oxygen of the acid would be equal to the oxygen in the base, thus :—

$$(FeO, MnO. SiO_2).$$

The fuel used in the blast-furnace is either charcoal, peat, coke, or raw coal. Charcoal is only used in small furnaces, on account of expense, but it is highly advantageous when very pure iron is required, owing to its freedom from sulphur and other impurities. Peat is only used in remote districts where other fuel is not available.

The value of coke for blast-furnace work is largely dependent upon its comparative freedom from sulphur and ash. The coke must be sufficiently hard and dense to resist the great pressure of materials it has to sustain in large furnaces; on the other hand it must be sufficiently porous to allow of the free passage of the ascending gas. Anthracite, notwithstanding its com-

parative purity, is very dense, and only permeable with difficulty; it is also very liable to decrepitate into small fragments, which retard the draught. In South Wales, where this fuel is used, it is necessary to work with an open tymp, so as to clear out the small particles of anthracite from the hearth.

Raw coal is very largely used, both alone and in admixture with coke, which is probably the most advantageous method. The coal employed must be of the non-caking variety, hence we find raw coal in use in the West of Scotland, Staffordshire, and Derbyshire.

Ferro-manganese.—This may be considered a variety of pig-iron in which the iron is replaced largely by manganese. It is produced by smelting, in the blast-furnace, ores containing much manganese, and it is possible to obtain a product having as much as 87 per cent. of manganese. The furnace must be worked with a large excess of fuel; a large amount of limestone, so as to produce a basic slag; and a considerable pressure of blast, previously raised to a higher temperature than is used for ordinary iron ores.

Ferro-manganese is a hard, crystalline substance, but the crystals are much smaller than those in spiegel-eisen. It is chiefly used in steel making by the Bessemer and Open-Hearth processes, as described on pp. 144, 155.

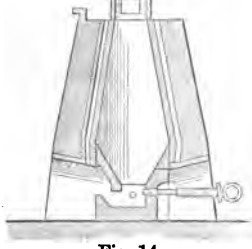

Fig. 14.

Blast-Furnace and its Accessories.

An English blast-furnace of the old type Fig. 14 is a very massive structure of stonework or brickwork, usually circular in form in the interior, which consists of a shaft approaching in sectional elevation to that of two truncated cones joined at their bases; the upper and more

acute being termed the "body," which is surmounted by a chimney containing one or more openings for the purposes of charging; the lower cone forms the "boshes." This lower cone is sometimes continued to the ground level, but more often the furnace is enlarged, forming the "hearth," in which the molten iron collects, three sides being continued to the bottom, and the other left open for means of access. The hearth is supported on a mass of masonry, with channels for the escape of moisture. The foundations are traversed by arched galleries in order to keep the whole building dry.

One of the objects in the construction is to keep the heat as much as possible in that part where it is required, and to diminish loss of heat by radiation. The interior is lined with fire-brick, and the outer part is built of rough sandstone, or ordinary brickwork, the two layers being separated by a space filled with sand or slag. The dimensions vary, in England, from 9 to 20 feet in diameter, and 30 to 45 feet in height.

The modern blast-furnace is an elongated barrel-shaped structure, the height being four to five times that of the greatest width. The body is formed of wrought iron plates, $\frac{1}{2}$ inch thick, riveted together, and within which is built the outer casing of ordinary masonry, the inside being lined with fire-brick, about 18 inches thick, while in some cases, between the two layers of brickwork, is a small space filled with sand to allow for expansion and contraction. The body or stack is supported on a cast-iron ring resting on iron columns, and the lower part, from the top of the columns to the tymp-arch, is also cased with iron. The hearth is independent of the masonry of the stack, and is built in after the stack is completed. It requires to be made of very refractory material of considerable thickness, having to withstand a very great heat, in addition to the corrosive action of the molten slags.

The hearth is perforated with three to six holes for

the introduction of twyers which convey the blast of air into the furnace. On the front or working side the hearth is extended outwards for a short distance, forming a rectangular cavity known as the fore-hearth, which is bounded in front by a refractory stone termed the dam-stone. The arch covering this cavity is called the tymp-arch. The tymp is made either of a block of refractory stone, or of a hollow cast-iron box built in the masonry, and through this box a current of water constantly circulates, in order to keep it cool.

In fig. 15, A is the charging gallery, B the cup and cone arrangement for charging, C the throat, D the body, EE the boshes, F the blast-main, G the iron ring supporting the body, HH the pillars, I the hearth, K the twyers, L the dam, *l* the iron dam-plate, *m* the fore-hearth. The dam is formed of fire-brick, and is carried up to the twyer level, a semi-circular notch in the top edge serving as a passage for the slag. The tap-hole for the molten iron is a narrow slit through the bottom of the dam. (*t*) is the tymp. N is the opening for collecting the waste gases which are utilised for heating the blast, boilers, etc.

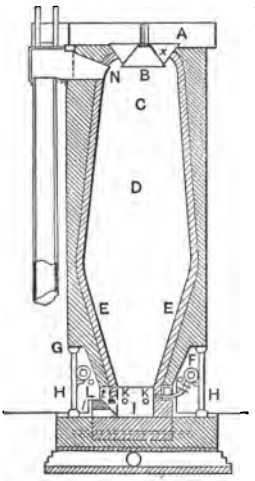

Fig. 15.

The charge is tipped into the cup or hopper (*x*), and allowed to fall into the furnace by lowering the cone B, which acts very advantageously in distributing the charge over the surface of the materials already in the furnace.

Form and interior dimensions.—The descent of the materials must, in all cases, be sufficiently slow for the reducing action of the gas and carbon to penetrate to the

centre of each fragment, before it reaches the region of fusion, and as a rule, the furnace is built smaller in proportion to the ease with which the various oxides are reduced.

The horizontal section given to the hearth must vary according to the pressure of the blast, and the porosity of the materials employed in the furnace. When hard coke is used, and the ore is in large pieces, a longer time is required for the air to penetrate to the centre of each lump, and a greater pressure is then needed. But this tends to produce a higher temperature, and, consequently, greater reducing energy, which necessarily makes the metal more impure. The height of the furnace should be limited when the fuel is friable, such as anthracite, and the ore in small pieces; for if the charge is too compact the gas can only circulate with difficulty. Moreover, in a mass of different materials, descending gradually, the difference of density becomes greater as the height of the furnace is greater; the heavier pieces of ore tend to descend vertically while the lighter particles of fuel are forced to the sides, which circumstance limits the possible height. The internal shape of a blast-furnace, should be that of the general form which it tends to assume after some weeks of working. It has been found in practice that the section is modified where the heat has been greatest, and that the sharp angles of the hearth and boshes of the older forms were invariably burned away. When a furnace is working irregularly, which often arises from an accumulation of lime and unreduced ore in the hearth and boshes, it is generally due to scaffolding. Fig. 16 is a section of a furnace showing an excrescence of this kind given by Mr. R. Howson who recommends the shape Fig. 17 as the best form for avoiding scaffolds.

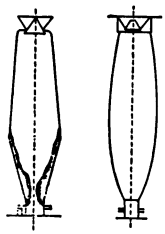

Fig. 16. Fig. 17.

Greater height may be given to a furnace to increase its capacity, and to intercept the heat more completely. Combustion should only occur in the neighbourhood of the twyers, and the greater the distance of the upper end of the charge from the zone of combustion, the more perfectly will the heat be extracted from the ascending gases, so that furnaces are now built 80 to 90 feet in height.

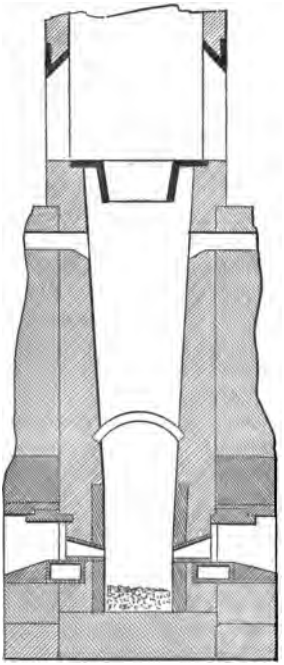

Fig. 18.

The section of most blast-furnaces is round, which economises the heat, and causes it to be more uniformly distributed; but there is always a difficulty in forcing the blast to the centre, since the charges sink more there than at the circumference. This circumstance induced Rachette to adopt an elliptical or rectangular section. The large production of 30 tons of grey iron in 24 hours in this small furnace is due to the suitable distribution of the blast, and the non-conducting nature of the walls. Truman states that the charges descend uniformly to the twyers, thus utilising the fuel more completely, and that the smelting is rapid. This furnace Fig. 18 is oblong and rectangular in shape, being 3 feet wide at the twyers, 7 feet at the throat, and about 30 feet high, with a capacity of 2000 cubic feet. The object of this shape is to keep the ascending gases

more to the centre and to cause a more perfect action on

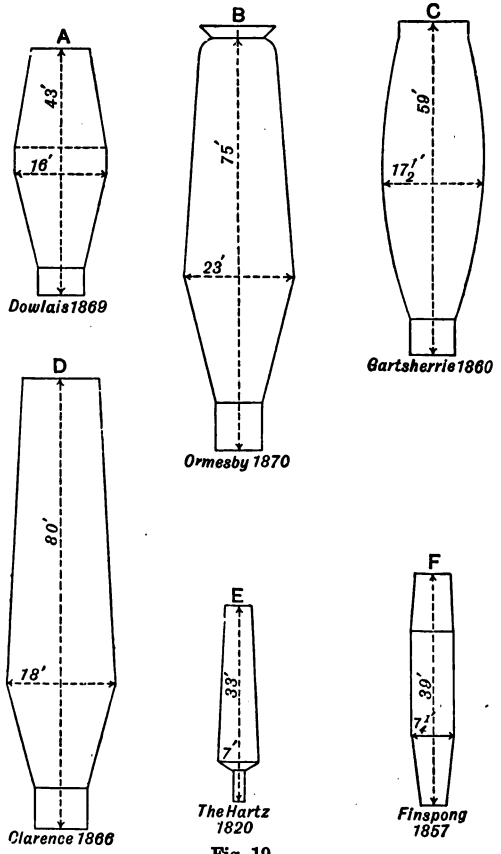

Fig. 19.

the descending solid materials. The blast is introduced through six or eight twyers, three or four being placed on

each of the longer sides of the hearth, thus causing a better distribution of the air.

The interior profile of a few different types of the blast-furnace is shown in Fig 19 A—F.

Collection of waste gases.—The waste gases of blast-furnaces were formerly allowed to escape, the furnace tops being always left open, but this system has been almost universally abandoned, except in a few localities where fuel is cheap and cold-blast is used. Various contrivances have, from time to time, been devised for closing the throat, so as to prevent the escape of the waste gases, which are conducted into suitable apparatus, where they are burnt to generate heat for heating the blast, etc., as before mentioned.

In the charcoal furnaces of Sweden, and some old coke furnaces, a portion of the gases is collected without closing the top, by introducing a number of iron pipes through the brickwork, at a depth of 10 or 12 feet below the top. In the Upper Hartz, and other places, an annular space is formed in the upper part of the masonry of the furnace, communicating with the interior, beneath the surface of the charge, by a number of openings inclining upwards, in order to prevent the lodgment of the charge in them. A large pipe opens into the annular space, and is connected with a high stack, so as to obtain the necessary draught for drawing off the gases. With some small straight furnaces a cast-iron cylinder is inserted in the throat, leaving an annular space which forms a collecting flue for the gases. The mode of charging by means of a central cylinder causes the more compact and finer particles to go to the centre, and the larger pieces to the sides, which latter then become more permeable by the gases. In order to correct this defect a fixed cone Fig. 20, supported by radial arms, is added, so as to distribute the charge more uniformly.

Escalle uses a fixed cone without a cylinder, Fig. 21. The top being closed, the gas is collected by the cone, the radial

arms which support it being hollow, so that the gases pass through them to the off-take. Moveable cones are now

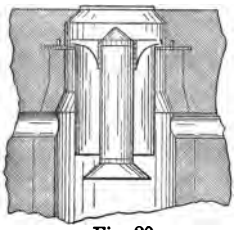

Fig. 20.

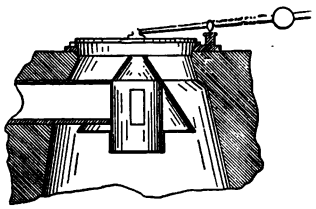

Fig. 21.

more generally used, both for collecting the gases and distributing the charge. The most simple and general form consists of a fixed cup (*a*), Fig. 22, and a moveable cone (*b*) suspended by a chain so that it may be raised or lowered at will. Various contrivances are in use for controlling the movement of the cone, a frequent form being a pinion moved by a hand-wheel, and gearing into a rack attached to a counterpoised weight. The gases pass through a lateral flue into the main pipe, which conducts them to the boilers, heating stove, etc.

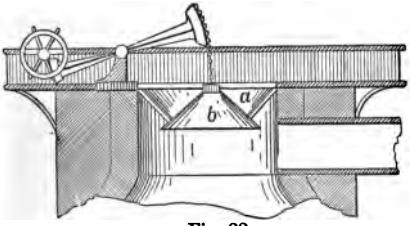

Fig. 22.

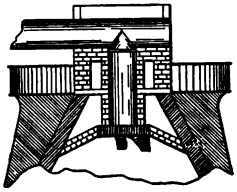

Fig. 23.

At Ulverstone in Cumberland a central iron tube Fig. 23, lined with brick, has been adopted for collecting the gases. The tube is about 5 feet in diameter, and extends about 5 feet into the throat of the furnace. It rests on six ribs of brickwork. In Langen's apparatus the gas collecting

tube is placed externally to the furnace, which may therefore be kept filled with the charge. It consists of a bell-shaped tube, which rests on an inverted conical charging cup. The bell is suspended from a lever, and the charge is placed in the conical cup, so that when the bell is raised the materials glide into the furnace.

Twyers.—The twyers, used for introducing the air into the blast-furnace, are subjected to intense heat, and require to be protected by a continuous circulation of water. They are therefore made with a double casing of wrought-iron, cast-iron, or bronze. Fig. 24 shows the arrangement of a Staffordshire twyer. Another form, known as Lloyd's spray-twyer, is open at the back, and the cooling water, in

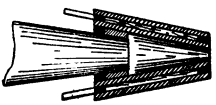

Fig. 24.

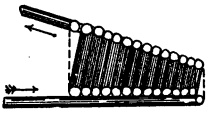

Fig. 25.

the form of spray, is driven from the end of a perforated pipe against the port of the twyer. Another form, termed the Scotch twyer, Fig. 25, consists of a spiral wrought iron tube enclosed in a cast-iron casing; a current of water circulates through the coil to keep it cool.

The number of twyers employed varies in different furnaces, according to the nature of the fuel and class of ore. An excess of blast causes the consumption of too much fuel, with the production of white iron; it also tends to cool the slags and impede the working. With an insufficient blast, the temperature of the furnace is lowered, and the production of iron lessened. With small charcoal furnaces two or three twyers are used. In large coke furnaces six or seven are arranged symmetrically round the hearth, with their axes pointing a little away from the centre. When producing forge-pig, the twyers are arranged horizontally, or slightly inclined

downwards, thus causing a partial decarburisation. For foundry-pig, the twyers are often slightly inclined upwards.

Hot-blast.—The use of hot air was first introduced by Neilson at the Clyde Iron Works in 1828, and was soon attended with great economy of fuel, and an increased make of iron. The arrangements for heating the blast are of two kinds:—cast-iron pipes through which air passes, heated externally; and chambers of refractory brickwork, constructed on the principle of Siemens' regenerators, which are now in more general use.

Cast-iron stoves.—Fig. 26 represents an old form of stove, which consists of a series of arched pipes of cast-iron, arranged in an oblong fire-brick chamber; along each of the long sides of this chamber are two circular mains, fitted with sockets, into which the legs of the vertical pipes are received, while between the mains, and running the full length of the stove, is a rectangular fireplace. The pipes are very unequally expanded by the heat, and this, when the extremities are fixed to the mains, leads to frequent breakages.

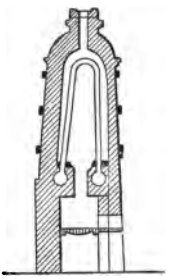

Fig. 26.

The defects of this arrangement have caused many modifications to be introduced. Thus the horse-shoe pipes have been replaced by an inverted **V** shape, which gives a smaller radius of curvature to the arch; and greater uniformity of heating is obtained by introducing stops at intervals in the entry main, so that the air passes alternately backwards and forwards across the arch. In some works, the vertical pipes instead of being arched are united by short horizontal limbs at right angles, and are placed close together.

In many German works a number of horizontal pipes of elliptical section are arranged in a fire-chamber, in a similar manner to the tubes of a locomotive,

and united into a continuous serpentine coil by arched bends, which are external to the fire, thus lessening the tendency of these bends to break by irregular expansion.

Of the regenerative type, two principal forms are employed, invented respectively by Cowper and Whitwell.

The Cowper stove Fig. 27, is a circular wrought iron tower, closed with a dome-shaped roof, and lined internally with fire-brick. It contains a circular fire-brick flame flue A, into which the waste gases from the blast-furnace pass by the valve B. The body of the stove is occupied by a checker work of fire-brick for absorbing the heat. The gas entering the flue A, is there burnt, the air necessary for combustion entering by the valve C. The hot products passing down through the checker work make it red-hot, and finally pass into the chimney-flue D.

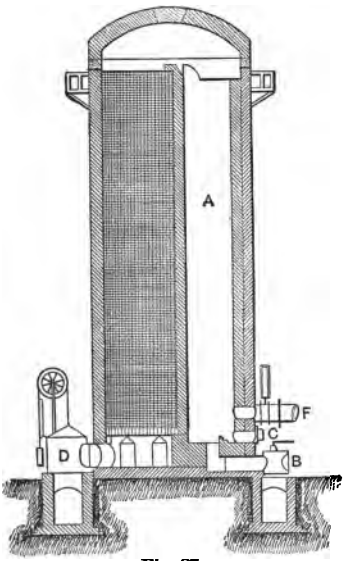

Fig. 27.

The stove having been thus heated, the valves B, C, and D are closed, and the cold-blast valve at the bottom of the stove opened, together with the hot-blast valve F. The cold air enters at the bottom or cooler end, and ascends through the brickwork, getting gradually hotter, and then escapes by the valve F, which communicates with the blast-furnace, at a temperature of 800° C. Two stoves are worked in conjunction, one being heated by the combustion of the waste gases, while the other is

being utilised in heating the blast. These stoves are 50 to 55 feet high, and 20 to 25 feet in diameter.

Whitwell's stove Fig. 28, differs from Cowper's chiefly in the arrangement of the absorbing brickwork. The air for the combustion of the waste gases is admitted at several points of the stove, so that the combustion is rendered more perfect. The regenerative brickwork is built so as to form a number of long and narrow vertical chambers, communicating with each other at the top and bottom. The blast-furnace gases enter through A, and meeting with warm air introduced through suitable passages, combustion takes place, and the flame rising up C, passes down the narrow passages, *x*, to the bottom. Here more air is admitted to burn completely the unconsumed gases, which rise up D and pass down through another series of narrow channels, finally leaving at the chimney valve E. When the stove is sufficiently heated, which takes about two hours, the gas- and chimney-valves are closed and the blast-valve opened, the blast entering in inverse order to the gases, as in the Cowper stove.

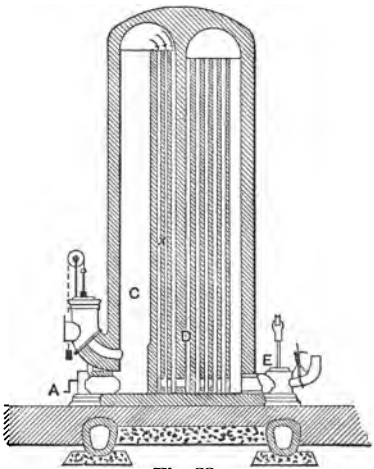

Fig. 28.

It is advisable to place the stoves as near to the furnace as is consistent with the other arrangements of the works, in order that the blast may retain as much of its heat as possible. With some charcoal furnaces the stoves are placed on a level with the fur-

nace top, and the hot-blast main carried down vertically to the twyers, but much greater regularity of draught, and freedom from dust is secured by bringing the waste gases to stoves on the ground level.

The advantages of hot-blast are :—(1) Economy of fuel, since less fuel is required, also the heated oxygen has a greater affinity for the carbon and hydrogen of the fuel; (2) the blast penetrates the fuel more freely on account of its density being less; (3) under equal circumstances, less pressure is required for hot- than for cold-blast; (4) irregularities are better overcome with hot-blast; (5) it facilitates and accelerates the blowing in of a furnace. The disadvantages are :—(1) The pig-iron is liable to be more impure, since silica, phosphoric acid, etc., are reduced to a greater extent, and (2), in consequence of the higher temperature, the furnace walls are more quickly destroyed.

Lifts.—In hilly countries the blast-furnace may be erected in a valley, the top being on a level with the ground. The charge is then tipped in without special apparatus. In most cases this is not possible, and lifts are required for raising the materials. These are of various kinds.

The inclined plane Fig. 29, consists of a railway

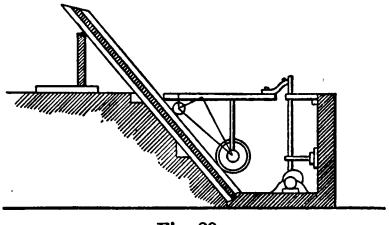

Fig. 29.

between the ground and top of furnace, inclined at an angle of 30°. On this incline runs a platform carriage, triangular in vertical section, with two pairs of unequal

wheels. The power is supplied from a steam engine working a winding drum, around which passes a wire rope or flat-linked chain.

Colliery lift.—This consists of a cage moving between vertical guides similar to those used in the shaft of a coal mine. It is worked by a direct-acting engine fixed either on the ground, or on the charging platform.

Water-balance.—This is a simple and effective lift still in use at several works, although more power is required for pumping water to the furnace top than for that of a direct lift; it is also difficult to keep the water-boxes tight. It consists of two cages moving vertically between guides, and connected by a chain passing over a pulley. Below the floor of each cage is fixed a water-tight box provided with a discharge-valve. When one cage is at the top, having discharged its load, water is caused to flow into its box until the weight is sufficient to pull up the other cage which is loaded.

Pneumatic lift.—This form of lift is now frequently used, the areas of the cylinders being adjusted for a pressure of from 4 to 7 lbs., so that the force of the air in the blast-main is sufficient to raise the required load. Gjers' lift Fig. 30, consists of a large cast-iron ram, which works in a 36 inch cylinder, rising the whole height of the furnace. From this piston pass wire ropes over four pulleys down to each corner of the lifting table, which is sufficiently large to hold four barrows. The weight of the ram is greater than that of the empty lift, and when the

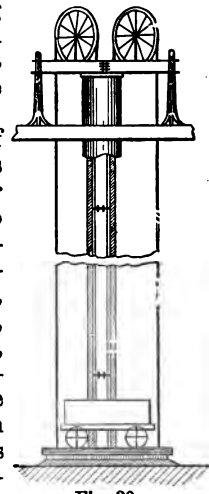

Fig. 30.

latter is at the top the ram will be at the bottom, so that by applying pressure beneath the ram, it rises, and the table is lowered. The loaded table is heavier than the ram, but when air is removed from under the ram a partial vacuum is formed, and the atmospheric pressure brings it down, and consequently lifts the loaded table up to the furnace-throat.

Blowing-cylinder.—This is used for supplying compressed air to the blast furnace. It resembles a steam cylinder but is of larger dimensions, and the lateral openings for admission of air are often omitted. The piston is made of plates of cast-iron fixed on an iron or steel shaft. On the circumference are arranged two leather rings which press against the sides of the cylinder, one for the up and the other for the down stroke. To avoid friction, fine plumbago dust is projected against the interior of the cylinder from time to time. Two sets of valves are arranged on the cylinder cover at each end, the longer series open inwards for admission of air as the piston recedes, and close at the return-stroke. Then the other series or discharge-valves open, and allow the compressed air to pass out.

Blowing-cylinders do not furnish a regular supply of air, the air being compressed most at the middle of the stroke, hence a "regulator" is placed in the course of the main between the engine-room and the furnaces. The regulator is a large cast-iron cylinder open at the top and closed with a weighted piston. When the supply of blast is greater than is required, the piston rises, but when the quantity diminishes, the piston falls and exerts a compressing force until equilibrium is restored. If the blast-main is of considerable length, or includes stoves, the regulator is unnecessary.

Blast-furnace gases.—Owing to the larger consumption of fuel, coke-furnaces give off more waste gases than charcoal-furnaces. Kerl gives the com-

position of the gases as shown in the following table :—

		Charcoal-Furnaces.		Coke-F.	Coal-F.
		I.	II.	III.	IV.
Nitrogen	N	63·4	59·7	64·4	56·3
Carbonic oxide	CO	29·6	20·2	34·6	21·5
Carbonic acid	CO_2	5·9	19·4	·9	15·2
Marsh gas	CH_4	1·0	·3	—	4·2
Olefiant gas	C_2H_4	—	—	—	1·8
Hydrogen	H	·1	·4	·1	1·0
		100	100	100	100

The following table gives the composition of the gases from some British furnaces :—

		Gartsherrie.	Alfreton.	Ormesby.
Nitrogen	N	54·42	55·35	54·91
Carbonic oxide	CO	30·31	25·97	26·66
Carbonic acid	CO_2	5·7	7·77	18·36
Marsh gas	CH_4	3·45	3·75	—
Olefiant gas	C_2H_4	·14	·43	—
Hydrogen	H	5·98	6·73	·07
		100	100	100

The large proportion of nitrogen is brought into the furnace in the blast along with the oxygen, but while the latter performs an essential part of the work in the furnace, the former passes through unchanged, and abstracts a valuable proportion of the heat, without contributing to its production. The amount of oxygen escaping is greater than that introduced by the blast, which increase is obtained from the solid materials in the furnace. The hydrogen, both the free, and that in combination with carbon, is derived from the decomposition of the water vapour of the air. The carbon is chiefly derived from the fuel. By withdrawing the gases at different levels, it is found that the proportion of carbonic acid to carbonic oxide diminishes progressively down the furnace, and that in the upper part of the hearth they consist almost entirely of nitrogen and carbonic oxide. The waste gases carry over with them a considerable amount of dust of a non-combustible nature, which greatly diminishes the heating power, so that the practice of washing the gases by passing them through a water trough, before going to the stoves and boilers, is often adopted.

Scaffolding, bears, etc.—Sometimes the charge of a furnace is obstructed in its descent, the lower portion being melted and withdrawn leaves a "scaffold," which, with the increasing weight from above, often gives way suddenly, and falls into the hearth. This is called a "slip," and deranges the working of the furnace.

In some cases large ferruginous masses, called "bears," are formed in the hearth of a blast-furnace, often containing iron, copper, silicon, graphite, manganese, nickel, cobalt, and cyano-nitride of titanium, a compound resembling copper in colour.

QUESTIONS.

1. Give a sketch in vertical section of a modern blast-furnace with a closed top.

2. Explain the working of a blast-furnace for smelting iron, more especially in regard to chemical changes as affecting carbon and phosphorus.

3. State the chief chemical changes taking place inside a blast-furnace using clay-ironstone and hot-blast, with lime-stone as flux, and coke as fuel.

4. In a blast-furnace it is impossible to make the fuel do its full duty. Why is this?

5. Why is more fuel required to produce Bessemer pig- than white pig-iron from a given ore, under constant conditions as to furnace, etc.?

6. How would you regulate the working of a blast-furnace so as to obtain varieties of pig-iron suitable for (1) casting, (2) for conversion into malleable iron by the puddling process?

7. Enumerate the different fluxes employed in smelting iron and state for which class of ore each is specially suitable.

8. Discuss the merits of charcoal, coke, and coal as fuel for smelting iron in the blast-furnace.

9. State the physical properties of ferro-manganese and how it is made on the large scale.

10. How would you bring into working order a blast-furnace in which the charge had become "chilled," that is, solidified in the neighbourhood of the twyers?

11. What are the relative advantages and disadvantages of "hot-" and "cold-"blast as applied to a blast-furnace for smelting iron?

12. Scaffolds are sometimes formed in a blast furnace, to what causes are they attributed and how may they be avoided?

13. What advantages have followed from increasing the height of blast-furnaces in recent years?

14. Sketch and describe the Rachette furnace.

15. Describe the Cowper-stove and explain how it differs from that of Whitwell.

16. Mention some methods of utilising blast-furnace slag.

17. Give the composition of the gases from the top of a modern iron smelting blast-furnace.

18. Describe different modes of closing the top of a blast-furnace for the purpose of collecting the waste gases.

19. Describe some form of hot-blast twyer.
20. Describe some form of lift in common use for raising materials to the top of a blast-furnace.
21. Describe the blowing-cylinder used for producing compressed air for a modern blast-furnace. Why is a regulator sometimes required?
22. What object is gained by washing blast-furnace gases?

CHAPTER VIII.

Refining Pig-Iron.

Two distinct methods have been adopted for the conversion of pig-iron into wrought-iron, depending on the kind of furnace employed, viz., *the open-fire or hearth-finery*, and the *puddling-furnace*, which is of the reverberatory type. The chemical reactions are similar in both cases, being based on the oxidation of the impurities by oxygen, both in the gaseous and in the combined form.

Open-fire or finery.—In former times this hearth was termed a "bloomery" from the nature of the product which was called a bloom. The hearth is rectangular, and formed of cast-iron plates lined with charcoal, the bottom being exposed to a current of air in order to keep it cool. Three sides are vertical while the remaining side slopes a little outwards. In the simplest or German forge the flames escape into an open hood, but in the Swedish forge the hearth is covered with a cylindrical roof, and communicates with the chimney by a lateral flue. The fuel employed is charcoal, the fire being blown by a blast of air issuing from a single twyer. A view of the finery in vertical section is given in Fig. 31.

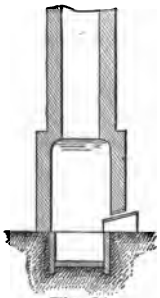

Fig. 31.

In the open-fire the iron is placed in contact with the fuel. Now this intermixture is objectionable, because the refining is based on oxidation, and the fuel acts as a reducer, so that which the air oxidises, the fuel tends to deoxidise, the purification being retarded thereby. The consumption of fuel is also very great. If the iron is designed to retain some carbon, so as to produce a steely product, then the open-fire is admissible.

The charge of pig-iron, usually in broad thin plates, is placed on a bed of glowing charcoal, which reaches to the level of the twyers. The operation of refining is hastened by the addition of hammer scale and rich slags, which assist in oxidising the impurities. The fusion of the iron is allowed to take place gradually, so as to expose it for a lengthened period to the oxygen of the blast. At the moment of fusion the foreign elements are rapidly oxidised. The silica unites with the oxide of manganese and oxide of iron to form a fusible slag, which, in consequence of the excess of metallic oxides, is called a basic silicate ($3FeO.SiO_2$).

The ferrous oxide FeO, acts as a vehicle for oxygen, absorbing the gas, and being converted into the black oxide Fe_3O_4. The latter coming in contact with the impure iron, oxidises the impurities, itself being again reduced to FeO. After a time the slag becomes neutral, and is in part removed; then fresh basic slag and hammer scale are added. To complete the operation, the masses of iron are lifted up to the twyer level in order to completely oxidise the combined carbon. The white-hot mass of iron, which is now of a spongy texture, is then taken to a heavy hammer and compressed to a slab, termed a "bloom." The subsequent treatment of the bloom varies in different districts. In Italy the partially refined mass is removed from the hearth and cooled with water; then broken up, and re-heated sufficiently to cause the iron and slag to cake together, when it is again removed. In the third stage the iron

is re-heated with rich slags until it is sufficiently refined.

In South Wales a superior quality of iron sheets for tin-plates is made from the best pig-iron in a charcoal-finery. The pig-iron is first partially refined in a hearth termed a "refinery," Fig. 32, which is described on the next page. The charge of $2\frac{1}{2}$ to 3 cwts. of refined iron from a coke "refinery" produces a finery ball, weighing about 2 cwts., which is shingled and drawn out to a long bar, 2 inches thick, under a lever-hammer. The bar is then nicked and broken into pieces, the best pieces being selected, and made into small bundles or piles. These bundles are re-heated in the flame of a coke-fire, in a special furnace known as the "hollow-fire," the upper part of which forms a chamber in which the piles are re-heated. The piles are then welded under a hammer and rolled into sheets. Before finishing, the sheets are annealed, pickled in sulphuric acid, and then rolled cold. Finery-slag is highly basic, containing upwards of 75 per cent. of ferrous oxide FeO.

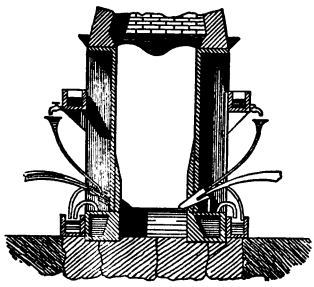

Fig. 32.

The Swedish-Lancashire finery is arched over at the top, and communicates with the chimney by a horizontal flue, in which the pig-iron undergoes a preliminary heating.

Refining in the Refinery.

For the better qualities of wrought iron, crude pig-iron was formerly submitted to a preliminary operation in a rectangular hearth, termed a refinery, Fig. 32, with

a number of twyers so arranged on two of its sides as to project a stream of air on to the molten iron, in order to oxidise its impurities. The iron is finally quenched, by running it into an iron trough, thus causing the carbon to remain in the combined form, which condition greatly facilitates puddling by the original "dry" method, as white iron assumes a pasty state before melting.

The hearth consists of a cast-iron framework with a sandstone or firebrick bottom, and is surmounted by a low brick chimney, bounded on its sides and back by hollow iron castings, through which a current of water is made constantly to circulate. The front of the hearth is closed by a cast-iron plate, having a tap hole for the metal and slag. The casting mould, placed in front of the hearth, is also made of thick cast-iron plates, and is about $3\frac{1}{2}$ feet wide by 10 feet long by 8 inches deep. It is placed upon the edges of two long cisterns, through which water circulates for the purpose of cooling the mould, which quickly cools the refined iron when it is run into the mould.

The iron, in the form of pigs and scrap, is placed in alternate layers with coke upon a bed of ignited fuel at the bottom of the hearth, and the blast supplied at a pressure of $1\frac{1}{2}$ to $2\frac{1}{2}$ lbs., according to the combustibility of the coke. In about 2 to $2\frac{1}{2}$ hours the charge is melted, and in another hour the blast has sufficiently oxidised the impurities in the iron. The refining is hastened when basic iron-slags and hammer-scale are added to the charge.

The element whose chemical affinity for oxygen is greatest will absorb this gas first, and others will be oxidised in turn in proportion to their chemical energy. The order of oxidation will be as follows:—Silicon, manganese, phosphorus, sulphur, carbon, and iron. But this order will be modified according to the temperature employed, and the kind of slag present. Also oxygen

will combine with the dominant metal by the influence of mass, so that refining slags always contain a large amount of oxide of iron, and may be represented by the formula $2FeO.SiO_2$.

The refined metal, forming a plate 3 inches thick, shows a silvery-white fracture, the lower part being compact, and the top part dull and cellular. The metal is very brittle, and is readily broken into pieces suitable for the puddling process.

Puddling—Dry and Wet.

The method of dry puddling in a reverberatory furnace was developed by Cort, and patented by him in 1784. The furnace-bottom was lined with sand, which became thinly glazed over with slag during the working. In later years the bottom was covered with a lining of oxide of iron, formed by oxidising scrap iron in the strongly oxidising atmosphere of the furnace. Each operation is composed of three periods—fusion, rabbling, and forming the blooms. White or refined iron is chiefly used. About 4 cwts. of refined metal are charged into the furnace, and are partially melted in about half an hour, forming a pasty mass, which does not become liquid as is the case in wet puddling. It is then stirred with iron tools so as to bring all parts under the oxidising influence of the air. As the impurities are removed the iron becomes less fusible, requiring the temperature to be gradually raised. The particles of iron are then collected into balls by the puddler, each ball weighing about 80 lbs.

The modern puddling-furnace Figs. 33 and 34 is a reverberatory, with a low flat roof, generally slanting from fireplace to flue. The fire-bridge A and flue-bridge B are formed of hollow iron castings encased in fire-brick; the bed is likewise formed of iron plates rebatted together; and the sides generally consist of hollow iron castings.

These hollow castings are kept cool by the circulation of air or water through them. The laboratory or working part C is about 6 feet long and 4 feet wide, tapering towards the flue-bridge. The grate area varies from one-third to one-half that of the laboratory. The bed is

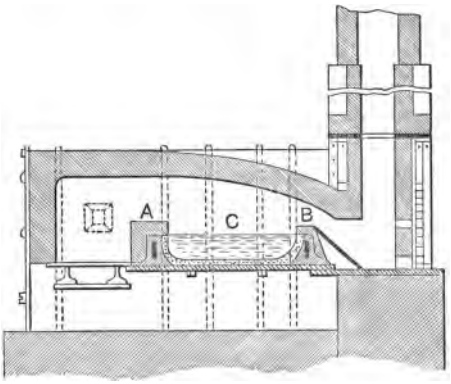

Fig. 33.

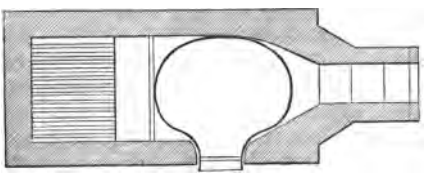

Fig. 34.

lined with broken slags, hammer scale, and red oxide of iron, and the sides with bull-dog, all being well rammed down; this is termed "fettling." The working door is on the same side as the fire hole, and is made of fire-brick set in an iron frame; it is suspended by a chain attached to a counterpoised lever. The flue generally

slopes down towards the stack, its sectional area being about one-fifth to one-seventh that of the fire-place.

Wet-puddling or pig-boiling.—This method is characterised by the complete fluidity of the pig-iron and the length of the puddling, which often lasts over an hour, so that the whole process requires about two hours. The preliminary refining is dispensed with. The pigs submitted to this process are siliceous or strongly carburetted, and should be manganiferous if steel is desired. Now manganese retards the decarburisation of the iron, by constantly reducing magnetic oxide Fe_3O_4 to ferrous oxide FeO, and ferrous oxide to metallic iron, which reduction would otherwise be effected by carbon, so that as long as the iron contains manganese its superior affinity for oxygen practically prevents Fe_3O_4 being formed. Moreover, slags containing oxide of manganese are more fluid, and more easily expelled by shingling and re-heating. A little manganese in steel also improves its quality.

The bed and sides of a modern puddling-furnace are lined with refractory materials rich in oxide of iron. When the iron is melted, it is between two oxidising influences—the air and oxide of iron—and the operation will be shorter and the product more uniform in proportion as the rabbling (or moving of the mass by the tools of the puddler) is more vigorous, because by that means a more thorough mixture of the iron and oxidising substances is effected. The ferruginous slag formed takes up oxygen from the air, causing FeO to pass into Fe_3O_4, which then oxidises the impurities in the order of their oxidisability, viz., silicon, manganese, phosphorus, sulphur, and carbon.

The period of rabbling has two distinct phases—1°, the scorification of silica and oxide of manganese; 2°, the very agitated period, termed the "boil," when decarburisation occurs, the bath of metal being covered with jets of burning carbonic oxide. The forcible ejection of

this gas causes the slag and globules of iron to be lifted up, giving the appearance of a liquid when boiling. As the carbon is removed the iron requires a higher temperature to keep it liquid, and particles of iron begin to solidify and join together, or, as it is technically termed, "come to nature," and form a spongy, sparkling mass. The metal is then collected into balls by the workman.

The excellence of the iron produced will mainly depend on the prevalence of a high temperature during the boil, so as to maintain a highly oxidising atmosphere; for if the temperature be too low, the reducing flame of carbonic oxide prevents the complete liberation of carbon, and hard iron or steel results. The quality of the iron will also depend on the kind of pig-iron operated upon, for the greater the quantity of impurities, especially phosphorus and sulphur, the more prolonged must the puddling be, and the greater will be the waste of iron. The slag from a puddling-furnace is essentially a silicate of iron $2FeO.SiO_2$, containing many of the impurities originally present in the iron, and is termed "tap-cinder."

Mechanical puddling.—Many attempts have been made to lessen the enormous amount of labour which has to be expended in puddling, by substituting mechanical appliances. The methods proposed are—tools imitating manual rabbling, and rotating or oscillating hearths.

Mechanical tools are so arranged as to be capable of a compound motion over the bed of the furnace, one of the simplest being that of Eastwood Fig. 35. The rabble is supported in a stirrup connected with one end of a bent lever placed overhead, which receives

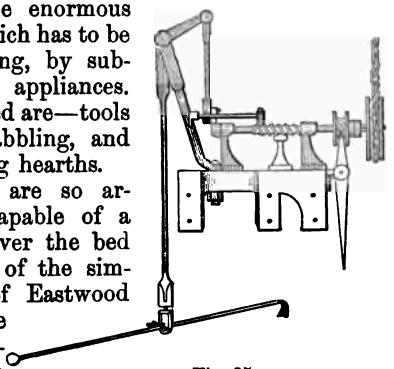

Fig. 35.

a to and fro motion through a crank, and a lateral motion through a screw and wormwheel gearing; this double motion enables it to be worked over the whole bed. The machine is bolted to the back of the casing, on the working side of the furnace, and by means of a fast and loose pulley may be put in and out of gear at will.

Danks' furnace.—This furnace Fig. 36 consists of a cast-iron cylinder with conical ends, 4 feet long and

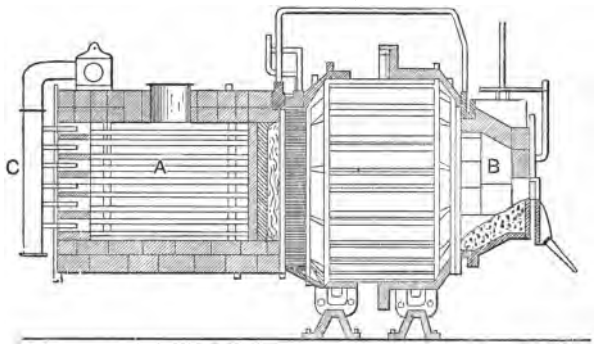

Fig. 36.

5 feet 3 inches in greatest diameter, bound with iron hoops. The shell is formed of segments bolted together, and on the inside are twelve radial ribs which keep the fettling in position. The cylinder is encircled at either end with a roller way which rests on anti-friction rollers. One end of the chamber is open to the fire-place, and the other end opens into an elbow-shaped moveable flue B leading to the chimney. The front conical cover has a tap-hole for slag, and the charge is withdrawn at the chimney-end by removing the moveable flue. The fire-place has an air-blast C, placed below the grate for increasing the combustion, and also small twyers in the back wall, through which air is blown at the level of the fire-bridge. The fire-bridge is hollow, being kept cool by a

current of water, and fettled on the inside. The chamber is first lined with a mixture of crushed iron-ore and lime, made into a mortar, which is then dried by a wood fire made inside. Then on this initial lining, is melted some iron-ore and hammer-slag, and into this, when liquid, are thrown pieces of "ilmenite" or harder ore, until the lining is studded with such pieces projecting from two to six inches. About 2½ tons of ore are required for fettling a 700 lbs. furnace.

The charge of pig-iron is introduced at the chimney-end with 20 per cent. of cinder, and as it melts the furnace is made to slowly revolve, so that the iron is continually exposed to the action of the air in all parts. The action is the same as in ordinary puddling. The speed is gradually increased as the operation proceeds, and when the particles of iron begin to adhere the speed is again reduced to two revolutions per minute. The iron is collected into one large ball, and removed at the flue end by a forked lever carried by a crane. The time required for working a charge varies from 1 hour to 1½ hours, accordingly as white or grey iron is used. Eight to ten charges may be worked for one fettling, with the consumption of 22 cwts. of coal per ton of iron. The oxidation of the impurities is chiefly effected by the oxides of iron in the fettling, and their removal is more perfect than by hand-puddling. A certain portion of the oxide of iron in the fettling is also reduced, so that one ton of puddled iron is obtained from 18½ cwts. of pig-iron employed.

The disadvantages of the process are:—that a large mass of 700 lbs. weight has to be hammered or squeezed, requiring special appliances; the slag is difficult to remove completely from the interior of the mass; the wear and tear is very great, requiring frequent repairs; and the lining very soon wears away. Mr. J. Williams describes the furnace thus: "As a worker of metals it is without an equal; as a melter it is inferior to many;

as to endurance it is the shortest lived of any; and as to convenience of repairs it is one of the most difficult."

Crampton's furnace.—Mr. Crampton has introduced a revolving furnace Fig. 37, similar to that of Danks, with a double casing, through which water circulates so as to preserve the lining. The essential point of this furnace is the use of finely divided fuel as the source of heat. The ordinary fire is replaced by a tube-piece

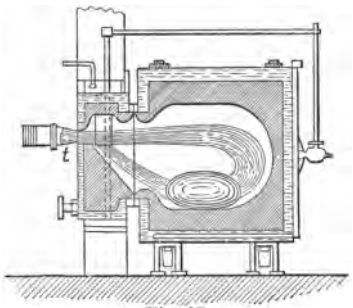

Fig. 37.

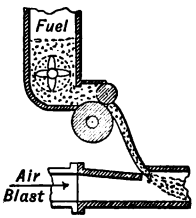

Fig. 38.

t, fitted into the end plate of the moveable flue-piece; it is bell-mouthed towards the flue, and through this tube a stream of fine coal, mixed with the necessary amount of air, is injected automatically. Fig. 38 shows the feeding arrangement. The fuel is perfectly consumed owing to its intimate admixture with air, producing a high and regular temperature.

Pernot's furnace.—M. Pernot at St. Chamond uses a furnace Fig. 39 with a fixed roof and circular turning bed, inclined at an angle of 5° or 6°. It consists of three parts;—the fire-place burning ordinary fuel, or a gas-producer for generating gaseous fuel; the puddling-chamber with moveable bed; and the flue leading to the chimney. Fig. 39 represents a Pernot furnace heated with gaseous fuel. The bed is made of hollow wrought iron segments,

and fettled in the usual way with oxide of iron and cinder. Below the bed is a strong iron carriage moving on rails. This carriage has two pairs of wheels, and upon the framework is mounted the socket of the revolving axis of the bed. Rotation is imparted by means of an endless screw and worm wheel, which is fixed to the circumference of the ring at the bottom of the bed. Conical friction-rollers are also provided to assist the central pivot in keeping the hearth in position as it rotates.

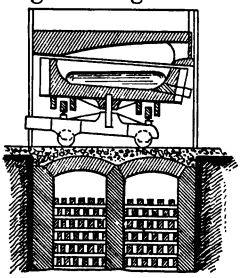

Fig. 39.

From 15 to 20 cwts. of pig-iron with some scrap iron are introduced, after having been previously heated to redness. The charge is rapidly melted, and when the refining is completed, the iron is balled up by workmen. From 9 to 10 charges are worked off every 24 hours. The inclination of the bed causes the lining to be alternately under the molten iron and exposed to the flame, so that the bottom heat is constantly renewed and sticking of the charge prevented. Moreover, the exposure of the lining at each rotation favours oxidation, so that any FeO which has been reduced by the carbon of the pig-iron, is again converted into Fe_3O_4. The rotation not only rabbles, but promotes the reaction of the lining on the pig-iron. The disadvantages of this method are :—the great initial cost, the large quantity of fettling used, and the rapid wear of the bed, while the manual labour required is the same as in an ordinary furnace, although the work is much less fatiguing. The advantages are :—the large increase of metal refined in a given time, with a great economy of fuel, which is its principal advantage. The bed being removeable, the roof is readily accessible for repairs, and a new bed can be run under and worked while the old one is being mended.

Gas-furnaces for puddling.—By the use of gas-producers, fuel may be used which is too inferior for ordinary furnaces and a higher temperature obtained by the combustion of the gas formed, than by using solid fuel directly. The puddling operation is the same as usual, except in such arrangements as Pernot's, where gas may be used in combination with mechanical puddling. In the case of Siemens' furnace, the regenerators are liable to be choked with dust, slag, and iron, carried over during the boiling stage. This may be largely remedied by passing the waste gases through an intermediate chamber, so as to deposit the solid matter before entering the regenerators. In some cases certain ferruginous substances have been placed at the entrance of the regenerators to act as a kind of filter. The difficulties arising from the deposition of dust, etc., have prevented the use of gas in many forges. The extreme heat produced in Siemens' furnace probably increases the affinity of iron for carbon, which renders the fining difficult, and tends to produce an imperfect, steely iron.

The system of heating on the regenerative principle was developed by Sir William Siemens, and so named by Stirling, the originator of the principle, because the waste heat was restored again to the furnace. The regenerators are chambers of open refractory brickwork, built in pairs, two pairs being required for each furnace, each pair being used alternately for absorbing the heat of the gaseous products from the furnace and heating the gas and air required for combustion. Fig. 40 shows the furnace in vertical section with the regenerators beneath the bed. The larger chamber in each pair is used for heating the air and the smaller for heating the gas. By means of a reversing valve the waste gases pass to the right or left pair at will. When the waste gases are passing down through the right pair, the cold air and gas are passing up through the left pair, the direction being reversed when sufficient heat has been absorbed. The ratio of gas-space

to air-space is as 4 : 7, which allows for varying amounts

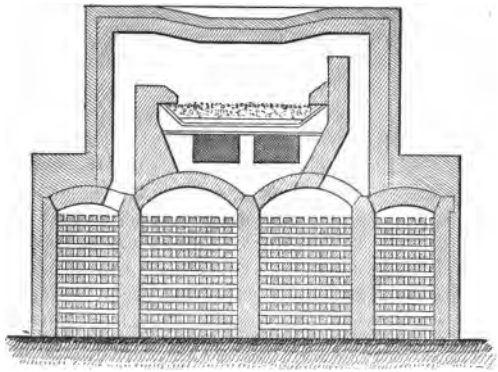

Fig. 40.

of air while the gas remains the same, and an oxidising or reducing flame as required.

The bed of the furnace is made of cast-iron boxes, cooled by circulation of water, and provided with similar water-bridges at each end. It is lined with oxide of iron, slag, etc., like an ordinary puddling-furnace. A heating chamber is arranged at each end of the furnace, in which the pig-iron is heated to redness before charging. The heated gas is brought into the furnace by a narrow rectangular chamber, opening into a slit in the body of the fire-bridge. The hot air enters through a parallel flue behind the gas-flue, but at a higher level, so that by its greater density it falls and mingles with the gas. At this point combustion takes place.

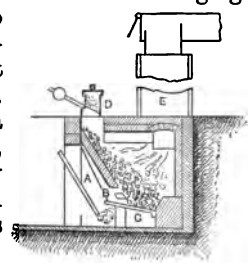

Fig. 41.

The gas-producer Fig. 41, is a nearly rectangular chamber lined with fire-brick.

The side A is formed of iron plates lined with fire-bricks, and has a step grate B, with wrought iron bars C. The fuel is charged through the hopper D. The gas passes up the pipe E, which is cased with iron, and into a horizontal wrought iron pipe which conveys it to the regenerator. The combustible portion of the gas consists chiefly of carbonic oxide CO, called air gas. When a jet of steam is introduced into the regenerator the gas liberated contains hydrogen and carburetted hydrogen; it is then called water gas. The gases generated in gas-producers for metallurgical purposes contain from 25 to 34 per cent. carbonic oxide, 55 to 60 per cent. nitrogen, the remaining portion consisting of carbonic acid, hydrogen, and hydrocarbons.

The effect of water vapour or steam on incandescent carbon is to form hydrogen, marsh-gas, and carbonic oxide, thus:

$$C + H_2O = CO + 2H,$$
$$3C + 2H_2O = 2CO + CH_4.$$

The effect of oxygen is to produce carbonic oxide. The amount of steam admitted should never exceed 10 per cent. of the air, otherwise the water vapour will tend to stop the process by diminishing the combustion. By the use of superheated steam a slightly larger amount than 10 per cent. may be advantageously admitted.

Waste heat.—The waste heat of furnaces used for refining iron has been utilised in a variety of ways, but chiefly for heating steam-boilers. The commonest form of boiler is a vertical cylinder with hemispherical dome, placed in the chimney. The flame passes round it, or through a central flue connected with the outer shell by horizontal tubes. Two furnaces are generally connected with one boiler.

At Rhonitz a combination of puddling and re-heating furnaces is adopted. An ordinary gas-producer using

wood fuel is combined with three hearths in one straight series. The first is used for re-heating, and receives the hot gases without air. The second is the puddling-furnace where the gases are burned by admitting air at the fire-bridge. The third is heated by the waste heat from the puddling-furnace, and used for heating the pigs previously to puddling. Lastly, a hot-blast stove is placed in the base of the chimney, by which means the air employed in the puddling-furnace for burning the gases is raised to 200° C.

The method of using the waste heat in Siemens' furnace has been already described. A somewhat analogous plan is employed by Ponsard (see Fig. 53).

The loss in puddling varies, according to the impurity of the pig-iron employed, from 5 to 10 per cent.; and the fuel consumed is from 20 to 25 cwt. per ton of puddled bars produced. The charge of pig-iron for an ordinary puddling-furnace is 4 to 4½ cwts., and in Staffordshire 5 to 7 heats are worked off in 12 hours.

QUESTIONS.

1. In what respects does the modern differ from the original process of puddling?
2. In puddling pig-iron containing phosphorus, sulphur, silicon, and manganese, in what way are these bodies removed?
3. Roughly sketch and describe some form of mechanical puddling-tool, and state its advantages and disadvantages as compared with hand-tools.
4. Describe some form of mechanical puddling-furnace, and state how far it has been successful.
5. Describe the chemical changes which take place during the puddling of pig-iron in the ordinary manner.
6. Describe the method of refining iron in the "finery."
7. Contrast the nature of the chemical changes taking place in the puddling-furnace with those occurring in the blast-furnace.
8. Sketch and describe a modern puddling-furnace.

9. Sketch and describe some form of rotating furnace used for puddling iron. State its advantages and disadvantages.

10. Describe some method of puddling iron in which gas is used instead of solid fuel.

11. How is the waste heat of puddling-furnaces utilised?

12. From puddling a ton of pig-iron of a given quality, how many cwts. of rails would you get?

CHAPTER IX.

Treatment of Puddled-Iron.

The operations which are conducted in that part of an iron-works known as the "forge," include puddling, shingling or hammering, rolling, etc. The oldest classes of hammers for shingling are the "tilt," where the axis is between the point of application of the cam and the head; and the "helve-," or lift-hammer, where the hammer-block and lifting-cam are on the same side of the fulcrum. The former is used for light work, the latter for heavier work, such as shingling puddled-balls, blooming piles, etc. The modern form is the steam-hammer, employed both for shingling and welding.

Various forms of squeezers are also used, instead of the hammer, for the treatment of puddled balls.

The rolling mill is generally used for merchant iron, the rolls being of two kinds—"roughing" rolls, and "finishing" rolls of several forms, according to the shape of the bar required.

The white-hot balls of iron formed in the puddling-furnace are taken to a hammer or squeezer, in order to expel the enclosed slag and weld the particles of iron into a compact mass, and also to confer upon them a shape suitable for passing through the rolls.

The tilt-hammer Fig. 42 rarely exceeds 5 cwts., and is not much used for shingling, except in works where small quantities are treated. It generally consists of a wooden shaft hooped with wrought iron; at one end is the head in the form of a heavy hammer, and the other end is depressed by the projecting teeth of a revolving cam, falling by its own weight as each tooth passes. The fulcrum is placed between the head and the cam, but nearer to the latter.

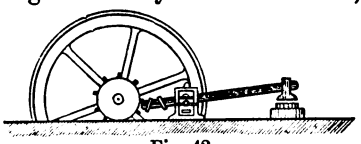

Fig. 42.

The helve-hammer consists of a heavy mass of cast-iron weighing from 2 to 10 tons, lifted by projecting pieces fixed in a cam-ring, and falls by its own gravity through a space of 16 to 48 inches. Fig. 43 represents a "belly-helve" in which the cam is placed below the surface of the ground, and acts on a projection termed a "bray," which can be lengthened or shortened according to the size of the iron to be hammered. This form enables the workman to go all round the hammer to inspect the work. The head of the arm contains the hammer face, made of wrought iron and dovetailed in. The anvil is also of wrought iron attached to a heavy casting weighing from 12 to 15 tons.

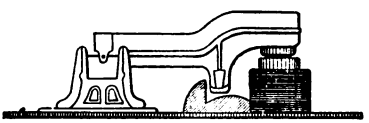

Fig. 43.

The steam-hammer Fig. 44 is now largely employed both for shingling and welding. It is a simple direct-acting machine, and takes up little room compared with the cumbrous wheel-work of the old helve. The force of the blow in shingling is generally required to be light at first, and with the steam-hammer the force can be varied with the work to be done. Another advantage

is, that the hammer always works parallel with the piece under operation, which is not the case with helves, the hammerman having to use thickness pieces to overcome

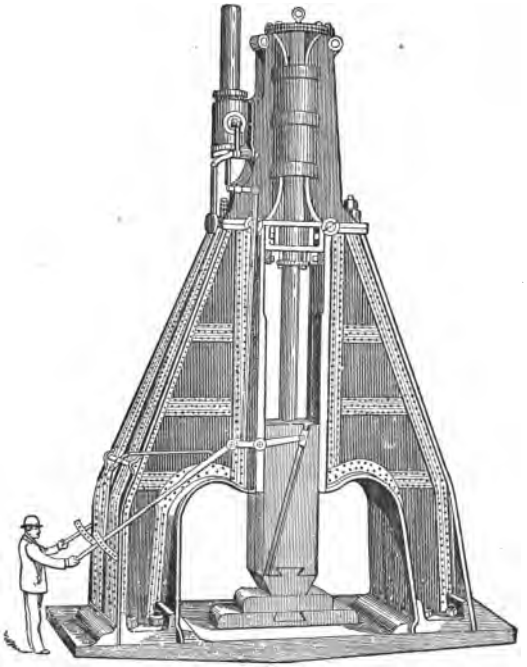

Fig. 44.

this difficulty. Both sides of the steam-hammer are also accessible for working.

It consists essentially of a vertical high-pressure engine with an inverted cylinder. The piston-rod is attached to a heavy block or "tup" moving between guides on the inner faces of the standards, which consist of a massive cast-iron framing. The ordinary hammer is double-acting,

the steam being exhausted above or below the piston. The slide-valve is balanced against the steam-pressure in the valve-chest so as to be easily moved. A lever moves the steam-admission-valve, and the exhaust is opened by the hammer moving a bent lever.

The hammer varies in weight from 30 to 60 cwts., but in forging very heavy masses the block may weigh 5 to 10 tons. The force of the blow is however, to a great extent, independent of the mass of the hammer head. The anvil is of great weight, having a massive foundation, which stands clear of the framing.

Squeezers.—These machines have superseded hammers in some forges, the welding of the ball being effected by pressure without impact. There are two kinds in use —lever and rotatory squeezers.

The crocodile-squeezer Fig. 45 is used both with single and with double jaws. The lower jaws are fixed

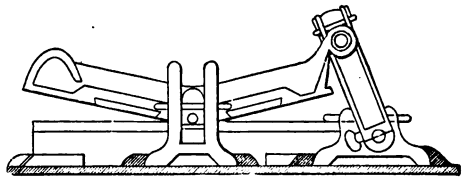

Fig. 45.

while the upper ones are opened and closed by a crank and connecting rod attached to the end of one of them. The upper jaw is sometimes serrated so as to better grip the puddled ball, which is inserted at the wide end and gradually rolled by the workman towards the narrow end. By this means the slag is expelled and the particles of iron firmly welded.

Rotatory-Squeezers.—Fig. 46 represents a horizontal machine, which consists of a revolving cylinder (*a*) having its surface corrugated or studded with teeth. This cylinder is placed eccentrically with regard to that

of the outer casing (*b*), the inside of which is similarly roughened. The ball is placed by the workman in the space (*c*) and carried forward by the rotation of the cylinder (*a*). The pathway gradually narrowing, the ball is compressed into smaller dimensions, and finally leaves at the narrowest part (*d*) in a condition ready for rolling. The cylinder revolves at the rate of 12 revolutions per minute, and is driven by a bevel-wheel and pinion placed beneath. The distance between the pressing surfaces is fixed, so that balls of a somewhat uniform size and weight must always be used.

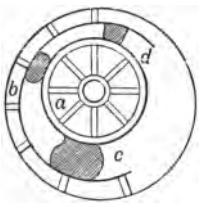

Fig. 46.

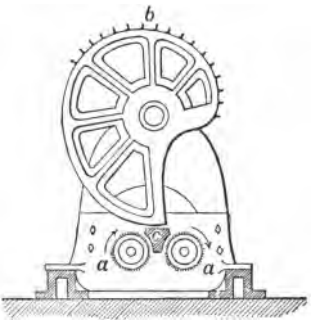

Fig. 47.

Mr. Danks uses a vertical squeezer on the rotatory plan Fig. 47. Two roughened parallel rolls (*aa*), 4 feet in length and 18 inches diameter, revolve in the same direction, and above these rolls, on a parallel shaft, is arranged a large cam (*b*), the periphery of which revolves at the same rate as the surface of the two rolls. At the end of the rolls is fixed a horizontal steam-hammer (*c*), the face of which hammers the bloom while it is being squeezed by the cam and rolls. The bloom is then re-heated and rolled.

Rolling-mill for puddled iron.—The forge-train Fig. 48 contains two sets of rolls—the roughing-

rolls, represented at the right hand, and the finishing-rolls to the left hand. The roughing-rolls are

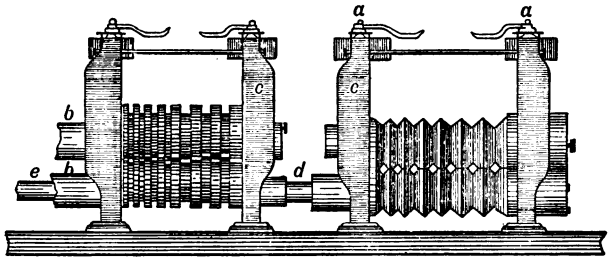

Fig. 48.

usually 5 feet long, and about 20 inches in diameter, forming a series of gothic and diamond-shaped grooves between them, diminishing in size from right to left. The larger grooves are gothic-shaped, and roughened, so as to more effectually lay hold of the iron; the smaller ones are diamond-shaped. The distance between the rolls is regulated by the screws (*a*) and the connection between them is established by means of the cogs attached to the ends (*bb*). The "journals" or necks of the rolls run in metal bearings, which are supported in cast-iron frames or "housings" (*cc*). The finishing-rolls are arranged in housings similar to the roughing pair, but have rectangular channels instead of the diamond grooves. These channels diminish in size from right to left. The two sets of rolls are connected together by heavy couplings (*d e*) keyed tightly together. The two rolls of each pair revolve at the same speed, which in the roughing-rolls is about 70 revolutions per minute, and in the finishing-rolls about 90 revolutions per minute.

The bloom of iron is first passed through the largest groove of the roughing-rolls, then lifted back over the top roller, turned one quarter round, and passed through the next smaller hole. This operation is repeated until the

bloom is reduced to a square bar small enough to enter the flat grooves of the finishing-rolls. In this pair, the process of reduction is continued until a puddled-bar of the desired thickness is obtained.

Re-heating and welding.—The bars and slabs of iron, obtained by shingling and rolling puddled-bars, are of inferior quality, and require to be further improved, so as to form good malleable iron. This is done by cutting up the bars into short lengths, arranging them in fagots or bundles, then re-heating them and hammering or rolling to any desired shape.

Bars are generally cut up by means of powerful lever shears, containing knife edges of hardened steel, termed crocodile- or cropping-shears Fig. 49. The lower blade is fixed to a cast-iron stancheon, and the upper one moves on a pin (*a*) passing through the same support. The lever (*a b*) is connected with the motor by the crank (*c*). The top jaw opens and closes at every revolution of the shaft by which the power is supplied. Guillotine-shears are also used, see page 106.

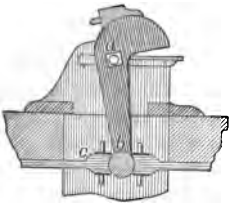

Fig. 49.

The piles or bundles, for re-heating, vary greatly in size and arrangement, according to the desired size and shape of the finished bar. For ordinary bar-iron the piles are made about 2 feet long and 4 inches square. For large sizes they may be 5 or 6 feet long and 10 or 12 inches square. In all cases it is advisable to have the pieces forming the pile of uniform size. Each bundle is bound firmly together by stout wire. For common iron puddled-bars are used, but for a better quality the iron from a second rolling is used to form the top and bottom plates of the pile; if the iron obtained from welding the latter pile is cut up and again fagoted, the iron is termed best-best.

For iron plates, bar-iron of suitable quality is made into piles of various lengths and thicknesses, then re-heated, and rolled to the desired thickness.

For large sheets, the piles are 20 inches long, 7 inches wide, and 4 inches deep, weighing about 70 lbs. The white-hot pile is made into a square bloom, by passing it through the grooves of the blooming-rolls, then through plain roughing-rolls, and finally through the polished finishing-rolls.

Black-plates, as the thin plates intended for tinning are called, are doubled over upon themselves after every re-heating, so that several sheets are rolled together. The plates are then cut to proper size and separated.

Nail-rods.—Two different methods are adopted for making nail rods—by rolling a bar to the desired thinness; and by slitting a strip of iron into parallel rods, which is by far the more common. Two or three pieces of iron are made into a pile, and raised to a welding-heat in a re-heating furnace. It is then taken to the rolls and extended into a bar 10 to 12 feet long and 4 inches wide; then passed between smooth rollers to obtain the desired thickness. It is then transferred to the slitting rolls Fig. 50. These consist of spindles carrying steel discs fixed at suitable distances. When revolving, the discs on the upper spindle project into the spaces of the lower series, thus forming a rotatory shearing-machine. On inserting one end of the iron strip between the guides, it is drawn forward by the shearing-discs and cut into rods, which are afterwards cut to length.

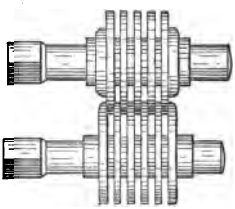

Fig. 50.

Hoop-iron is made from small piles, which are heated and rolled between grooved rolls, and finished between a pair of cylindrical rolls, where it is pressed to the desired thickness. The great length of the bars, and their tend-

ency to cool quickly, make it necessary to drive the grooved rolls at great velocity, but the finishing-rolls work at an ordinary speed of 100 revolutions per minute.

Small sizes of flat, square, and round iron are rolled with trains having three rollers in height, so as to hasten the work while the iron is hot, the mill being driven from the middle roll. The bar is passed between the bottom pair and returned between the upper pair, so that the operation is performed in both directions. A speed of 230 revolutions per minute is common. In rolling bars of small section, guides are used to keep them straight. It is usual to attach parallel guides, with friction-rollers, to the tables in front of the rolls, which are then termed "guide-mills" or "trains." In the short finishing-rolls for round iron, each has a semi-circular groove, and the two together form a complete circle.

Plate-mills are usually made with two sets of rolls, each being a plain cylinder of uniform diameter. The first or roughing-pair has the top roll balanced by counterweights, whilst the top finishing-roll runs freely. These latter rolls are cast in chills and highly polished. The size varies from 5 to 9 feet long and from 20 to 36 inches in diameter. The speed is 25 to 40 revolutions per minute, the higher speeds being used for light plates.

Guillotine-shears.—These shears are used when a cut of considerable length is required, as in the shearing of heavy plates, sheets, etc. The form Fig. 51 is now also used in some works, in place of the crocodile-shears, for puddled-bars, blooms, etc. It contains two diagonal-edged knife blades (*aa*), the upper one moving vertically between guides, and worked by a crank (*b*).

Rails and thick bars are finished by cutting off, whilst hot, the rough or crop ends with circular saws, $3\frac{1}{2}$ to $4\frac{1}{2}$ feet in diameter, and driven at great velocity.

The rolling mill employed for finishing puddled iron, so as to form merchant bar, consists of two sets—the roughing and the finishing rolls. The rolls are arranged

in housings with adjustments similar to those described for the forge-train, except that the finishing-rolls are provided with lateral tightening screws for keeping them always in exact position. In order to prevent lamination, the pile is passed through the roughing-rolls with the joints alternately flat and edgeways, which renders the welding uniform.

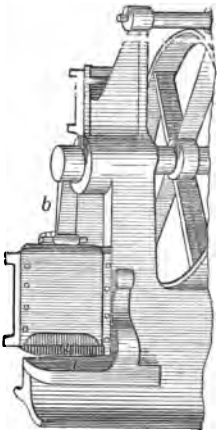

Fig. 51.

Universal rolling-mill.—The contrivance consists of a combination of vertical and horizontal rolls, so arranged as to compress the pile equally in both directions at once. Fig. 52 shows the position of the rolls. The vertical rolls work upon slides, and can be adjusted to different distances by means of screws. The horizontal pair are driven in the usual way from the bottom roll, and the vertical pair are connected with them by an intermediate shaft, which receives its motion from the driving-pinion.

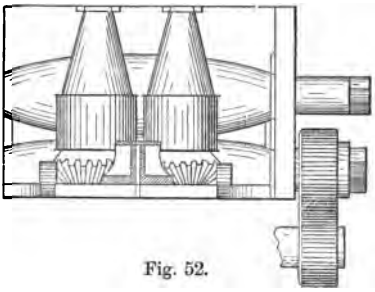
Fig. 52.

In the forging of heavy piles, steel ingots, etc., great advantage is gained by the use of a hydraulic-squeezer or press. It consists of a vertical cylinder with its ram acting downwards against a table or anvil; or a pair of dies are used for special shapes. The ram is connected with the piston of a smaller press, by which it is raised.

Re-heating furnaces.—The shingled masses, and bars of iron obtained from the forge, contain slag and impurities, which have not been eliminated in the previous operations, and the object of re-heating is to remove these substances as much as possible, and raise the billets or slabs of iron to a welding temperature. The enclosed slag partially liquates out as a fluid basic silicate, leaving a basic residue mixed with black oxide of iron Fe_3O_4, which is largely removed in rolling. The basic slag also acts on the manganese, silicon, phosphorus, etc., retained by the iron, oxidising them, the oxides passing into the fluid slag. The sulphur and carbon are also partly oxidised in the same way, and probably removed as gases.

The re-heating furnace Fig. 53 is somewhat similar in shape to the puddling-furnace; the bed is flat and

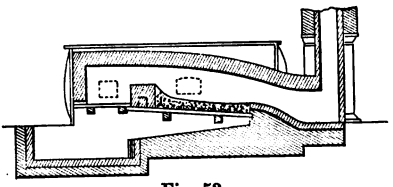

Fig. 53.

slightly inclines down to the flue, and is lined with sand. In some works basic material is used. It is essential that the fire-place should be large enough for the furnace to be rapidly raised to a white heat; the ratio of the section of the fire-place to the bed being about 2 : 1. The arch of the roof should be as low as is compatible with the size of the piles, or other mass of iron, to be heated. The slag runs off the bed constantly to the bottom of the flue, and is termed "flue cinder."

Of late years gas-furnaces have been used for re-heating, such as Siemens' furnace. A modification of the regenerative furnace has been applied to re-heating by

Ponsard Fig. 54. In this arrangement the gas from the producer is delivered directly to the furnace, and burnt

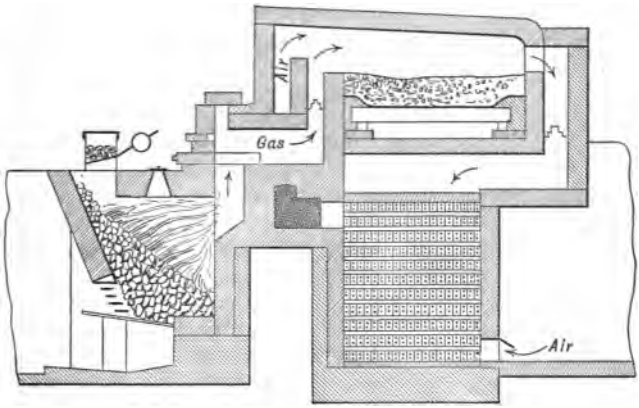

Fig. 54.

with hot air, which is heated by a " recuperator " placed under the bed of the furnace. The recuperator is a brick chamber, partly solid and partly hollow, containing a number of vertical passages, the adjacent ones being separated, and the alternate ones connected by horizontal passages in the perforated bricks. The flame passes downwards, while the cold air, admitted at the bottom, passes upwards by separate channels, the action being continuous.

The Boëtius furnace differs from the preceding one, in the manner of heating the air required for the combustion of the gas used. Fig. 55 shows the general arrangement in vertical section. The gas-producer is constructed with passages in its walls, through which the air supplied to the furnace is compelled to pass, thus being heated. It meets and mingles with the gas at the furnace-bridge, where combustion

takes place. The economy of this system over an ordinary re-heating furnace, burning solid fuel, is con-

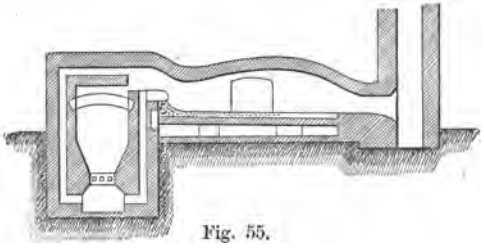

Fig. 55.

siderable, a saving of 20 per cent. of fuel being effected by its use. The producer is a deep rectangular chamber closed with an arched roof, and is built as a part of the furnace itself.

The Bicheroux furnace is used both for puddling and re-heating with gaseous fuel. The gas is made in an ordinary Siemens-producer, built with the furnace, and burned directly, as in the Ponsard and Boëtius methods. The air for combustion is heated by contact with the bed of the furnace, a broad flat flue, which runs under the bed, being provided for this purpose. It is also further heated by circulating round a large vertical pipe, which conveys the gas from the producer to the furnace. In a modification of this furnace, termed the Casson-Bicheroux, the walls of the producer are made with narrow channels, as in the Boëtius plan, in order to provide an additional supply of hot air.

Tinning Iron Plates.

The iron plates are first thoroughly cleansed in warm dilute sulphuric acid, then washed and scrubbed with sand to remove all traces of rust, which would prevent the tin from adhering; the plates are then immersed in a bath of melted tallow, which dries them thoroughly.

The tinning arrangement comprises six pots, each heated by a separate fire, and termed respectively—the tinman's-pot, tin-pot, washing-pot (divided into two compartments), grease-pot, cold-pot, and the list-pot. The plates from the tallow- or tinman's-pot are placed in the tin-pot, the surface of the molten tin being covered with tallow to prevent oxidation; after being heated for an hour and a half in the melted metal they are removed, drained, and plunged into the first division of the washing-pot, which also contains molten tin, then removed and brushed to remove excess of tin; afterwards they are quickly dipped in the tin in the second division to remove the brush marks. They are then transferred to the grease-pot containing melted tallow, which removes any excess of tin by draining. After about ten minutes the plates are inserted in melted tallow contained in the cold-pot. Lastly, in order to remove the tin which has drained down and formed a bead at the lower edge of the plate, the edge of each plate is dipped in the list-pot, which contains melted tin, about ½ inch deep; then by striking the plate sharply with a stick the superfluous metal is detached. The plates are rubbed with bran, and afterwards with sheepskin, when they are ready for use.

An inferior variety of tin-plate, in which the iron is coated with an alloy of tin and lead, is termed "terne-plate."

GALVANISING.

Galvanised iron is a term applied to iron plate, and iron articles coated with zinc, to prevent the iron rusting. The zinc was originally deposited by means of an electric current. It is now manufactured by dipping the clean iron into a bath of molten zinc, the surface of which is covered with sal-ammoniac in order to prevent oxidation, and at the same time to remove any oxide that may be formed. The iron is cleansed in dilute sulphuric acid before dipping it in the molten zinc.

Composition of Refining-Slags.

	From a Refinery.	From a Puddling-furnace.	From a Re-heating furnace.
Ferric oxide (Fe_2O_3), - -	—	8·27	—
Ferrous oxide (FeO), - -	65·52	66·32	76·73
Silica (SiO_2), - - - - -	25·77	7·71	15·15
Manganous oxide (MnO), -	1·57	1·29	1·51
Alumina (Al_2O_3), - - - -	3·60	1·63	1·95
Lime (CaO), - - - - -	·45	3·91	—
Magnesia (MgO), - - - -	1·28	·34	—
Sulphur (S), - - - - -	·23	1·78	1·36
Phosphorus (P), - - - -	1·37	—	—
Phosphoric acid (P_2O_5), - -	—	8·07	2·22
	99·79	99·32	98·92

QUESTIONS.

1. Give a description of some form of steam-hammer and its mode of use in forging large masses of iron.
2. Describe a lever- and a rotatory-squeezer for compressing puddled-iron.
3. A bloom of puddled-iron being given, how would you convert it into bars?
4. What is the object of re-heating iron? What purpose is served by piling or fagoting?
5. Concisely describe the appliances and manipulation requisite to convert a bloom of well-puddled-iron into nail rods.
6. How are the thin iron sheets produced which are subsequently used for tinning?
7. What is the difference in the method of rolling thick bars, and small bars of iron?
8. Describe the method of producing iron plate, and describe the rolls employed.

9. What kind of appliance is used in forging heavy piles and steel ingots?
10. Describe the Ponsard re-heating furnace.
11. Describe the Boëtius re-heating furnace.
12. Explain the principle of the Casson-Bicheroux furnace.
13. What is the difference in composition between the slag from a re-heating furnace, and that from a puddling-furnace?
14. Describe the process of tinning iron plates.
15. What is meant by galvanising, and how is it done?

CHAPTER X.

IRON-FOUNDING.

THE art of founding, although not strictly a modern process, is one that has been greatly developed of late years. The caster generally works from a pattern, an impression of which is made in sand, or other suitable material. The moulding material must possess considerable pliability, be non-fusible, and unalterable in composition, so as to lend itself readily to the making of moulds, into which the fluid metal is poured, thus obtaining an exact fac-simile of the pattern.

The pattern is made larger than the desired object, about $\frac{1}{8}$th of an inch to the foot being allowed for the shrinkage of the cast-iron, varying with the iron and the articles to be cast. When a pattern is required for a standard, from which castings will often be required, mahogany is preferred on account of its durability; in other cases pine is generally used. Most patterns are coated with shellac-varnish so as to present a hard surface, and to close up the pores of the wood, thus rendering it impervious to moisture, which might so distort the pattern as to render it useless. It also imparts a smooth surface, so that the sand has less tendency to stick to it when the pattern is withdrawn from the mould.

The pattern often requires to be modified from what the casting is to be, in order to render the moulding practicable. For instance, castings which require to have recesses left in them necessitate the use of a piece of wood called a "print." This is placed in the exact place on the pattern where the required hole is to be, and a core-box is made to furnish a core of the shape of the hole desired.

Pig-iron used.—A mixture of different kinds of pig-iron is generally preferable to any single brand, because the metal runs more solid. Further, as cast-iron articles are required of different degrees of hardness and strength, according to the purposes for which they are required, it is difficult to get the requisite quality without mixture. A slightly mottled fine-grained pig-iron is suitable for castings where great strength is required, and a whiter variety offers a great resistance to a crushing force, while a greyer iron is weaker. The different kinds of grey iron have a tendency to become whiter when remelted, owing to some of the carbon passing into the combined form; this produces a slightly-mottled cast-iron when a small-grained grey pig is used. It sometimes happens that the reverse is the case, and a softer iron is then obtained.

The condition of the carbon is modified by a variety of circumstances, such as the mode of melting, the rate of cooling, and the presence of impurities. It has been already stated, that quick cooling tends to increase the amount of combined carbon, and slow cooling to increase the amount of free carbon. Manganese, phosphorus, and sulphur, in notable quantity, cause white iron to be formed, while silicon acts in the opposite way, causing the separation of graphite. When a number of foreign elements are present, they modify the effect which each would have on the iron when present alone.

Grey iron is most generally employed, because it has the property of becoming thinly liquid when melted, and of

expanding when on the point of solidifying, which makes it particularly suitable for foundry work. Mr. T. Turner has shown that silicon, when added to white iron, produces a soft grey iron by the separation of graphite, and when present in suitable proportion improves the quality of the metal. From his experiments he deduces the following:—

1. "White pig-iron contains less than 1 per cent. of silicon, but when sulphur or manganese is present the iron may still be white, although more than 1 per cent. of silicon is present."

2. "Mottled iron contains about 1 per cent. of silicon, and a small proportion of sulphur considerably affects the product."

3. "In grey iron the carbon is almost entirely graphitic, and it usually contains about 1·8 per cent. of silicon, the maximum limit being 3 per cent."

In addition to pig-iron the founder adds scrap cast-iron to the melting charge for most purposes. This scrap consists of gates, runners, heads, etc., and worn-out and waste castings of all kinds. The larger the amount of scrap to be used, the softer should be the pig-iron melted with it. Scrap, however, unless its composition is known, obviously cannot be much used where exact and definite mixtures are required.

The tensile strength of pig-iron varies from 4 to 10 tons per square inch, the average being about 7½ tons. The crushing strength should bear a proportion to the tensile strength of 4 to 1. When the ratio is much less than this, the metal is weak; and when the ratio exceeds that of 6 to 1, the metal is hard and brittle.

In remelting pig-iron for foundry purposes two kinds of furnaces are employed—Reverberatory-furnaces and Cupola-furnaces.

The reverberatory-furnace Fig. 56 varies in size according to the work required, and has a capacity of from 3 to 10 tons. The charging doors are on

one side and the tap-hole on the other. It is used for melting iron for casting large pieces, and for remelting faulty castings. The large volume of air passing over the bed has a refining influence on the molten iron, oxidising some of the silicon, phosphorus, etc. This furnace is said to produce a tougher and more homogeneous product than the blast-furnace. On the other hand, more iron is oxidised and wasted in the slag, and more fuel is consumed. This furnace is also used when it is desired to melt the iron out of contact with the fuel, so as to prevent any impurities in the latter from uniting with the iron.

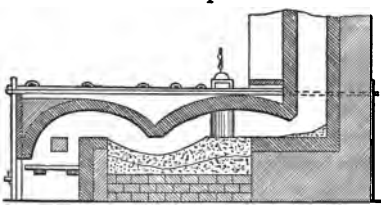

Fig. 56.

The cupola-furnace generally employed for foundry purposes has a cylindrical hearth, and tapers somewhat towards the top; it differs from a smelting blast-furnace in the absence of boshes. Coke-furnaces generally have a closed front wall with no fore-hearth, the metal being removed at one tapping. Charcoal-furnaces are often narrower at the top and bottom than in the middle. They often have a fore-hearth, which enables the furnace to contain more iron. The flux employed is principally limestone, which forms a slag with the ash of the coke, the sand adhering to the pigs, and with parts of the furnace lining. Some founders add fluor-spar, which produces a more liquid slag. The waste heat of cupolas has been utilised in some furnaces for heating the blast, thus effecting an economy of fuel. If too high a temperature be employed the thinly liquid slag rapidly attacks the lining. If too low a temperature be used, the iron becomes too pasty, and the slag forms a nose on the twyers. The blast is usually supplied by a fan.

An improved form of cupola has been invented by Mr. Stewart. Fig. 57 represents a vertical section. The charge is introduced at the door (*a*) from a landing-stage not shown in the figure. The twyers are arranged at three different levels (*bbb*), so that there are three zones of fusion, thus distributing the blast and causing a more perfect combustion. The cupola is arched at the top,

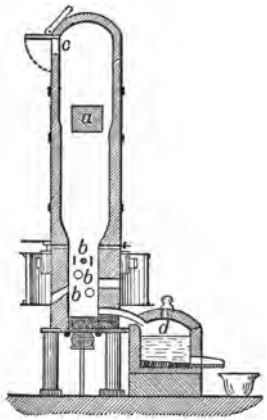

Fig. 57.

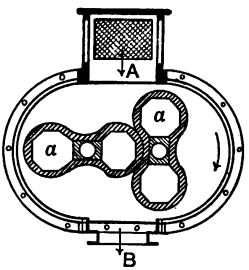

Fig. 58.

and is provided with an opening (*c*) for the escape of gases. The furnace is supported on four pillars and is provided with a drop-bottom. A receiver (*d*) is fixed in front for the molten metal, from which it is tapped into the casting-ladle. The blast is provided by a Root's blower Fig. 58.

This machine consists of a pair of rotatory 8-shaped revolvers (*aa*) enclosed in an iron case. These revolvers are mounted on steel spindles, working in gun-metal bearings in the ends of the case, and coupled outside by means of a pair of toothed wheels, so as to control the position of the pieces with regard to each other. The

blower is driven by means of two leather belts, one crossed and the other open, working on to pulleys on opposite ends of the respective spindles. The air-inlet as a rule is at A and the outlet at B, but in special cases the direction may be reversed. By means of this blower a pressure of blast is said to be procured, far in excess of that attainable with a fan, and with less expenditure of power.

In the case of heavy castings, requiring several tons of metal, a common plan is to melt about two tons of iron in a cupola, and tap it into a ladle. Then to close the tap hole, and melt another two tons, which require about half an hour, then to run it into the ladle containing the first charge. This may be repeated three or four times, until the requisite quantity of iron for the casting is obtained. The metal from each tapping is covered with charcoal, about an inch thick, to diminish the loss of heat; and the excess of heat imparted by each addition of metal to the ladle is sufficient to keep the whole in a molten condition for upwards of three hours.

Moulding and casting.—The founder distinguishes iron castings as:—open-sand, green-sand, dry-sand, loam, and chilled casting, according to the nature of the mould employed. Occasionally a complex piece may embrace two or more methods.

1° **Open-sand.**—This method is employed for rough work where boxes could not be used, but the castings are rough on one side. A bed is prepared in the floor of the foundry and if the casting is of large dimensions a layer of coal or coke is laid down. This is covered with coarse moulding-sand 2 feet thick, and upon this the ordinary moulding-sand is sifted. The pattern is laid down, and sand rammed in and around it; then a dam of sand is formed round the pattern. The sand is next pierced by the moulder with a bent wire, passing under the pattern without touching it, and then the pattern is removed. The mould is next dusted over with burnt sand or charcoal-powder, and if deep, weights are placed on the vacant

places to keep the sand from rising. A gutter is then made, termed a "runner," to feed the mould with molten iron, which, in deep work passes to the bottom, and branches off to convey the metal to different parts. The metal, when set, is covered with a layer of sand, and then left to cool.

2° **Green-sand.**—This method is used for light work, or common castings, such as grates, bars, water-pipes, etc. It differs from open-sand casting in the use of a box to cover the mould during casting. The raw sand is sifted and mixed with some coal-dust, the portion next to the pattern only being used once, so that a certain amount of fresh sand is required for each casting. The model is laid on a flat board on the floor and covered with one half of a box (*a*) which is then filled with sand. The first portions of sand, termed "facing-sand," are sifted through a fine sieve, then ordinary moulding-sand is well rammed in. (*a*) is now inverted and the second half of the box (*b*) is fixed on the lower one, then filled with sand and well rammed in, when the whole box is turned upside down. That which forms the upper half (*a*) is now removed, leaving the pattern in the lower one (*b*). The sand in (*a*) is now knocked out, the frame replaced on (*b*) and sand filled in, rammed, and levelled as before. The two halves are now separated, the pattern removed, then put together again, and the metal run in.

The metal is run through gutters made in the sand, termed "gates." These are made by laying in wooden taper pins sufficiently long to reach above the edge of the upper box, which pins are removed at the same time as the pattern.

Green-sand with dried cores.—When a casting is required to be made with a certain part left hollow, in order to lighten its weight, or to produce a necessary cavity, a core of sand of the desired shape of the cavity is used. The core is formed by pressing sand into a wood

or iron mould, termed a "core-box," consisting of two halves, so as to be readily detachable for taking out the core, which is then blackened and well dried.

The moulding is performed in the same way as described under the head of "green-sand," and when the pattern is removed the core is fitted into the mould, and the casting conducted as before. This system is used for pipes, columns, and similar hollow work.

Dry-sand.—This method is employed for large castings where green-sand would not sufficiently resist the pressure applied, and for ornamental work, such as parts of machinery, long tubes, statues, etc. The sand used is a mixture of old loam and fresh sand. The process o. moulding is the same as with green-sand, but when the moulds are finished and blackened they are dried in a stove from 12 to 24 hours. The metal is then poured in the usual way.

Loam.—This branch of moulding differs from the preceding ones, in the use of a clayey-sand termed "loam," and in not generally using a pattern to form the mould. The loam is formed of a mixture of sand, clay, and cowhair moistened with water. Take the case of an ordinary round evaporating pan. A board (*a*), Fig. 59, is first made and attached to a spindle (*c*) to form the inside, and a similar board (*b*) to form the outside diameter and shape. These are termed strickle-boards.

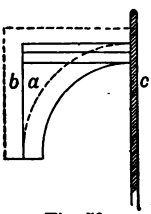

Fig. 59.

The mould is commenced at the bottom of a pit, by making a foundation formed of a layer of bricks, and then covering it with loam. A flat plate or ring of iron is placed level on the loam, and in the centre is fixed the iron spindle (*c*), the lower part of which is turned slightly conical, fitting into a bored bush with arms or feet attached; this is rammed up in the floor, or attached to the base plate of the mould. The top part of the spindle

is kept in position by a hole in a plank laid across the mouth of the pit. The board (*a*) is now swept round and another layer of bricks and loam added, and so on until a space is filled up of the size and shape of the interior of the pan, which is generally cast bottom upwards. For large work the moulder leaves a space round the spindle, in which a fire is suspended in a grate for drying the loam, after removing the spindle and board. In some cases it is dried in portions as it is built up. After blacking the core, the loam is struck up by the board (*b*), which leaves a coating of loam exactly the thickness of the metal afterwards forming the pan. A cope or cover corresponding to the top flask of a sand-mould has now to be made. This may be built up in bricks and loam in the same way as the interior, and dried and blackened on removal; or a sand top-part may be rammed around the thickness contained in a flask or box. In either case, the top is lifted when the operation is completed, and the thickness, formed by the board, removed. The top, after drying and blacking, is then lowered into place again. The whole is placed in a pit and well rammed all around with sand, in order to prevent rupture or distortion of the mould when the metal is run in.

The mould and casting are left to cool for a period depending on the size of the article. In some cases, portions of the core have to be removed immediately the metal has solidified, in order to prevent the casting splitting by contraction.

Some founders, instead of striking up the thickness on the core, and subsequently moulding the cover, strike the outside of the pan direct, on an independent plate, the board being made in this case the reverse way, as in Fig. 60. This outside, after drying and blacking, is placed in the pit and the inverted core lowered into it. This plan is particularly advantageous in cases where the

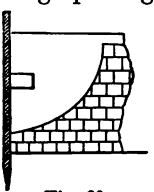

Fig. 60.

bottom of the pan has to withstand great heat when in use, since the casting will be sounder at the bottom, because of the sullage, etc., rising to the top part of the mould.

Casting in Chills.—This process may be illustrated by a brief description of the method employed for casting chilled-rolls. Such rolls must have a close grain, and a hard, smooth, highly polished surface.

The mould is made up of a combination of sand and cast-iron. The parts, intended to form the bearing and driving- or tenon-ends, are moulded in a strong sand, then thoroughly dried, and coated with blacking. The mould, for the working-part or barrel of the roll, is formed of a heavy cylindrical casting of iron, truly bored out to a size sufficient to allow of the roll being turned to the proper dimensions. The sand-moulds are secured to this casting by means of cotter-pins, and the whole is then placed vertically in a casting-pit. The iron, after melting in a reverberatory furnace, is run in by a gate formed in the bottom box, and enters the lower bearing in a tangential direction, so that the molten metal is caused to rotate rapidly, forcing the dirt and slag to the centre of the mould, as the centrifugal action of the spinning metal causes the heavier and purer particles of iron to fly outwards towards the surface, while the lighter particles, being kept inwards, flow out through the head. This rotatory action greatly diminishes the liabilityto pin-holes. The metal, after filling the mould, rises to the top into a supplementary channel called the "head," where the dross or "sullage" is collected. This opening also serves the purpose of feeding the casting with fresh iron as the various parts set and contract.

The effect of using the iron cylinder as a mould, is to cause the iron to solidify rapidly in contact with the walls of the "chill-mould," in consequence of the heat being rapidly conducted away. The depth of the chilled surface is made to vary, according to the purpose for

which the casting is required, and can be regulated by mixing various pig-irons in the proper proportion, and then testing the iron by means of test pieces, of uniform size, cast in chill-moulds. By fracturing these tests, the depth of the chill is ascertained and the right mixture determined. Pin-holes and split-castings are caused in various ways, such as by injudicious mixing of unsuitable pig-irons, porous chill-moulds, bad melting, pouring too hot or too cold, etc.

Malleable-iron castings are made in the same way as ordinary green- or dry-sand castings, if of medium size; and by the methods of "odd-side" and "plate-moulding," if of small dimensions. These castings are largely used to take the place of small forgings in light work, such as sewing machines, bicycles, wringing machines, frames of pulley blocks, spanners, keys, etc. Their great toughness as compared with ordinary cast-iron, together with the small cost as compared with wrought iron forgings, render them well fitted for many purposes.

Mitis castings.—Messrs. Nordenfeldt and Ostberg have succeeded in producing castings from wrought iron by alloying it with aluminium. The iron is heated in crucibles, in a specially constructed furnace burning petroleum as fuel. When the iron is just melted, a little aluminium is added, varying from ·05 to ·1 per cent., which lowers the melting point of the iron sufficiently to enable it to be manipulated, and poured into moulds. By this means the inventors claim that gases are not absorbed, (as is the case when a metal is raised considerably above its melting point), and sound castings are thus obtained. The castings do not require annealing when taken out of the mould. The tensile strength is said to be from 20 to 50 per cent. greater than that of the raw material.

QUESTIONS.

1. In casting from a pattern, what precautions are necessary with regard to the construction of the latter?
2. What kind of pig-iron is most suitable for castings?
3. For what purpose does the founder add scrap to the melting charge?
4. Briefly describe a founder's reverberatory-furnace, and mention its advantages and disadvantages as compared with a cupola-furnace.
5. Describe some form of cupola-furnace used for foundry-purposes. How is this furnace usually blown?
6. What is meant by open-sand and green-sand casting, and to what articles is each kind applicable?
7. Describe the method you would adopt in producing a "chill-casting" in the form of a solid cylinder.
8. Describe the process of casting an iron pillar weighing two tons.
9. Briefly describe the process of casting a hemispherical iron pot, such as an ordinary household washing-copper.
10. What are the characteristic features of loam-moulding, and what precautions are necessary?
11. What is malleable-cast-iron? How are malleable-castings made, and what kind of iron is requisite?
12. What are Mitis castings, and what advantage is claimed by the inventors for the process?

STEEL.

CHAPTER XI.

Properties and Alloys of Steel.

The definition of the term "Steel" presents many difficulties, seeing that authorities differ considerably as to the precise meaning which is to be attached to the word, but all agree that it forms the connecting link between malleable- and pig-iron, and also that carbon is an essential constituent. The International Commission of the Philadelphia Exhibition in 1876 recommended the following terms for adoption:—

(*a*) *Weld-iron*, for all malleable compounds of iron (containing the ordinary ingredients) prepared in any form other than the liquid state, and which cannot be hardened and tempered.

(*b*) *Weld-steel*, for all bodies similar to (*a*) which can be hardened and tempered.

(*c*) *Ingot-iron*, for all compounds of iron (containing the ordinary ingredients) which have been melted and cast, and which cannot be sensibly hardened and tempered.

(*d*) *Ingot-steel*, for all compounds similar to (*c*) which are capable of being hardened and tempered.

Steel may be defined, simply, as a compound of iron

with from ·15 to 1·8 per cent. of carbon, which latter may be partially replaced by manganese, and to a small extent by other elements, malleability being essential. Sir Joseph Whitworth proposed to designate iron or steel according to its tensile strength, in tons per square inch of section, and the amount of its elongation before fracture, when a standard test-piece is employed.

Properties.—Steel, in the soft state, has a white colour with a bluish tinge, and becomes whiter when hardened, sometimes almost pure white. The lustre is similar to that of iron. When freshly broken the fractured surface affords some indication of its quality, being generally finely granular or crystalline, uniform in structure, and destitute of fibre; but these will vary with the mode of breaking, and with the amount of carbon and other elements which the steel contains. Much carbon makes steel close-grained and lustrous. When mild steel is broken by a sudden blow the surface is crystalline, but when broken with progressive stresses, the appearance inclines to the fibrous state. The tenacity of good steel is very high, exceeding that of any other metal, and is increased by cold-rolling, or by wire-drawing. Steel possesses the valuable property of being hardened by quick cooling after heating, and hard steel may be annealed or softened by making it red-hot and cooling it slowly. The hardness of hardened steel may be reduced, by gradually raising it in temperature up to a certain point, when it becomes highly elastic; this reduction is termed "tempering." Steel requires to be welded at a lower temperature than iron, and its power of being welded diminishes with the increase of carbon. The melting-point of steel is probably from 1600° to 1800° C., the fusibility increasing with the amount of carbon and other elements present. The specific gravity of steel varies from 7·6 to 7·8, being slightly less in the hardened than in the softened state, in consequence of the increase in bulk caused by this process. Steel resists the

influence of magnetism more than iron, but when magnetised the property is permanent; the presence of much manganese prevents the acceptance of magnetic power. Steel is less readily oxidised by exposure to air than iron, but the presence of other metals, such as manganese and chromium, increases its liability to oxidation.

Effect of Various Elements on Steel.

Phosphorus.—The presence of this element is much more prejudicial in steel than in iron, and the more phosphorus a steel contains the more readily does it lose its characteristic properties by repeated heatings, becoming finally incapable of being tempered. Phosphorus hardens steel more than carbon does, makes it cold-short, more fusible, more brittle, more rigid, and less elastic, especially when the carbon is high. Gruner states that two or three parts of phosphorus in a thousand makes steel strong and elastic, but diminishes the tenacity. Steel with ·5 per cent. of carbon must not contain more than ·04 per cent. of phosphorus, or it will not roll well, so that a greater proportion than this can only be used by keeping the carbon low. This is effected by the use of ferro-manganese in the place of spiegeleisen, in the manufacture of Bessemer and Siemens steel.

Silicon.—This element appears to harden steel to a less extent than phosphorus, and causes the metal to be red-short, brittle, and less tenacious, but a very small quantity may improve the steel. Silicon readily oxidises, forming silica SiO_2, and this being an acid, unites with bases, such as manganese oxide, iron oxide, etc., to form a slag; for this reason silicon only occurs in steel in small quantities. It also lowers the proportion of combined carbon.

Sulphur.—The presence of sulphur in steel in notable quantity makes it red-short, more fusible, brittle, and

less tenacious. It also prevents steel from welding, but is not so injurious in cold working.

Manganese.—This metal hardens iron, but in a less degree than carbon. When present in small quantity it improves the quality of steel, increasing its tenacity and elasticity. The bodies known as ferro-manganese and spiegel-eisen, used in steel making, have been already described. The use of manganese is valuable, for the refining influence its oxide exerts on the impurities contained in the iron, such as silicon. phosphorus, sulphur, etc., removing them as oxides. It also neutralises the effect of the small quantities of these elements retained in the steel. Of late years Mr. Hadfield has introduced steels, containing very little carbon, and from 7 to 22 per cent. of manganese, which are extremely hard, tough, and non-magnetic. The strongest alloy contains 14 per cent. of manganese.

Chromium gives whiteness and brilliancy to steel, which then possesses great hardness and strength. Chromium has a remarkable influence in increasing the resistance of steel to compression, and when present in small quantity increases the ductility and tenacity.

Tungsten, when present in steel to the extent of 1 to 3 per cent., is said to make tough and ductile alloys, which are also very hard, with a fine crystalline structure. Such steels possess great coercive force, powerfully retaining their magnetism after being once excited.

Titanium may exist in steel in small quantity, but although much of this element may be present in the pig-iron, it is usually removed in refining, like silicon.

Copper is often present in small amounts in steel, usually not exceeding ·03 per cent. Its effect is to make iron and steel very hard, and in small quantity does not seriously affect the mechanical properties of steel. Mr. F. Stubbs considers that $\frac{1}{2}$ per cent. of copper in steel gives to it the peculiar property of resisting oxidation at high temperatures. The bad effect generally attributed

to copper in steel is probably due to sulphur, which usually accompanies copper in iron ores. Swedish iron is practically free from this element.

Tin alloys with steel, making it red-short and unweldable, even when present in small quantity.

Carbon.—The effect of carbon on iron has been discussed (p. 36). Carbon exists in steel in two forms, corresponding to its condition in white and grey cast-iron. When the carbon is present in the combined form the steel is hard, and when present in the free-state the steel is soft, so that the relative hardness of two samples of steel will depend upon the amount of carbon in combination in each case. Sir F. Abel, after an exhaustive series of experiments on this subject, draws the following conclusions:—

1°. "That in the annealed state, carbon exists as a carbide* (Fe_3C), uniformly diffused through the mass."

2°. "Cold rolled samples are in a similar condition to No. 1."

3°. "Hardening by sudden cooling prevents the separation of carbon as a carbide, its condition being the same as when the steel is in the fused state. Imperfect hardening will allow some carbide to separate out."

4°. "In tempered steel the condition of the carbon is intermediate between that of hardened and annealed steel, a blue temper being about half-way between these extremes."

Hardening.—Steel is hardened by compression, and hammering hardens more than rolling, being more efficient. In the various methods of hardening, the quantity of liquid used, its specific gravity, conducting power, specific heat, boiling point, and heat of vaporisation influence the final result.

Take four liquids—mercury, water, oil, and coal-tar; raise four pieces of the same steel to the same tem-

* This is what is generally described as "free carbon."

perature, and plunge one into each of the above liquids, and it will be found that the hardness will be in the order given, mercury producing the greatest degree of hardness, and coal-tar the least. The hardening power of water is influenced by other substances which may be present in it, as well as by its temperature, thus: sulphuric acid and dissolved salts increase the conducting power and hasten the cooling, rendering the steel harder. Hot water on the other hand will induce less hardness. Further, the rate of cooling is also dependent on the way the steel is held in the liquid. The rapidity with which the steel is cooled down to 300° C. has a greater effect on the hardening than the subsequent cooling to the ordinary temperature. The hardening power of steel increases with the amount of carbon, as does also its brittleness, both of which properties are often further increased by the presence of other elements.

The cause of hardening is generally attributed to the sudden cooling fixing the condition of the particles in the same way as when hot, that is, the carbon is retained in the combined form; but much of the brittleness of hardened steel results from the unequal contraction, caused by the different rates of cooling of the interior and the exterior, which inequality induces so strong a tension between the various parts, that a slight force is often sufficient to overcome their cohesion.

Tempering.—By cautiously re-heating hardened steel to a certain point, the tension is greatly released, some carbon or carbide is set free, and the metal loses its brittleness, and becomes softer in proportion to the temperature to which it is raised; so that by this means various degrees of hardness may be produced in the same steel to suit the requirements of different articles; this operation is termed "tempering." The surface of the steel is made bright before heating, and when the temperature reaches 220° C. a faint yellow colour appears,

succeeded by other colours as the process proceeds, so that the colour indicates the temperature of the steel, and therefore the degree of softness or "temper." These colours are due to a thin coating of oxide, which forms on the surface and produces the colour as an optical effect. The following table shows the tempers used for various articles, the lowest temperature indicating the hardest temper :—

Temperature.	Colour.	Article.
220° C.	Faint yellow.	Surgical knives.
230	Straw yellow.	Razors.
255	Brownish yellow.	Scissors, hard chisels
265	Purplish brown.	Axes, planes.
277	Purple.	Table knives.
288	Light blue.	Swords, springs.
293	Dark blue.	Fine saws, augers.
316	Blackish blue.	Hand saws.

When the steel is heated much beyond this point it becomes too soft for any kind of tools. The term "temper" is used to express the hardness, whether due to treatment or composition.

All kinds of steel expand on hardening, varying with the amount of carbon present. The temperature to which steel should be raised for purposes of hardening, must be regulated according to the quantity of carbon it contains, since overheating is highly injurious. The harder the brand of steel, that is, the more highly carbonised it is, the lower will be the temperature required; moreover a small article will require a lower temperature than a large one made of the same steel, because it is more suddenly cooled. Bulky articles, such as the face of an anvil, cannot be hardened by plunging into water face downwards, but must be placed upright in water and deluged with a large stream of cold water falling from above. The same remarks apply also to smaller articles having steel faces.

In hardening files it is important to protect the teeth from oxidation during heating, which is done by covering them with a fusible paste, made of common salt and flour or ale-grounds. The files are then heated in a coke-fire, then placed on a block with lead rests, and straightened with a leaden hammer. The workman, holding the tang by means of tongs, dips the file in a saturated solution of salt and water, and removes it when the hissing noise ceases. If the file has warped, it may be sprung a little by means of pressure exerted by the workman. The hardening of edge-tools is effected by heating in coke-fires and plunging them into water. They are then rubbed bright and tempered by placing on a thick cast-iron plate which is below a red-heat. Those tools, such as plane-irons, which are made of a combination of steel and iron, invariably become convex on the steel side, and require to be set by placing them iron side downwards on an anvil, and hammering the steel side with a particular shaped hammer. The setting of cast steel chisels, knives, etc., is done by placing the convex side on the anvil, and striking the other side with a setting hammer.

Saws are hardened by heating them in an air-furnace, and dipping into whale-oil, or a mixture of whale-oil and tallow. Care is required in removing them from the furnace so as not to bend them with the tongs. They are next tempered by being passed over a clear charcoal-fire, until the oily matter is burnt off. The saws are now flattened while warm, and any buckling removed by careful hammering. A method adopted by some hardeners of steel, is to heat the article in a bath of molten lead kept at a uniform temperature, by which all parts are equally heated. This plan is said to be well adapted for all kinds of cutlery as well as files. In hardening irregular shaped masses of steel the more bulky part should be immersed in the water first if possible, and the more pointed parts last. To prevent buckling in pieces of irregular shape and thickness, encasing the thinner parts

in iron, and hardening as a whole, is sometimes resorted to.

Welding steel.—It is much more difficult to weld steel than iron, and the greater the amount of carbon, the greater is the divergence. Various fluxes have been recommended to prevent the carbon burning away, and to render the welding surfaces clean, but have not come into common use; sand, and a mixture of borax and sal-ammoniac being the best. It is important that the temperature of the metal should not be raised higher than absolutely necessary; the higher the amount of carbon the lower should be the temperature used, hence the necessity of heavier hammers. The pieces should be tapped gently at first, and when they have begun to adhere they may be struck more heavily. The temperature at the finish must not be too low. It is best to work the steel rapidly, reheating as often as necessary (in order to prevent finishing too cold), and to anneal the whole piece when finished, so as to correct the effects of local hardening. When steel is to be welded to iron, the latter may be at a higher temperature with advantage.

QUESTIONS.

1. What is steel?
2. What is the influence of phosphorus and silicon respectively on steel?
3. Describe the physical properties of an alloy of iron containing but little carbon and 15 per cent. of manganese.
4. How would you distinguish steel from iron?
5. Why is the presence of sulphur so injurious in steel?
6. How is steel hardened and tempered, and what is the object of the latter operation?
7. In what states does carbon exist in steel hardened in the usual manner, and in the same steel after annealing?
8. In hardening a circular saw of large dimensions, what steps would you take to prevent buckling?
9. Describe the process to be gone through in tempering an ordinary cast steel chisel.

10. Describe the process of hardening files.
11. How are edge-tools hardened and tempered?
12. Describe the comparative results of tempering mild steel in water and in oil, and so far as you are able, give a reason for the difference.
13. What class of ores is best adapted for the manufacture of steel?
14. What are the peculiar advantages of the Swedish wrought-iron employed for making the best steel?
15. Describe the process of welding steel. Why is it more difficult to weld steel to iron than iron to iron?

CHAPTER XII.

Production of Steel by Puddling, Cementation, Etc.

The different methods of making steel may be classified thus:—(1) By direct methods as in the Catalan forge, etc.; (2) From pig-iron in the finery; (3) By puddling pig-iron; (4) By the cementation process; (5) By the treatment of blister-steel, or iron and carbon in crucibles; (6) By pneumatic processes, such as that of Bessemer; (7) In open-hearths, such as that of Siemens.

1. **The direct methods** in the Catalan-forge, Siemens' rotator, Blair's furnace, etc., have been described when treating of iron.

2. **Finery method.**—This differs but little from that employed in making iron, the operation being conducted so as to leave sufficient carbon in the bloom to constitute steel. This is done by prolonging the operation, thus leaving the iron a longer time in contact with incandescent carbon, and by using a less oxidising blast. The best pig-irons for this purpose are the strongly mottled- and spiegel-eisen varieties. This method is now almost obsolete.

3. **Puddling method.**—This is essentially the same as that used for wrought iron, but greater care is required in selecting the pig-iron employed, which should preferably contain manganese. This metal acts in retarding the decarburisation, in consequence of its superior affinity for oxygen, by constantly reducing tetroxide of iron to protoxide, and the protoxide to metallic iron; thus preventing the carbon from being oxidised. Oxide of manganese also produces a very fluid slag, which is easily expelled. A little metallic manganese improves the quality of steel. The addition of spiegel-eisen to the charge of non-manganiferous pig-iron, does not answer so well as when the manganese already exists in the pig-iron employed.

A thinly liquid slag is essential to protect the iron from a too rapid oxidation, and thus permits a more prolonged rabbling, so as to remove the impurities other than carbon. A slag with a double base of FeO and MnO, containing about 10 per cent. of the latter, is very fusible, and but feebly decarburising. Only one class of iron is operated upon at a time, as in a charge of mixed irons one kind would be purified sooner than another.

The melting of the charge must be rapidly performed in order to lessen oxidation. The rabbling requires great care, and when the metal "comes to nature" in the form of fine white, brilliant grains, it indicates good and uniform steel. A lower temperature is employed during the final stages of the rabbling period than when puddling for iron, so that the metal separates more readily while carbon is still present in it. The balling is done in a neutral atmosphere, and the balls taken quickly to the hammer. 8 to 9 charges of iron would be worked off in the same time as 6 to 7 of steel.

Cementation process.—This consists of exposing bars of malleable iron in contact with charcoal, to a high and prolonged temperature, in closed vessels, from which the air is excluded, in this way forming blister-steel.

The furnace Fig. 61 is rectangular in plan, and covered with an arch, having a hole 12 inches square in the centre, which hole is opened during cooling. It contains two rectangular fire-brick or fire-stone vessels, arranged one on each side the fireplace, which runs the whole length of the furnace. Each of these vessels is about 12 feet long and 4 feet square, but the sizes differ in different works.

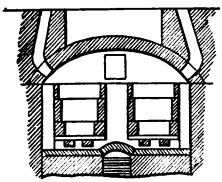

Fig. 61.

Swedish bar-iron is preferred for making the best kinds of steel, and hammered bars generally to rolled bars. Ordinary sizes of bars for cementation are 2 to 5 inches wide, and $\frac{3}{4}$ inch thick. The pots are charged by covering the bottom with coarse charcoal, and on this is placed a row of iron bars about half an inch apart, and so on alternately, until the vessel is full. The top is then covered with wheel-swarf or mud from grindstones, which melts and forms a glaze when heated, thus excluding the air. The charge for one pot may be from 15 to 30 tons of iron. Two small holes are left in the furnace, corresponding to two similar holes in the vessels, through which a bar, termed the "trial-bar" or "tap-bar," projects from each vessel. When the fire is lighted, two or three days are required to obtain the proper temperature, which is then maintained from seven to nine days according to the temper of steel required, the hardest steel requiring the longest time. On examining the trial-bar from time to time, by withdrawal and fracture, the conversion is seen to have penetrated gradually to the centre, when the vessels are allowed six days to cool down. Conversion begins at a temperature of 1000° C., but goes on more actively at 1170°; at higher temperatures cast-iron is produced.* By cementation the

* Bauerman, *Metallurgy of Iron*, p. 421.

fibrous iron is changed to a more or less crystalline steel, and the surface of each bar is covered with blisters, which in good steel are small and fairly regular. These blisters are probably due to the reduction of oxide of iron contained in the enclosed slag, and the evolution of carbonic oxide. The fractured surface shows a reddish-white, crystalline structure, which is darker in colour and finer in grain the greater the amount of carbon. If air has gained access to the bars during conversion, they are rough on the surface and have a skin of iron. When the temperature has been too high, and fusion on the surface has taken place, they are called "glazed" bars. Both aired and glazed bars are unfit for making cast-steel.

Different varieties of blister-steel are manufactured, and named according to their degree of carburisation, which depends on the length of exposure to the action of the carbon. In what is termed "spring-heat" the core of the bar contains unaltered iron; in "country-heat" the iron is more completely changed; in "single-shear-heat" still less iron is unchanged; in "double-shear-heat" the amounts of altered and unaltered iron are about equal. In all cases the transitions from steel to iron must be gradual, for if the line of separation is sudden the process has been too rapid, and the bars are said to be "flushed." In "steel-through-heat" the iron is completely converted into steel. The increase of weight in converted bars is from $\frac{1}{2}$ to $\frac{3}{4}$ per cent.

The manner in which the carbon passes through the iron so as to produce cement-steel is unknown; it may be transmitted in the form of gaseous compounds of carbon, such as carbonic oxide CO, cyanogen CN, and hydrocarbons, such as marsh gas CH_4. According to this view the gases are decomposed in the pores of the bars, and the carbon unites with the iron. The CO gives up carbon, being changed to CO_2, thus,

$2CO$	$=$	CO_2	$+$	C.
Carbonic oxide.		Carbonic acid.		Carbon.

The liberated nascent nitrogen and hydrogen passing outwards are brought in contact with charcoal, with which they again unite. Also carbonic acid takes up fresh carbon forming carbonic oxide, thus,

$$\underset{\text{Carbonic acid.}}{CO_2} + \underset{\text{Carbon.}}{C} = \underset{\text{Carbonic oxide.}}{2CO.}$$

These gases act as vehicles for the transmission of carbon to the interior. On the other hand, it may be that the gaseous compounds of carbon are decomposed at the surface of the bars, and the combined carbon transmitted to the interior. We may assume that solid carbon unites directly with iron, on the surface of the bars with which it is in contact.

Blister-steel is used for common purposes without further treatment, but generally the bars are fagoted and welded one or more times. Re-heating tends to decarburise the steel, so that the surfaces of the piles are covered with clay, or with sand and borax, which forms a fused coating and protects the metal from oxidation.

"Spring-steel" is obtained by re-heating, and drawing out between the rolls, the variety of cement-steel termed "spring-heat." "Shear-steel" is obtained from a better quality first drawn out into bars, then re-heated and fagoted. "Double shear-steel" is of still superior quality, generally re-heated and welded, then again cut up, heated, and welded.

The texture of blister-steel is modified accordingly as it has been rolled or hammered. Hammered steel has a finer grain, and a more compact structure than rolled steel; it has a greater power of resistance, with greater uniformity and density.

Case-hardening.—This is a kind of cementation on a small scale, and consists of the production of a surface coating of steel on iron articles, by exposing them to a high temperature, for a short period, in contact with carbonaceous matter. The articles are enclosed in an iron case with charcoal, leather, ferrocyanide of potassium

K_4FeCy_6, etc., and the case made air-tight; then the whole is heated in a furnace for a time proportionate to the thickness of the steel-facing required. The conversion may extend to a depth of $\frac{1}{4}$ inch in 4 hours. The work is hardened by plunging it into water while hot. Small articles are case hardened by rubbing them when red-hot in powdered ferrocyanide of potassium, re-heating to decompose the powder, and then plunging them in water.

Cast-steel.—The method of melting blister-steel in crucibles, instead of finishing it in the solid state, as described in the preceding processes, was introduced by Huntsman in 1740, who by this means produced a much more homogeneous metal, than was generally obtained by working crude steel under the hammer. Bar iron, carbon, and oxide of manganese, or spiegel-eisen are frequently added to the blister-steel to produce different qualities. Cast steel is also made directly in crucibles, by melting bar-iron with carbon and oxide of manganese, or spiegel-eisen.

The melting-house consists of a number of melting furnaces arranged in a row. Each furnace is oval or rectangular in shape, lined with fire-brick or ganister, large enough to contain two melting-pots, one in front of the other, and deep enough to allow of sufficient coke to cover the lids. 3 feet deep by $1\frac{1}{2}$ feet wide is a common size. From each furnace a flue leads into a square stack, 40 feet in height, which receives the flues from several furnaces. The house-floor is on a level with the top of the melting-holes, and the grate-bars, as well as a flue leading into the chimney to regulate the draught, are accessible from the cellar.

The application of gas-furnaces for melting is gradually superseding coke-fires. The principle is the same as described on p. 94, and the general arrangement is shown in Fig. 62. The top of the melting-chamber, like that of the ordinary furnace, is below the ground

level, the moveable covers alone projecting above the surface.

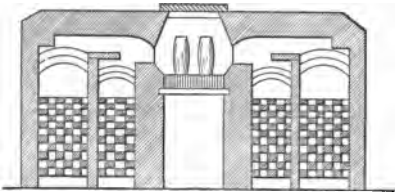

Fig. 62.

The pots for melting steel are made of a mixture of different clays, burnt-clay, and coke-dust. In Sheffield they are composed of a mixture of Burton and Stannington clays, to which is sometimes added Stourbridge clay, and if the pots have to withstand excessive heat, china-clay is also added. This mixture is incorporated with about a third of its quantity of coke-dust and old pots, the whole being ground very fine and sifted. The pots are moulded in an iron frame by means of a wooden plug, then slowly dried, and the night previous to being used, they are gradually raised to a dull red-heat; this is termed annealing. Each pot is about 18 inches high, 7 inches in diameter at the mouth, and lasts one day, during which time three charges are melted of about 50 lbs., 44 lbs., and 38 lbs., respectively.

The bars of blister-steel are carefully selected, according to the temper required, all "flushed" or "aired" bars being rejected. They are broken up into small pieces, weighed, and introduced into the pot, and the lid carefully adjusted. When the melting is completed, the crucible is removed and the metal skimmed, then poured or "teemed," as it is termed, into a mould. Should a piece of coke accidentally get into the pot, it makes the steel red-short, and produces a bright glittering fracture. If the steel does not remain a sufficient time in the fire,

or if poured at too high a temperature, it will teem "fiery," and the ingot will be honeycombed. If the metal remain too long in the fire it will teem "dead," the fracture will appear scorched, and though sound, it will be brittle if hard, and wanting in tenacity if mild. If the metal be cooled too much before teeming, the fracture will be dull in colour and full of pin-holes. Mild steel rises in the mould after teeming, and to make the ingot sound a cast-iron stopper is inserted in the top of the mould. Hard steel, containing from $\frac{3}{4}$ per cent. of carbon and upwards, teems "dead," that is, settles down 3 or 4 inches at top of the ingot. A pot of cast steel, when removed from the fire, has the appearance of a boiling liquid from the liberation of gases, which are accompanied by scintillations, and if poured in such a condition the metal would boil over in the mould, and produce a spongy structure; it is therefore allowed to stand some time to be "killed," as it is termed. For large ingots, the contents of several crucibles are poured simultaneously, by gangs of men, into channels which convey the steel to the mould.

For the best class of cast steel, the iron obtained from Dannemora ore, which is a magnetite containing manganese, is used; good steel cannot be made from inferior iron, containing sulphur, phosphorus, silicon, etc. in notable quantity, as these elements are very hurtful. All elements present in addition to carbon increase the hardness, brittleness, and liability of the steel to crack in hardening, but small quantities of each confer special properties, which may be useful in specific cases.

In 1801 Mushet introduced the method of making cast steel, by melting malleable iron with carbon and oxide of manganese in crucibles, which method has since been largely practised, but such steel is only of secondary quality. Another plan is to melt bar-iron with charcoal, and add a little spiegel-eisen at the end of the melting. The celebrated Heath process consists

of adding to the crucible, with the steel, a carbide, (obtained by reducing oxide of manganese with carbon, or a mixture of oxide of manganese with carbonised pitch) to improve the steel in melting. Sherman introduced a little potassium iodide into the pot along with the steel, with the object of removing sulphur and phosphorus, in virtue of their strong affinity for iodine. Many other physics have been tried from time to time, such as sal-ammoniac, common salt, yellow prussiate of potash, potassium chromate, etc., with the object of making high quality cast-steel from inferior bar-iron, but without success.

Indian- or Wootz' steel is made in crucibles by melting 1 lb. of malleable iron with 10 per cent. of the wood and leaves of the "*Cassia auriculata*" and the surface covered with green leaves. A lid is luted on, or the mouth stopped up with clay. The charge, at the conclusion of the heating, is allowed to cool in the crucible, which is then broken, the iron re-heated, and drawn into a bar.

Malleable cast-iron.—This variety of iron is produced by an "oxidising" cementation. For this purpose, the cast articles should be made of a superior quality of iron, such as that produced from Cumberland hæmatite smelted with charcoal, white pig-iron being preferred, especially for large castings.

The articles are embedded in powdered red hæmatite, in cast-iron or wrought-iron cases, which are arranged in a furnace or annealing oven as it is termed, heated with gas or with the flames from solid fuel. At each operation, a certain portion of fresh ore or iron scale from rolling mills is added, the used ore being mixed with it, which, being somewhat clotted, renders the mass more permeable to the gases generated inside. About three days are required for annealing small articles, and five to six days for large work, the temperature being gradually raised at the commencement, and allowed to cool slowly at the conclusion.

The oxide of iron Fe_2O_3, which is used as the cement powder, gives up oxygen, itself being reduced to the magnetic oxide Fe_3O_4. This oxygen unites with carbon and other impurities forming oxides, but only the gaseous oxides, such as carbonic oxide CO, are removed from the iron, hence silicon and phosphorus remain, which explains why only pure cast-iron can be employed. Some chemists consider that the change in physical properties is not due to the removal of carbon by oxidation, but to the separation of amorphous carbon within the metal, without which the metal would remain brittle, notwithstanding the oxidation of carbon on the surface. The iron, by this annealing process, is changed from very brittle white iron to malleable iron, of a greyish white colour when broken, resembling mild steel; it is only with very great care that it can be welded.

QUESTIONS.

1. How is steel produced in the finery? What iron is most suitable for this process?
2. What is the difference in the processes employed for producing puddled-iron and puddled-steel?
3. Describe the process of converting wrought-iron into steel by the system of cementation.
4. How is iron case-hardened?
5. What is shear-steel and how is it made?
6. What is blister-steel? Describe the character of its fractured surface. For what purposes is it used?
7. How is blister-steel made into cast-steel? What is the general character of cast-steel?
8. On comparing cast-steel with cast-iron, what points of resemblance and difference respectively would be observed?
9. Describe the chemical changes which occur during the conversion of a bar of iron into blister-steel.
10. How do you account for the change which occurs in bar iron by the process of converting it into blister-steel?
11. Describe some form of crucible-furnace in which gas is used as fuel.

12. What are the nature and composition of the pots used in melting steel?

13. Explain the use of manganese in making cast-steel.

CHAPTER XIII.

The Bessemer Process for Steel.

This process consists of blowing air through molten pig-iron, in a vessel called a converter, whereby the carbon, silicon, and some of the iron are oxidised; the oxidation produces a very high temperature, keeping the mass in a liquid state, without the aid of ordinary fuel, and leaving the iron commercially pure.

Two distinct modes of working, employing totally different classes of pig-iron are now adopted. In one, the converter is lined with an acid material, termed ganister, and the method may be designated the "Acid" Bessemer-process; in the other, the vessel is lined with calcined dolomite, which is a basic material. This method is called the "Basic" Bessemer-process. In the acid process, the iron employed must be free from sulphur and phosphorus, as these elements are not removed from the iron, so that only the purer classes of pig-iron can be used, such as those obtained from Cumberland hæmatite.

The converter is sometimes fixed, as in the Clapp-Griffiths process, but more generally it is so arranged as to be moveable through an angle of 180°, thus enabling the metal and slag to be poured from the mouth. Figs. 63 and 64 represent the most usual form of vessel; it consists of a shell of wrought-iron plates riveted together, the neck being inclined at an angle of 30° to the axis of the body. The centre of the body is enclosed with a stout band of iron, upon which are fixed two arms, termed trunnions, by which the vessel is suspended on iron standards.

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thus equalised. The wrought iron shell is put together in 3 parts—the neck, the body, and the bottom being so connected by bolts and cotters as to be easily detached for repairs. The tipping-gear consists of a worm-wheel 8 feet in diameter attached to the belt of the converter, and gearing with a screw of 4½ inch pitch, the screw receiving its motion from the cranks of a pair of hydraulic engines, mounted on one of the standards of the converter. A 15 ton converter is 24 feet high and 10½ feet internal diameter.

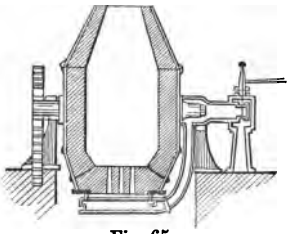

Fig. 65.

The lining having been dried, the converter is made red-hot by burning coke inside, the unburnt coke and ashes being then tipped out, and the vessel brought into the horizontal position. Molten pig-iron is then run in from a cupola or reverberatory melting furnace, the amount varying from 1½ to 10 tons, according to the size of the converter. It is then rotated into the vertical position, the blast being first turned on to prevent the metal running through the twyer-holes. For the first five minutes the flame is but slightly luminous, and but few sparks are emitted. During this period the graphite is converted into combined carbon, and the silicon and manganese are oxidised, also a little iron, forming a silicate of iron and manganese. Then the carbon begins to burn, the action gradually becomes very violent, the flame is brilliant, and showers of sparks, consisting of carbon, iron, and slag are ejected, through the rapid ebullition produced by the escape of carbonic oxide from all parts of the metal. This lasts for seven or eight minutes, when the activity diminishes. When the last trace of carbon is burned, the flame suddenly drops, and if the blast is continued, the iron

itself burns; but the heat produced by the combustion of the iron is less than the cooling effect of the air, so that the metal would soon solidify. The converter is then brought to the horizontal position, about 10 per cent. of spiegel-eisen, or an equivalent amount of ferro-manganese being run in, or dropped in in the solid state. The metal is then poured into the ladle, and thence into ingot-moulds. The duration of a blow depends to a great extent on the amount of silicon present. A feebly siliceous iron will be refined in 15 minutes, but a very siliceous one may require 30 minutes, depending on the nature and amount of the other impurities. In the latter case, the first period lasts about 10 minutes, and the second period 20 minutes. As iron, after decarburisation in the Bessemer vessel, always contains oxygen, the object of adding spiegel-eisen or ferro-manganese is to give sufficient manganese to combine with this oxygen, and enough carbon to convert the iron into steel, the oxide of manganese formed combines with the silica, rendering the slag more fusible. The slag from the acid Bessemer-process contains excess of silica, and thus differs from tap-cinder, which is neutral or basic. The following analysis of Bessemer slag will make this point clear:—

Silica (SiO_2), - - -	73·15
Alumina (Al_2O_3), - -	2·54
Ferrous oxide (FeO), -	20·02
Manganese oxide (MnO), -	2·65
Lime (CaO), - - -	·95
Sulphur (S), - - -	·68
	99·99

The following analyses by Snelus give, by volume, the

composition of the gases given off from the converter during an 18 minutes blow :—

Name	Formula.	After 2 min.	After 4 min.	After 6 min.	After 10 min.	After 14 min.
Carbonic acid,	CO_2	9·96	8·57	8·05	3·58	1·34
Carbonic oxide,	CO	·03	3·95	4·58	19·59	31·11
Oxygen,	O	·76	—	—	—	—
Hydrogen,	H	—	·90	2·00	76·83	67·55
Nitrogen,	N	89·25	86·58	85·37		
		100	100	100	100	100

The iron used in the acid Bessemer-process must be practically free from phosphorus and sulphur, as these bodies are not removed during the blow; but silicon to the extent of 2 to 3 per cent. is advisable, as it furnishes great heat by its union with oxygen, so that grey iron rich in silicon is preferred. When the silicon is deficient, the blow is said to be too "cold," which may be remedied by adding some silicon-iron, and increasing the pressure of the blast. Also when white pig-iron is used, the combined carbon burns, forming carbonic oxide at the early stages of the blow. This passes away from the mouth of the vessel, the heating power of the carbon only being partially utilised, thus making the blow too cold.

Basic Bessemer-process.—In 1872 Snelus showed that the retention of phosphorus by iron was intimately connected with the composition of the slag, which, in the acid process, is an acid silicate, and that when this was made basic, the phosphorus passed into the slag, as in puddling. Thomas and Gilchrist introduced the method of using basic linings for the Bessemer vessel in 1878, and succeeded in making good steel from common

pig-iron, containing 2 to 3 per cent. of phosphorus. The great difficulty in the early experiments was to get a lining, which would act on the phosphoric acid and silica produced by the blast, forming with them a fusible slag, and yet endure a reasonable time. This is now accomplished by having a double lining;—one fixed, made of calcined dolomite mixed with tar, and rammed in round a central core;—the other renewable, consisting of lime thrown in during the blow.

In the acid process, white iron can only be treated with difficulty and much waste; the carbon being in the combined form produces carbonic oxide at an early stage and does not yield sufficient heat. Now, in the basic process, white iron, poor in silicon but rich in phosphorus, is preferred, although grey and mottled iron may be used. Pink states that 1 to 2 per cent. of phosphorus is indispensable, hence ferro-phosphorus is added to pig-iron containing only ·5 per cent. of phosphorus.

The converter employed in the basic process is similar to the ordinary one, but is generally wider; and, as the lining wears rapidly away, special facilities for changing a vessel, wholly or in part, are necessary. For this reason the concentric converter with detachable parts is the most suitable. The lime and metal are lifted by the blast during the blow, and when the violence of the reactions between the oxygen of the air and the oxidisable elements in the iron is somewhat expended, the materials ejected drop into the vessel, when the new form is employed, whilst in the ordinary shaped vessel some material would cling to the nose.

When the metal has been run in, the blast is turned on and the vessel turned up into the vertical position. A short flame is at first perceived, due to the liberation of a little carbonic acid CO_2, contained in the lime. In about two minutes the sparks begin to leave the converter in a continuous shower. After about eight minutes the yellow sodium-line is seen, when

the flame is looked at through a spectroscope; this commences the second period, which lasts ten or twelve minutes, when the carbon lines disappear. The blow is then continued for two minutes, called the "after-blow," during which the phosphorus passes into the slag. Then the vessel is turned into a nearly horizontal position, and a sample taken for testing by flattening under the hammer. The first sample may be brittle, with an open crystalline grain, and contains say ·7 per cent. of phosphorus. The vessel is again turned up and the after-blow continued for half a minute, when on again testing as before it may still be brittle, and contain ·4 per cent. of phosphorus. The blow is repeated, and the test may this time be malleable, with a close grain, representing say ·07 per cent. of phosphorus. Now 10 per cent. of ferro-manganese is added in lumps, when a long series of sparks is discharged. After the addition of the ferro-manganese, some of the phosphate of lime in the slag is decomposed by the carbonic oxide produced, so that the metal contains more phosphorus than before its addition. The slag is first poured off, then the metal is run into the ladle.

The slag is much greater in quantity than that from the acid process, and highly basic in character, as the following analysis will show :—

Silica (SiO_2), - - -	8·02
Phosphoric acid (P_2O_5), -	17·15
Ferrous oxide (FeO), -	9·04
Manganese oxide (MnO), -	6·27
Lime (CaO), - - -	56·03
Magnesia (MgO), - -	3·20
Sulphur (S), - - -	·29
	100·00

It is stated that the phosphorus exists in the slag as a tetrabasic phosphate of lime ($4CaO.P_2O_5$). This slag

when finely ground is sold to farmers as a manure. It is also utilised in admixture with tar as a lining material for re-heating furnaces.

The ladle Fig. 66 used in Bessemer works is made of wrought iron, lined inside with a refractory substance similar to that lining the converter, having a hole at the bottom for running out the metal, and closed by an iron rod or stopper (*a*), also coated with refractory material. The opposite end passes through a slide-bar (*b*) on the outside, which is worked by a hand-lever.

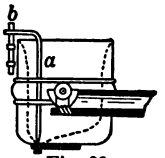

Fig. 66.

The ladle is suspended on a moveable platform, and is provided with a worm-wheel gearing for tipping it over, for conveniently removing the slag. The platform is fixed to the top of a central hydraulic ram, by the motion of which it is raised or lowered. Around this ram the platform revolves by means of spur gearing, worked by a man standing at the middle of the platform, so as to bring the hole of the ladle over each of the moulds as required when tapping.

The regulation of the blast, the movement of the converter, the platform, and the crane by which the ingot-moulds are lifted, are effected by a man on a raised platform outside the casting pit.

The moulds are made of cast-iron, open at both ends, tapering towards the top to facilitate the removal of the ingots. The moulds are generally filled from the top, then sand is thrown on the surface of the metal, and the lid tightly secured, to ensure sound ingots. Sometimes a group of moulds is filled from the bottom, being arranged round a large one in the centre, into which the metal is tapped. From the bottom of this run feeding-tubes of fire-clay, opening upwards into each member of the group.

The rapidity with which pig-iron is refined and converted into steel by the Bessemer-process, together with

the operation upon large quantities at a time, and the small amount of labour as compared with puddling and cementation, give it an immense advantage as regards economy; but the metal is inferior to the high class steel produced by the older processes, although it is well adapted for rails and many other articles for which mild steel is suitable.

Clapp and Griffiths' process.—This is a pneumatic process like the Bessemer, but the vessel is fixed, and the blast is introduced from the lower part of the sides, instead of at the bottom, which appears to bring about different chemical reactions. The ordinary converter is about 5½ feet internal diameter and 10 feet high, lined with silica-bricks, and provided with from four to six horizontal twyers, fitted with valves for regulating the blast. The twyers are arranged about 9 inches above the floor of the converter, and about 5 inches below the surface of the metal when charged, which enables a soft blast of 5 or 6 lbs. per square inch to be used. As the slag rises, it is run off through a slag-hole during the intermediate stages of the blow. At the conclusion the metal is tapped as from a cupola. Ferro-manganese is then added to the metal in the ladle to form mild steel. The process appears to almost completely eliminate the silicon, but leaves the phosphorus untouched, so that good hæmatite pig-iron must be used. One great advantage of this method is that it enables the smaller users to manufacture their own steel without an enormous outlay for plant at the start.

QUESTIONS.

1. Describe the construction of an ordinary Bessemer-converter.

2. A blow in the Bessemer-converter is found to be too "cold." How can the temperature be rapidly raised? To what cause do you attribute variations in temperature during the blow?

3. How is the lining of a Bessemer-converter effected during the blow? Give the composition of the ordinary lining.
4. What kind of pig-iron is considered essential for the acid Bessemer-process?
5. What is meant by the basic Bessemer-process, and how does it differ from the acid process?
6. What is the nature of the gases given off from the Bessemer-vessel during the blow?
7. How do you account for the removal of phosphorus from the iron by the basic process?
8. What is the nature of basic slag, and in what state of combination does phosphorus exist in it?
9. Name any applications of basic slag to useful purposes.
10. Show by means of a sketch in vertical section the arrangement of a Bessemer-converter during the blow and also during the period of pouring.
11. Describe the ladle employed for receiving the charge of a Bessemer-converter.
12. Describe Clapp and Griffiths' modification of the Bessemer-process, and state what advantages are claimed for it.

CHAPTER XIV.

Open-Hearth Process.

This process is conducted in a Siemens' regenerative furnace and comprises three modifications:—1°. Pig and scrap process; 2°. Pig and ore process; 3°. A combination of the two former is now generally adopted and termed the Siemens-Martin process.

The first or Martin-process consists of melting malleable iron with pig-iron, preferably one low in silicon and containing manganese. When the charge is melted, it may be kept in fusion, because the intensity of the oxidising action may be easily maintained. In order to hasten the operation, the pig-iron is charged into the

furnace in the liquid state and speedily raised to a white-heat; the malleable iron, previously made red-hot, is then added in lumps. With a neutral flame, No. 1 grey pig will dissolve 9 times its weight of Bessemer-scrap, while No. 3 pig will not dissolve more than 4 times its weight, and when the flame is oxidising, considerably less. The oxide of iron Fe_3O_4, formed by oxidation, reacts on the carbon of the pig-iron, producing carbonic oxide, which, on escaping, agitates the bath of metal, and thus tends to make it uniform in composition. When the whole is melted a test is taken, and when the metal shows the proper fracture and toughness as well as the right degree of decarburisation by Eggertz' test, it is run into a ladle, and cast into ingot-moulds as in the Bessemer-process. This method of working is only possible with the best pig-iron, so that the usual plan is to completely decarburise, and then add spiegel-eisen or ferro-manganese. The latter, containing less carbon, produces a milder steel than the former.

The second or Siemens-process is worked with pig-iron and pure rich oxides, the latter replacing the scrap-iron of the Martin process. In the latter the iron takes up carbon from the pig-iron, but in the Siemens method the oxide of iron assists the atmosphere in its oxidising action. It partly removes the silicon, manganese, and carbon, so that the process is hastened and the material used is less costly. The difficulty has been to make the light ore thoroughly penetrate the denser metal. This difficulty has been partly avoided by adding the ore in small portions at intervals. The weak point of this method is the corrosive action of the basic oxide on the lining of the furnace, forming an acid silicate of iron, which increases with the amount of ore used, especially when a large portion is added at one charge. At Landore the charge of ore and scrap is added cold, and 8 to 12 per cent. of spiegel or ferro-manganese is added at the conclusion as usual.

The third modification or Siemens-Martin process is similar to the Siemens method in the mode of working. Pig-iron is first charged into the hot furnace, and then iron and steel scrap are added in small quantities at a time, and a certain quantity of rich oxide of iron. Spiegel or ferro-manganese is added at the conclusion.

In the three modifications as above described, it has been assumed that the pig-iron contains but little phosphorus and sulphur. These elements are only to a small extent removed by the process, in consequence of the siliceous nature of the slag, which is but feebly oxidising, so that phosphate of iron could have but a temporary existence.

The Siemens open-hearth furnace is of the reverberatory type, having a slightly concave bed lined with sand, which has been well rammed in and strongly heated (see Fig. 40). The bed also slightly inclines towards the tap-hole, which is situated beneath the middle working door on the front side of the furnace. In the newer forms of this furnace the roof has a strong slope from each side to the centre, giving a very plunging flame; the air-space beneath the bed is enlarged, the gas-ports are longer and narrower, and the regenerators are larger and roofed with semi-circular arches, so as to give a larger exhaust flue for the flame, and thus modify its temperature before it reaches the regenerators.

Pernot's furnace with moveable bed, already described as used in puddling iron, is also used for making steel. (See Fig. 39, p. 93.) The inclination of the bed and the rotation of the furnace cause a more energetic oxidising action than occurs in the Siemens furnace, so that less scrap and ore are necessary for the charge. At St. Chamond the pig-iron is charged after being heated to redness, and the steel- or iron-scrap is added cold at the same time. The bed is made to rotate three to four times per minute during charging and working. The pig-iron melts first and

forms a liquid bath, and the scrap is alternately exposed to the action of the air and molten metal by the motion of the bed. The pig-iron is thus uniformly oxidised by the oxide of iron Fe_3O_4 formed at each revolution, when the unmelted iron is exposed to the air, the iron thus acts as a vehicle for oxygen.

It is claimed for this method that with a 5 ton charge, 5 operations may be completed in 24 hours, each charge only requiring 7 cwts. of coal, and $1\frac{1}{4}$ cwts. for the preliminary heating of the pig-iron. The charge consists of $\frac{1}{5}$th pig-iron and $\frac{4}{5}$ths crop ends of rails, etc. At the conclusion of the refining, spiegel-eisen or ferro-manganese is added as in the Siemens process.

Ponsard has modified the Pernot furnace by the addition of two twyers inserted in the side lining. These twyers work alternately, with the object of hastening the first part of the process. The bed only moves half a revolution, since in a complete revolution the twyers would be alternately in and out of the metal. The central spindle upon which the hearth rotates is made hollow, and through this passage the blast passes to the twyers. This method then is a combination of the Bessemer and Siemens systems of making steel.

Open-hearth basic process.—The object of a basic lining, as in the Bessemer converter, is to enable common pig-iron containing phosphorus and sulphur to be used. The fixed lining of calcined dolomite and tar, and the addition of lime to the charge, causes a highly basic slag to be formed, which takes up a portion of the phosphorus and sulphur as well as the silicon. In the basic Bessemer-process, the phosphorus largely passes into the slag during the "after-blow," when the carbon is reduced to a minimum, so that this after-blow, with the consequent loss of iron, seems essential. In the Siemens furnace, this refining influence is absent, and Gruner states that unless a similar contrivance be adopted, such as Ponsard's, it is doubtful whether mild steel, free from

phosphorus, can be produced from common phosphoric pig-iron.

Dick's open-hearth furnace.—This furnace Fig. 67, is the same in principle as the ordinary Siemens furnace,

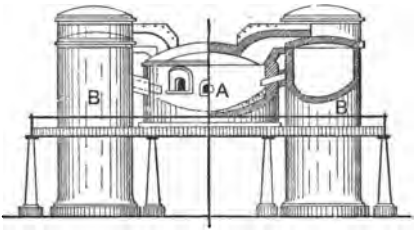

Fig. 67.

but differs in construction and arrangement of the parts. The furnace or melting chamber (A) consists of a circular or oval body with an iron or steel casing. It is placed on a platform, supported by girders, and left entirely clear underneath, so that the bottom is kept cool and the lining better preserved. The four regenerators (BB) form four circular towers, and instead of being situated below the bed of the furnace, are placed in pairs at opposite sides of the furnace; each regenerator forms a separate structure, which is out of harm's way in case of the metal breaking out, and as it has only its own weight to carry it cannot get out of shape. It is very desirable to regulate the relative amounts of the heated gases passing through the regenerators, in order to control the relative amounts of heat stored up in these chambers. The tendency is for the gas-chamber to receive the largest share of the waste heat, whereas the air-chamber should be the more highly heated of the two. This is effected by the adoption of a new kind of disc-valves.

This class of furnace is adopted by the Patent Shaft and Axle Company, Wednesbury, where Mr. Wailes has made several improvements in the parts, with the result that

steel is made with an average consumption of 9 cwts. of coal per ton of steel. These furnaces are worked with a basic lining for the bed, which can be rammed round a core as in the Bessemer vessel. The roof consists of a strong iron ring, lined with silica-bricks, and suspended from girders so as not to rest on the sides of the hearth, a space of $\frac{1}{4}$ inch being left between the basic and acid linings. An opening at the side allows the inflow of heated gas, and directly over this is an opening in the roof through which the hot air is admitted, thus acting like a blowpipe. The charge of scrap and common pig-iron is put into the hot furnace and melted in four hours, a slag being formed; the reaction is maintained for another four hours by occasional additions of iron and lime, until the boiling ceases. Towards the end of the process a little pig-iron, rich in carbon, is added to produce a lively boiling for about twenty minutes. Samples are taken and tested in the usual way.

QUESTIONS.

1. Describe the process of making the so-called Siemens-Martin steel and the chemical reactions concerned therein.
2. Sketch and describe Siemens' open-hearth furnace.
3. Describe Pernot's open-hearth furnace, and state what advantages are claimed for its use.
4. Describe a Siemens gas-producer and state the chemical changes which occur therein.
5. What attempts have been made to remove phosphorus from steel in the open-hearth furnace, and how far have they been successful?
6. The regenerators in an open-hearth furnace have of late years been built separately from the furnace. What advantage is gained by this method?
7. What advantage is claimed for the use of a circular bed instead of one somewhat rectangular?
8. Contrast the basic open-hearth process with the basic Bessemer-process and state which you consider most successful.

9. Why is steel prepared by the Siemens-process usually not well suited for the best kinds of cutting instruments? What class of steel is preferred for that purpose?

CHAPTER XV.

STEEL CASTING. TREATMENT OF STEEL INGOTS, TESTING, ETC.

Steel Castings. (See p. 140-141).—The operation of pouring molten steel requires great care so as to get compact and weldable ingots. The higher the temperature of the liquid metal the more gas it absorbs, and as the temperature falls the absorbed gases are liberated; if however, the steel be poured at too high a temperature some of these gases will remain after the surface has solidified, and produce a honeycombed appearance; the cavities are termed blow-holes.

A ladle of Bessemer- or Siemens-steel is a seething mass, and if poured in this state is very liable to produce unsound castings. About thirty years ago Bessemer used a siliceous pig-iron for mixing with the spiegel-eisen, in order to quiet the steel, and insure greater soundness, and if the blow was not too hot, it was fairly successful. Great caution however should be exercised in adding substances to neutralise the effects of impurities, as more injurious ingredients may be introduced, making the steel brittle and too hard. A great advantage is gained by mechanical agitation of the metal, and for this purpose Mr. Allen lowers into the ladle of steel a rotating paddle, the motion of which facilitates the escape of the gases, and in a great measure prevents blow-holes in the ingots. By the aid of this agitator, and the use of ferro-manganese alone as a quieting agent, good sound castings are obtained.

"Glazed" iron (which is iron containing silicon) and a triple compound of iron, manganese, and silicon, termed "silicon-ferro-manganese," are now largely used for adding to molten steel to produce sound ingots. With regard to this subject, Mr. Pourcel says; "On analysing a sample free from blow-holes, silicon is always found; whilst a honeycombed sample contains interposed slag but no free silicon."

Silicon is more oxidisable than carbon, so that solid silica SiO_2 is formed instead of gaseous carbonic oxide CO. Moreover, silica forms with oxide of iron and oxide of manganese a fluid slag, which largely liquates out when the steel solidifies. This is especially important in basic steel, where the ordinary slag is less fusible, since it is the slag between the molecules which makes the steel red-short. The two reducing bodies, manganese and silicon, act simultaneously in reducing the oxide of iron formed while the liquid metal is exposed to the air.

Müller considers that silicon acts by increasing the solvent action of steel, which then retains the gases in solution instead of being liberated. He also suggests that the beneficial effect of adding spiegel-eisen, is partly due to the evolution of carbonic oxide which ensues, sweeping out some hydrogen at the same time, thus reducing the liability to blow-holes. The different opinions as to the cause of blow-holes may be summarised as follows:—1°. By gases in solution. 2°. By gases formed by the action of the air on the metal during pouring. 3°. By air and gases carried into the metal mechanically when the metal is being run into the moulds, the viscous mass preventing them from escaping.

In large complicated castings due allowance must be made for contraction, for steel contracts twice as much as cast iron; therefore large castings are often made in two or more pieces to avoid internal strains. In consequence of the contraction, steel castings have often been destroyed when left in the moulds to cool. They should be re-

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directly through the "cogging-" or roughing-rolls, then re-heated and rolled in the finishing-rolls to the required section. For rails, the blooms after "cogging" are finished right off without re-heating, being rolled in long lengths and then cut into rails of the required length by circular saws. This reduces the amount of waste from the crop-ends, as a fewer number of rough ends require to be cut off, than when the rails are made in short lengths.

Compound armour-plates are made by casting a steel face on to a wrought iron back, and rolling the mass, when sufficiently cold, into a plate of the required dimensions. The face being hard offers a great resistance to the penetration of projectiles, while the soft iron back prevents the plate cracking by the impact. The mode of production is to take a foundation plate of iron 12 inches thick, and connect it by screws, etc., to a mild steel plate 2 inches thick, leaving a space 5½ inches between. These are made red-hot, placed upright in a moulding-box sunk into sand in an ordinary casting-pit, and the space filled with open-hearth steel, run from a ladle at the highest possible temperature into feeders, which lead to the mould. The steel face-plate is protected from melting by being placed against a thick cast-iron plate.

Gjers' soaking-pits.—The object of these is to utilise the internal sensible heat, given out by the metal while cooling, for the purpose of bringing the whole ingot to the proper temperature for rolling, without the necessity of re-heating. The pits are square in section, and are built of masonry. The depth and height are a little greater than the size of the ingots to be placed in them. They are used for steel ingots obtained from the Bessemer and open-hearth processes. Soaking-pits are represented in H Fig. 68 used in connection with a Bessemer plant. A is the converter, B the ladle, C the moveable platform, D two of the ingot moulds, E the crane to remove the ingots from the moulds to the soaking-pits, H the brick soaking-pits,

F the crane for lifting the ingots from the soaking-pits to the rolls G. The ingot of metal is removed from the

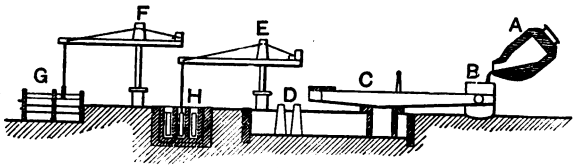

Fig. 68.

moulds as soon as it has sufficiently solidified, then placed in the hot pit, and closely covered. By this means the heat given out by the metal is absorbed and stored up by the brickwork. In about an hour the ingot will be at a uniform temperature throughout, and sufficiently hot for rolling. During the soaking process a quantity of gases is liberated from the metal, consisting of hydrogen, nitrogen, carbonic oxide, etc. ; thus excluding the air, and preventing oxidation. If the brickwork becomes overheated, it may be cooled by dropping in a piece of coal, when the surplus heat is absorbed in gasifying the coal and in volatilising the products. Considerable economy is claimed for this mode of working, as the loss of metal by oxidation during re-heating, together with the requisite expenditure of fuel, is avoided.

Mechanical Tests and Properties.

The value of different varieties of iron and steel, for many purposes, is determined by submitting them to certain mechanical tests, such as tensile, transverse, and crushing stresses; by the amount of elongation before rupture, and by their limits of elasticity. Some brands are tested by their malleability and toughness. For Admiralty requirements, iron ship-plates of the first class must have a tensile strength of twenty-two tons per

square inch lengthways, and eighteen tons per square inch crossways. Plates one inch thick and under must be capable of being bent hot, without fracture, to an angle of 125° lengthways of the grain, and to 90° crossways. In the cold, one inch plates must bend to an angle of 15° along the grain, and to 5° across the grain, without fracture. Half-inch plates are required to bend to angles of 35° and 15° respectively.

Rivets, which should be made of the toughest wrought iron, or mild steel, should be capable of being bent double in the cold without cracking, and the heads hammered, when hot, until the diameter is two-and-a-half times that of the shank, without fracture on the edges. Mr. Boyd has shown that rivets, made of Siemens steel, are stronger and tougher than iron ones.

* "**Angle-iron** may be tested hot by being bent as in A, B Fig. 69, or one flange cut off and bent in the cold as in C.

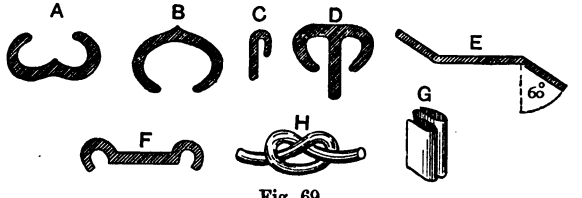

Fig. 69.

Tee-iron may be tested when hot by bending it into the form D, and by treating it in the cold as C.

Z and ⌴ or channel-iron may be tested by bending when hot as in E, F, and when cold as in C.

G represents a piece of Landore-Siemens steel plate doubled fourfold without fracture. H represents a piece of Siemens half-inch round bar steel formed into a knot $2\frac{1}{4} \times 1\frac{1}{2}$ inches without fracture."

* Bancroft's papers on mechanical tests.

The physical tests to which iron and steel are subjected are usually certain defined alterations in shape, as previously indicated, or endeavours to produce fracture, the stress required being carefully determined.

Stress is the term applied to any force, either of extension or compression, and tends to produce an alteration of form.

Strain is the term applied to the alteration of form produced by the action of a stress, and within certain limits, varying in different bodies, is proportional to it. The limit in any case where this proportionality ceases is termed the "limit of elasticity."

Elasticity is the resistance to alteration of form which a body possesses, and is measured by the stress required to produce a given strain.

The modulus of elasticity is the calculated stress, applied as a stretching force, which would double the length of the body tested, if the elasticity were perfect.

Within the limits of elasticity, a body will recover its original dimensions when the stress is removed. Beyond the limits of elasticity the strain increases more rapidly than the stress, and in part remains when the stress is removed. The permanent strain is commonly termed permanent-set.

Tensile testing.—In testing a bar of iron or steel three things are generally determined, viz.—the force required to produce rupture; the amount of elongation produced by the stretching force; and the limit of elasticity. Iron and steel are elastic bodies, and admit of the application of a considerable force before breaking, but in ordinary cast-iron the limit of elasticity is low. The elastic limit in any given quality of iron or steel will depend partly on the mechanical treatment it has undergone, but if such treatment raises the elastic limit in one direction it is done at the expense of its elastic limit in the opposite direction; thus, if the elastic limit be raised for tension it is lowered for compression. The ultimate

elongation is merely an average of the elongations of the length of a bar, the parts of which have elongated very differently, and that percentage will vary for every different length of the bar for which it is calculated; hence in accurate testing an arrangement is used for determining the condition of such different parts during the progress of the test.

The shape and length of the test-piece, as well as the method of holding it, also has an influence on its apparent strength. The old method of holding specimens was by means of pins Fig. 70 A, and if the pin is sufficiently large, and the hole exactly in the axis the plan is satisfactory, but expensive. It is usual now to use shackles with wedge-shaped grips for plate specimens, using test

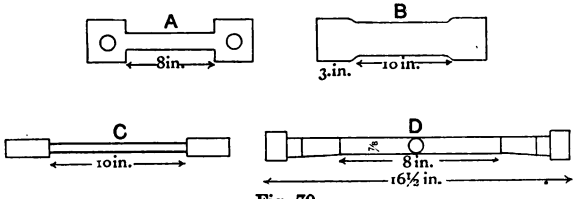

Fig. 70.

bars as shown in Fig. 70 B. With materials which are brittle the test-bar must be recessed, but with ductile materials it is often left parallel; nevertheless the recessed form is best, and the distance between the shoulders should be eight or ten inches. Fig. 70 C, shows the form of round bars for friction grips with V-shaped recesses, which are simple and convenient. The defect of a clip like this, is, that the specimen may slip a little on the one side, being held less tightly than on the other; the specimen then breaks by tearing. Many specimens are prepared with a screw-thread chased on the ends, on which nuts are screwed, these being held in a clip; this plan is expensive, and is objectionable if the screw-threads are not accurate. Professor Unwin considers

the official German test-bar Fig. 70 D the best form of specimen for tension experiments. The test-bar is formed with collars, under which are placed two halves of a ring having a spherical bearing-surface, the only objection being its expense.

Tensile testing-machines.—These machines are chiefly made with two pairs of jaws, in which the test-piece is held, one pair being connected with the head of the ram of a hydraulic cylinder, and the other end with a lever carrying weights, by which the tensile-stress exerted by the hydraulic power is measured. Some machines have the jaws and test-piece so arranged as to produce a pull in a vertical plane, while in others the jaws are made to work horizontally.

Fig. 71 represents a simple 30-ton machine, in which

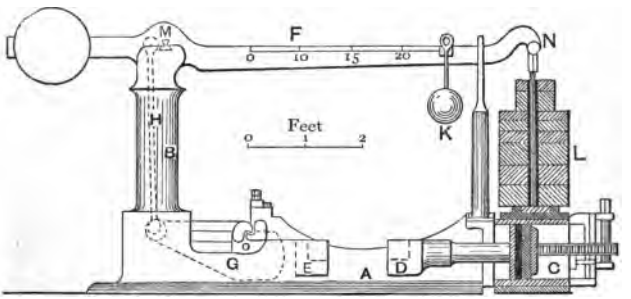

Fig. 71

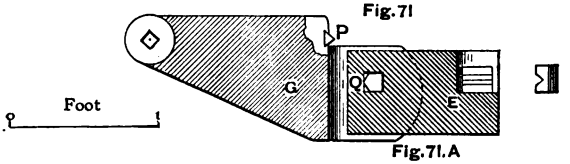

Fig. 71.A

A is the cast-iron bed-plate, B a hollow standard supporting a beam or lever F at the top. C is the hydraulic pump, the ram of which is attached to a pair

of jaws D. The opposite pair of jaws E are connected with the levers F and G by a connecting rod H. The lever F carries a jockey-weight K, and also a rod and plate for supporting additional weights L, which represent tons and half tons. The beam F is supported on a knife-edge at M, the shorter arm being balanced by a dead-weight. The distance of the knife-edge from the point of attachment of the rod H is 2 inches, and the length of the arm MN 56 inches, which gives a leverage of 28 to 1. When the jockey-weight K is placed at No. 20 of the scale, it exerts a pull of 1 ton on the jaws E. The bell-crank lever G is also supported on brackets O; it is 15 inches long, and the vertical distance from the point of attachment to the knife-edges P is 3 inches, giving a leverage of 5 to 1. The pull is exerted through a third knife-edge shown at Q. Thus the total advantage gained by the compound lever is $28 \times 5 = 140$; therefore a weight of 8 lbs. suspended at L represents 1120 lbs. or $\frac{1}{2}$ ton. The moveable grips or dies which hold the test-piece are shown in Fig. 71 B. They are parallel and serrated on their inner faces, but tapered at the back to an incline of 1 in 6, causing the grip to be tightened in proportion to the pull, and loosened when the stress is removed. The hydraulic ram has a stroke of 8 inches.

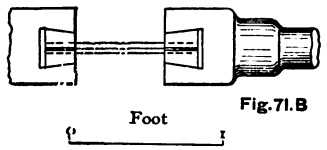

Fig. 71. B

To test a bar of iron or steel $\frac{3}{4}$ inch diameter and 8 to 12 inches long, it is placed in the grips and pressure applied by the hydraulic pump, the jockey-weight being at zero of the scale. A weight representing $2\frac{1}{2}$ tons is placed on its seat, and the jockey gradually moved towards the point marked 20. If this is found insufficient to balance the pressure exerted by the pump, and the bar

shows no signs of breaking, the jockey is returned to zero and an additional weight added. The above process is then repeated, and so on until the bar breaks, when the weights added representing tons, and the position of the jockey representing fractions of a ton, are noted, the pump being worked continuously, except during the intervals of moving the weights. The bar is then measured, to determine its amount of elongation between two marks previously made on the bar, and its reduction of area at the point of rupture.

In making comparative tests it is essential that all test-pieces should be of the same length and thickness, for a thin section will give a proportionately higher resistance per unit of area than a thicker one. The proportional elongation before fracture is greater with short pieces than with long ones.

Cast-iron.—The tensile strength of cast-iron is sometimes determined for special purposes, but it is much more common to test it for transverse stress and the amount of deflection without breaking. When the iron is required for casting columns and similar work which have to support great weights, its crushing strength is then required to be known. The test-pieces for transverse tests are generally cast 3 feet 6 inches long, 2 inches deep, and 1 inch wide, thus allowing a distance of 3 feet between the supports. Now the strength of a rectangular bar, supported at the ends and loaded at the centre, is inversely as the distance between the supports, and directly as the width, and the square of the depth. $S = \frac{wd^2}{l}$. Therefore a bar 1 foot long between the supports, and 1 square inch in section, would have a strength equal to $\frac{3}{4}$ths that of the standard test-bar mentioned above.

Transverse testing-machine.—A 40 cwt. machine for testing bars for transverse stress is represented in Fig. 72. It consists of a bed-plate A of cast-iron, which

supports a hollow square pillar B. On the top of this rests a wrought-iron lever C, balanced on a knife-edge D, and adjusted by means of a counterpoise E. Inside the pillar is an eye-bolt FF, through which the test-piece is placed, the extremities of which pass through the

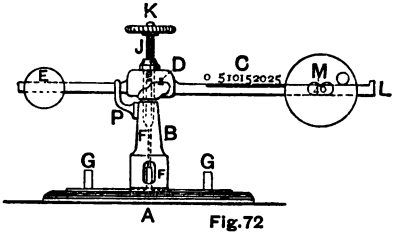

Fig.72

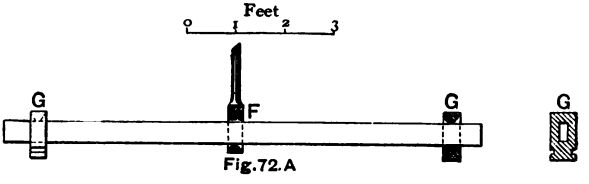

Fig.72.A

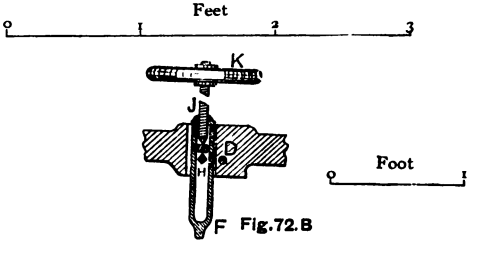

Fig.72.B

moveable dogs or eye-pieces GG Fig. 72 A, which may be fixed 3 feet apart, or less if desired. Near the top of the eye-bolt at H Fig. 72 B is another knife-edge which supports the eye-bolt, and between the knife-edge and the screw is placed a distance-piece, which prevents

the point of the screw J from touching the knife-edge when pressure is applied by the screw by means of the hand-wheel K.

The arm CL is graduated to represent cwts. and fractions of a cwt., and carries a heavy sliding-weight M, moved by a small friction-roller. When the centre of the weight points to 0, it is just counterpoised by the weight E, and when it is at the mark 40, it exerts a pressure of 40 cwts. on the centre of the test-bar. The movement of the lever C is limited by the check-bracket P.

The horizontal distance from the knife-edge D to the line passing through the centre of the screw J, along which the pressure is exerted, is $1\frac{3}{4}$ inches, and the distance from 0 to 40 of the scale is 35 inches, which gives an advantage of 20 as regards leverage. The weight M weighs 2 cwts., and this multiplied by 20 equals 40 cwts.

To test a bar of cast-iron it is placed in the position shown in Fig. 72A. The centre of the weight M pointing to 0, the screw is made tight and the sliding weight moved a little away from zero, which causes the arm C to dip. The screw is again tightened, which produces a pull on the centre of the bar and restores equilibrium in the lever C. The weight is again moved along the scale and the screw again tightened. The amount of deflection is now measured by means of a rule and calipers, and the process repeated with frequent measurements until the bar breaks, when the breaking weight is noted.

Punching and drilling.—Punching holes in iron and steel plates weakens the metal more than drilling, but if a smaller hole than required be punched and afterwards rimered out to the proper size, the strength appears to be about the same as by drilling alone. The effect of punching is to cause a compressed ring round the punched hole, and rimering removes the metal which is thus forced into a state of tension.

The tensile strength of good wrought iron varies from

20 to 27 tons per square inch, and that of steel from 27 tons upwards per square inch, varying with the amount of carbon. The tenacity of both iron and steel is considerably increased by cold-rolling, and by wire-drawing. The following table will show the effect of different proportions of carbon on iron :—

Carbon per cent.	Tensile stress in tons per square inch.
1·5	34–39
1·2	37–40
·9	56–59
·6	37-41
·33	33
·21	27
·06	22

The tensile strength of cast-iron varies from 4 to 14 tons per square inch of section, but the average of good cast-iron is about 7½ tons. The crushing strength is about four times that of the tensile strength, ranging from 25 to 50 tons per square inch. The safe working stress however is 7 tons for compression, and 1½ tons for tension. With regard to transverse stress, a bar of cast iron 3 feet long by 2 inches deep by 1 inch wide, is required by engineers to bear a load at its centre of 25 to 30 cwts. and to give ¼ inch deflection without breaking.

QUESTIONS.

1. If you wished to produce a large steel casting, would you use the open-hearth process or the Bessemer-process in the production of the steel? Give your reason for the selection.
2. What methods have been adopted for the prevention of blow-holes in steel castings?

3. How do you account for the formation of blow-holes in cast-steel?

4. Why is steel cast under great pressure, as in Sir Joseph Whitworth's process, alleged to be superior to the same kind of steel cast *not* under pressure?

5. Steel-castings are sometimes found to be useless when cold; to what causes may the defect be attributed?

6. What is the nature of silicon-ferro-manganese; for what is it used; and how do you account for its efficacy?

7. How are compound armour-plates prepared? What advantages are gained by the peculiar mode of construction.

8. Describe the construction, mode of use, and advantages of Gjers' soaking-pits.

9. What kind of tests would you apply to a sample of wrought iron and steel respectively to determine their value as constructive materials?

10. The tensile strength of iron is increased by the addition of carbon. To what extent is this the case?

11. What effect is produced on the tensile strength of a bar of wrought iron by "cold-hammering" or "cold-rolling" when the strength is tested in the usual manner and when it is tested by concussive action?

12. Define the terms "tensile-strength," "stress," "strain" and "limit of elasticity."

13. Describe with sketch some simple form of tensile testing-machine.

14. What is the average ultimate tenacity of good cast-iron, good wrought iron, mild steel, and high quality cast-steel?

15. Show with the aid of a sketch the shape and dimensions of a piece of steel used in determining its tenacity.

16. What influence have the dimensions and shape of the test-piece on the result of the test?

17. Describe the method used in various tensile testing-machines for holding the test-piece, and state which method is the most suitable.

18. What are the usual tests applied to cast-iron? Why do they differ from those required for steel?

19. Sketch and describe some form of transverse testing-machine.

20. How would you conduct a transverse test with a sample of cast-iron, and what sized test-piece would you employ?

INDEX.

GLASGOW: PRINTED BY ROBERT MACLEHOSE AT THE UNIVERSITY PRESS.

September, 1889

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OF

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