The Manufacture and Properties of

IRON AND STEEL

BY

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To

All Those, Famous or Obscure,

Who, by the Furnace, in the Shop, or at the Desk,

Are Joining Hand and Brain to Solve the

Problems of

The Metallurgic Art,

This Volume is Fraternally Dedicated.

PREFACE TO SECOND EDITION.

There are many engineers who wish a brief statement of the art of making steel. It is quite impossible to do this and at the same time to discuss the metallurgical details, for this involves much shop language that is not understood by any one except the metallurgist. The great electrician whose genius has been crowned with the laurels of two hemispheres referred to the first edition of this book and laughingly, but earnestly, declared that the chapter on the open-hearth was too abstruse for his intellect, while an uneducated open-hearth melter told me he had learned, from that same chapter, how to build a furnace, how to run it, and how to make a good livelihood. The melter understood my language, but to Edison it was a foreign tongue.

In this edition I have tried to give in Part I a sort of Introduction for those who are not metallurgists. It does not pretend to give all the qualifying conditions, but simply the main principles. Part II embraces the ground covered by the first edition of Structural Steel, but many chapters have been entirely rewritten and a great deal of new matter added. Much of the text relating to the chemical history of the open-hearth furnace has been condensed from certain papers which I contributed to the Trans. Am. Inst. Mining Engineers, Vol. XIX, pp. 128 to 187; Vol. XX, pp. 227 to 232, and Vol. XXII, pp. 345 to 511, and 679 to 696, while portions of Chapters XVI, XVII and XVIII appeared in the Trans. Am. Soc. Civil Engineers, April, 1895. In many cases the present book is an amplification of previous work. The experiments and investigations have been conducted at the works of The Pennsylvania Steel Company, of Steelton, Pa., and all the details of manufacture and treatment have been under my direct observation.

In Part III I have entered into a more comprehensive comparison of the industrial situation and have compared the salient points of foreign and American practice. Each country has something to learn from every other. There are still many small economies to effect in the art; there will be a constant cheapening as the cost of all supplies and of transportation is lowered by the natural progress in engineering skill; there are certain important improvements that are in plain view; and there may be still more radical changes not yet foreseen. Every dollar taken from the cost of a ton of steel increases the consumption by opening new markets; by rendering possible, for instance, the extension of railways and telegraphs to the uttermost corners of the earth, and in this way the metallurgist becomes not only a giver of dividends to his employer, but a philanthropist whose benefactions reach to the valleys of the Himalayas and to the sources of the Nile.

I have compared at some length the condition of the industry in each separate country. These descriptions of the various districts or provinces are not intended as complete investigations. It would be impossible for instance to describe the American districts so fully that every engineer and metallurgist of our country would find all the information he might wish, or even find a record of all that he already knows. It would also be impossible to tell an English engineer much about those parts of his own country with which he is acquainted. It may be possible, however, to give some facts for the benefit of travelers; to clear the way for a foreigner visiting America, or an American visiting other lands. It is for this purpose only that these articles have been written and their end will be accomplished if they furnish certain fundamental facts on which to base such a journey.

Some readers might prefer that less space should be devoted to theoretical matter and more to descriptions and drawings of furnaces and apparatus, but in my opinion the place for such information is in the trade periodicals. It takes so long to print a book like this that the drawings are antiquated when the issue appears, and every year that it stands upon the shelf it becomes more and more a catalogue of discarded devices, while on the other hand the fundamental principles of metallurgy remain the same from year to year, and their value knows no depreciation.

A book just issued in England refers very courteously to the former edition of this work, but states that little information is given concerning the practical details of operation. That same book sets forth that an open-hearth furnace is charged by putting the pig-iron in first; that in a twenty-five-ton furnace not over nine men can be employed, even when there are doors on both sides, and that with rapid work it takes two hours to charge a heat. Now those figures are true for the district with which that writer was familiar, but in America the pig-iron is put in last, while at Steelton on a furnace of the size mentioned we use twice the number of men and with good scrap finish the work by charging, by hand labor only, in a period ranging from thirty minutes down to eleven minutes. Of equal value is much of the so-called practical information given in metallurgical treatises.

In many places in these pages I have tried to give credit to the many friends who have rendered assistance in divers ways. It only remains to thank them as a whole, both those at home and abroad, for aiding in this work which has been accomplished in the intervals of what I trust is not otherwise an entirely idle life.

H. H. CAMPBELL.

Steelton, Pa., December, 1902.

PREFACE TO THIRD EDITION.

It is only a few months since the second edition was issued, and it is a source of satisfaction to find that the supply is so soon exhausted. It is also a source of regret since any such book must contain mistakes, and some time must elapse before they are all discovered. Every attempt has been made to corroborate the accounts given of the iron industry in foreign countries and copies of the book have been sent to many foreign metallurgists with duplicate sheets for alterations. The replies indicate that the descriptions were correct; in the case of Germany there were certain errors in statistics, but a personal visit to Westphalia gave an opportunity to get more accurate information, and the chapter on that country has been revised accordingly. This visit also gave a chance for a further study of the practical details of the basic Bessemer process and furnished material for some changes in the treatment of that subject.

Some late statistics have been added, but as a rule no attempt has been made to bring all the records of production down to date. No other book has ever published in detail the output of each producing district, and the only object in doing so was to compare the relative importance of the different parts of each country. Much of the information was collected with great difficulty, and it is impossible to get later figures in each case. I have, however, looked over various statistics from different sources, but fail to find any change in the relative conditions of the different countries or the separate districts. For purposes of comparison, therefore, it is unnecessary to get the very latest data.

H. H. CAMPBELL.

STEELTON, PA., October, 1903.

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A. I. M. E.—American Institute of Mining Engineers.

Am. Soc. Civil Eng.—American Society of Civil Engineers.

A. S. Mech. Eng. or Am. Soc. Mech. Eng.—American Society of Mechanical Engineers.

Journal Frank. Inst.—Journal of the Franklin Institute.

Journal I. and S. I., or I. and S. I. Journal.—Journal of the Iron and Steel Institute of Great Britain.

Proc. Inst. Civil Eng.—Proceedings of the Institute of Civil Engineers (England).

Proc. English Inst. Mech. Eng.—Proceedings of the English Institute of Mechanical Engineers.

Trans. A. I. M. E.—Transactions of the American Institute of Mining Engineers.

Trans. A. S. Mech. Eng., or Trans. Am. Soc. Mech. Eng.—Transactions of the American Society of Mechanical Engineers.

Trans. Am. Soc. Civil Eng.—Transactions of the American Society of Civil Engineers.

C by comb.—carbon as determined gravimetrically.

C by color.—carbon as determined by the color method.

Graph.—graphite.

Tr.—trace.

Und. or undet.—undetermined.

PART I.

INTRODUCTION.

The Main Principles of Iron Metallurgy.

INTRODUCTION.

THE MAKING OF PIG-IRON.

The process of making steel begins by making pig-iron from iron ore. This iron ore is natural iron rust. It is a combination of iron and oxygen, and if we take away the oxygen the iron is left alone. Charcoal or coke or carbon in any form will rob iron ore of its oxygen, and it will do this at a very moderate temperature, the action taking place if the ore and coke are mixed and heated red hot. But it is necessary to do more than this. The iron must be melted and the earthy parts of the ore and coke must be separated from the iron. The operation is conducted in a furnace about one hundred feet high, filled with a mixture of coke, iron ore and limestone, and superheated air is blown in at the bottom. A portion of the coke is burned by the oxygen of the air and serves to maintain the furnace at a high temperature, while another portion is employed in robbing the iron ore of its oxygen.

The air that is blown into the furnace is first heated to a dull red heat by passing it through "stoves." These stoves are in turn heated by burning in them the gases escaping from the top of the furnace. In ancient days these gases were allowed to escape freely, but now the tops are closed tight and all the gas is taken down to the level of the ground, part being used under boilers to generate steam to run the blowing engines, and part in the stoves to preheat the blast.

As the air is red hot when it enters the tuyeres, and as it immediately meets glowing coke which has been heated by its downward passage through the furnace, it follows that a very high temperature must be caused at this point. This region, therefore, immediately about the tuyeres is called the "zone of fusion." It is here that the real melting occurs, but a great deal of the work is done higher up in the furnace, for the gases from this hot zone of fusion ascend through the overlying 70 or 80 feet of stock and heat it to a high temperature, and under these conditions there is a reaction between the carbon of the gas and the iron ore, whereby the oxygen of the ore unites with the carbon and leaves the iron in the finely divided metallic state known as "spongy iron." The reaction is not complete and a great deal of ore reaches the zone of fusion in a nearly raw state, but in this zone the extremely high temperature quickly completes all reactions; the raw ore is rapidly reduced, the earthy impurities unite with the limestone and are fused into slag, while the metallic iron melts and is collected in the hearth below the tuyeres.

The metal so produced is not pure iron, for while it is in contact with white-hot coke in the furnace, it absorbs a certain amount of carbon. This amount is quite constant, and it is safe to assume that any piece of ordinary pig-iron, no matter what its appearance may be, contains from 3.5 to 4.0 per cent. of carbon. Some of this carbon is chemically combined with the iron, and some is held in suspension as graphite. If a large proportion is combined, the fracture of the iron looks white and the metal is hard and brittle. If a large proportion is in the free state, the fracture will be gray or black, with loose scales of graphite, and the iron is soft and tough. Very slow cooling tends to put the carbon into the condition of graphite, while sudden chilling from the liquid state tends to keep it in combination and give a hard and white iron.

The iron also contains silicon, which is absorbed in the furnace from the ash of the coke. Sometimes this silicon will amount to only one-half of 1 per cent. and sometimes it will be 3 per cent. Usually there will be from 1 to 2 per cent.

A certain small proportion of sulphur will also be present. It is not wanted at all, but there is seldom less than two-hundredths of one per cent., while there may be one-quarter of one per cent., and even more. When there is over one-tenth of one per cent. the iron is apt to be hard and brittle and to have a close and white fracture. In such iron, the silicon is usually low and this contributes to the closeness of the grain.

The percentages of silicon and sulphur that are present in the iron depend in great measure upon the conditions in the blast furnace, and hence may be controlled by the furnaceman. But there is one element which is universally present, over which he has no control. This element is phosphorus. Whatever quantity is present in the ore and fuel will be found in the pig-iron, so that the only way to get an iron low in phosphorus is to get ore and coke which contain only a small percentage. In irons used for making steel by the usual Bessemer process, the iron is not allowed to contain over one-tenth of one per cent. of phosphorus. For basic steel and for foundry work no fixed limit can be given.

Where great toughness is required in iron castings it is well to use what is called "Bessemer pig-iron," by which term is meant an iron containing not over one-tenth of one per cent. of phosphorus. Such an iron costs very little more than ordinary foundry grades. In other cases a high percentage is desired to confer great fluidity, and irons carrying 3 per cent. of phosphorus are in demand, a certain proportion of such metal being used in making intricate castings where the metal must accurately fill every corner of the mold.

Pure iron itself is very difficult to melt; it is soft, tough and malleable both hot and cold, but the elements above described, preëminently the presence of nearly 4 per cent. of carbon, change its character completely in the following ways:

(1) It is more fusible.
(2) It is brittle.
(3) It cannot be forged either hot or cold.

Thus we have what the general public calls cast-iron. In the trade, however, this term is applied to it only after it has been melted again and cast into some finished form. The product of the blast-furnace is always spoken of as pig-iron. It is the foundation stone of all the iron industry; it is one of the great staples in the commerce of the world. The foundryman makes from it his kettles and stoves; the puddler refines it and supplies the village blacksmith with bars for chains and horseshoes; the steel maker transmutes it into watch-springs and cannon.

THE MAKING OF WROUGHT-IRON.

When the Bessemer process of steel making was invented it was confidently predicted that it sounded the death-knell of the puddling furnace, but although there have been several announcements of the funeral, the great event has never actually occurred. There seem to be a few places where wrought-iron is needed, and there are many more places where the blacksmith and the machinist find steel unsatisfactory, because they do not know anything about the metal and refuse to learn, usually stating that they have been "working long enough to know."

Wrought-iron is made by melting pig-iron in contact with iron ore and burning out the silicon, carbon and phosphorus, leaving metallic iron. This iron is not in a melted state when finished, for the temperature of the furnace is not sufficiently high to keep it fluid after the carbon has burned. It is in a pasty condition and is mixed with slag and when taken out of the furnace is a honeycomb of iron, with each cell full of melted lava, and this honeycomb is squeezed and rolled until most of the slag is worked out and the iron framework is welded together into a compact mass. The bars are rough and full of flaws and are regarded as an intermediate product. This "muck bar" is then cut up and "piled" and heated to a welding heat and rolled again, and this time the bar is clean and becomes the "merchant iron" of commerce.

The previous description refers to the use of pig-iron only, but in many works this practice is modified by using scrap of various kinds, especially steel turnings from machine shops. Oftentimes almost the entire charge is made of cast-iron borings and steel turnings, although a certain amount of larger steel scrap is generally used to make the ball hold together. In making the pile for the second rolling a certain proportion of soft steel scrap is often used, as this welds up with the rest, so as to be practically the same, and this increases the tensile strength of the bar. The main principles of the process, however, remain the same in all its forms.

A DEFINITION OF STEEL.

In the olden time all kinds of steel, whether made in the crucible, in the cementation chamber, or in the puddle furnace, contained carbon enough to make them suitable for cutting tools when hardened in water, and the steels that were made in the Bessemer converter during the early days of its history were all more or less hard, much of it being used for tools; consequently the metal made in the converter was rightly called Bessemer *steel.*

As time went on and the cost of the operation was reduced below that of making wrought-iron, a great deal of very soft metal was made in the converter and in the open-hearth furnace. This new metal did not fill the old definition of steel, but it was impossible to draw any line between the steel used for rails and that used for forgings, and it was impossible to draw a line between the metal used for forgings and that used for boiler plate, and as it was impossible to do this, practical men in America and England did not try to do it, but called everything that was made in the Bessemer converter, or in the open-hearth furnace, or in the crucible, by the name "steel."

A few scientific committees tried to make new names, but their labors came to naught in England and America. In Germany the committees had their way for many years, and the soft metals of the converter and the open-hearth were called ingot-iron. This term still survives in metallurgical literature, but in the German works where the metal is made, it is called *steel,* and the plant itself is called a *stahl werke* (steel works), so that we have the peculiar anomaly of a steel works making what is called steel by the workmen, while the official reports declare that it makes no steel at all. It seems inevitable that Germany must soon give up this outgrown system.

The current usage in our country and in England in regard to wrought-iron and steel may be summarized in the following definitions:

(1) By the term wrought-iron is meant the product of the puddling furnace or the sinking fire.

(2) By the term steel is meant the product of the cementation process, or the malleable compounds of iron made in the crucible, the converter or the open-hearth furnace.

THE MAKING OF CRUCIBLE STEEL.

Most of the hard steel in the market to-day is made in the open-hearth furnace. Enormous quantities are used for car springs and agricultural machinery, and both the acid and basic furnaces furnish a share. There are some purposes, however, which call for a steel entirely free from the minute imperfections often present in open-hearth metal. Such is the case in watch-springs, needles and razors; and it is found that the old crucible process gives in the long run the most satisfactory metal for such work.

This process consists in putting into a crucible a proper mixture of scrap, pig-iron, or charcoal and heating it until everything is thoroughly melted, the crucible being kept tightly closed to prevent the admittance of air. This process is a century old, but bids fair to round out another with little change.

THE ACID BESSEMER PROCESS.

The Bessemer process consists in blowing cold air through liquid pig-iron. Sometimes the pig-iron is brought directly from the blast-furnace while fluid, and sometimes it is remelted in cupolas. In the early plants in England and America the lining of the vessel which held the iron was of ordinary silicious rock and clay, and this is still the universal practice in America. In other countries it has been necessary to develop a modification of the process, the linings being made of basic material, whereby the chemistry of the operation is greatly changed.

The growth of the basic Bessemer practice made it necessary to have a distinguishing name for the old way, and it is therefore called the *acid* process, the word being used in a chemical sense rather difficult to explain to any one not versed in chemistry.

In the acid process, the air passing through the iron burns the silicon and carbon, while the heat caused by their combustion furnishes sufficient heat to not only sustain the bath in a liquid state, but to increase its temperature, and to oftentimes necessitate the addition of scrap or steam as a cooling agent.

This increase in temperature is due principally to the silicon, which is of great calorific power, while the burning of the carbon gives barely sufficient heat for the bath to hold its own. It is necessary, therefore, that the iron contain sufficient silicon to raise the temperature to the point where steel will remain perfectly fluid. In the old days when operations in a steel works were slow and converters were allowed to cool off between charges, it was necessary for the pig-iron to have about 2 per cent. of silicon to get sufficient heat, but with the rapid methods of to-day, it is found that 1 per cent. is enough.

When the silicon and carbon are all burned, a certain amount of manganese is added in order that the steel shall be tough while hot, and be able to stand the distortions it is subjected to in the rolling mills. If soft steel is wanted, this manganese is obtained by using a rich alloy called ferromanganese, containing 80 per cent. of manganese, while if rail steel is being made, the usual method is to make a liquid addition of spiegel iron—a pig-iron containing about 12 per cent. of manganese.

For every ten tons of steel about one ton of this spiegel will be added, and this at the same time gives enough manganese to make it roll well, and enough carbon to confer the necessary hardness. When the rich alloy is used to make soft steel, as before explained, the amount added is very small and the carbon thus carried into the bath is trifling.

The resulting steel is poured into a ladle, and the slag, being very light, floats on the top. The steel is then tapped from the bottom, the separation of metal and slag being perfect. Minute cavities of slag are often found in steel, but these come from internal chemical reactions, or sometimes from dirt in the mold. They do not arise from mixture of the metal and slag when poured in the way that is almost universally used in Bessemer and open-hearth works.

In this acid process there can be no removal of phosphorus or sulphur, and as no steel is allowed to contain over one-tenth of one per cent. of either, it is plain that the pig-iron must not contain more than this allowable amount. It has been shown, in the discussion of the manufacture of pig-iron, that the phosphorus in the ore will appear in the metal. Consequently if the ores of any district contain more than one-twentieth of one per cent. of phosphorus, which will give one-tenth of one per cent. in the iron, that district cannot possibly use the acid Bessemer process. If they do contain as little as this, then this process is the cheapest method of making steel that has ever been discovered or probably ever will be.

THE BASIC BESSEMER PROCESS.

The basic Bessemer process is similar to the acid Bessemer, both being founded upon the general truth that if cold air be blown through pig-iron, the combustion of the impurities in the iron will furnish sufficient heat to keep the metal in a fluid state. In the acid process it has been shown that only two elements are thus burned, viz., silicon and carbon, and that the silicon supplies most of the heat.

In the basic process the lining is made of basic material, usually of hard burned dolomite, which is a limestone containing from 30 to 40 per cent. of magnesia. When the linings are basic, it is a bad thing to have much silicon in the iron, because when silicon is oxidized it forms silica (SiO_2), and this attacks the lime lining. The percentage of silicon is therefore kept as low as possible, and this makes it necessary that some other source of heat be provided. This is the more necessary because more heat is needed in the basic process than in the acid, on account of the lime which is added in the converter and which must be melted during the operation.

The element used to take the place of silicon and supply heat is phosphorus. In the acid process phosphorus is not eliminated at all, but when the linings are basic it is possible to add lime and make a basic slag in which phosphorus can exist as phosphate of lime or phosphate of iron. In the acid process it is not feasible to add lime, because the lining of the converter would be eaten away and the slag could not remain basic enough to hold the phosphorus.

As already stated, the basic Bessemer process requires more heat than the acid process, because considerable time must be added to give a basic slag, and because the lining of the vessel is eaten away much faster. It has also been explained that silicon is not allowed in the iron to any extent, because the more silicon there is present, the more lime must be added to counteract it.

Inasmuch as silicon is the principal source of heat in the acid process, and as still more heat is required in the basic converter where silicon is not allowed, it is evident that phosphorus, which replaces silicon as a heat producing agent, must be present in considerable quantity. In most basic Bessemer works the iron contains about 2 per cent. of this element. If it falls below 2 per cent. the heat produced is not sufficient to give the proper temperature to the fluid metal at the end of the blow. With very fast work and a short time between charges this percentage could doubtless be reduced considerably.

Thus it happens that the Bessemer process is applicable to only two kinds of ores:

(1) Those containing only a trace of phosphorus, giving an iron suitable for the acid process.

(2) Those containing a high percentage giving an iron containing 2 per cent. of phosphorus, suitable for the basic process.

There are many deposits of ore in different parts of the world which are intermediate between these classes, and which give a pig-iron ranging from one-tenth of one per cent. up to one and one-half per cent. These irons are not suitable for either form of the Bessemer process, although it often happens that an iron which contains too little phosphorus for the basic vessel can be used in admixture with an iron that contains a surplus. When this is impracticable, such irons can be used for steel only in the basic open-hearth furnace.

When the air is blown through the melted iron in a basic converter the silicon is first oxidized, and the carbon next. Thus far the operation is the same in both the acid and the basic vessel.

At that point the acid process ceases, but in the basic process the blast of air is continued and the phosphorus is oxidized and passes into the slag. The slag therefore contains a considerable percentage of phosphorus and this makes it valuable as a fertilizer. The demand for it is unlimited and the revenue derived from it is a very important matter to all plants using this process. The cost of labor, however, and the greater waste and diminished output of a basic Bessemer render this process out of the question except where suitable pig-iron can be had at a much lower price than iron fit for the acid process. In the United States this condition does not exist and there is no plant in operation in this country.

The final operation of adding spiegel iron or ferromanganese is conducted in practically the same way in the basic Bessemer vessel, as has already been described in the account of the acid process.

THE OPEN-HEARTH FURNACE.

An open-hearth furnace really means a furnace having a hearth exposed to the flame, so that any piece of steel or other material placed upon the hearth is exposed openly to the action of the burning gases. The term has been narrowed by custom to denote such a furnace where steel is melted. A furnace for this purpose must be regenerative in order to get the requisite intense temperature. Regenerative furnaces are also used very generally for heating steel in rolling mills, but they are not called open-hearth furnaces except when the steel is actually melted.

By a regenerative furnace is meant one in which the heat carried away in the stack gases is used to warm the air and gas before they enter the furnace. Strictly speaking, a furnace would be regenerative if air pipes were put into the stack and the air blast were passed through these pipes. But by custom the term means only a furnace which is heated by gas, and where both gas and air are heated before they enter the furnace by being passed through chambers filled with bricks loosely laid, these bricks having previously been heated by the waste gases. By having two sets of chambers, one set can be used to absorb the heat in the waste products and the other set to warm the incoming gases. By proper systems of reversing valves these two sets of chambers can be used alternately for each purpose, and in this way the gas and air are heated to a yellow heat before they unite, and it is quite evident that yellow-hot air and yellow-hot gas will give a very intense heat.

The problem in an open-hearth melting furnace is not to *reach* the desired temperature, but to *control* the temperature and prevent the roof and walls from melting down.

THE ACID OPEN-HEARTH PROCESS.

The term acid open-hearth furnace means a regenerative gas furnace used for melting steel, and lined with silicious material (sand). It has been shown that the Bessemer process can be conducted in a vessel lined with silicious material, or in a vessel lined with basic material, and it has been shown that this difference in lining makes a radical difference in the process. In the same way the manner in which a steel melting furnace is lined profoundly influences the subsequent operations. Contrary to popular belief, the bottom in itself plays very little part and has very little influence, but the character of the bottom determines the character of the slag that can be carried, and the character of the slag determines the chemistry of the process.

In the acid open-hearth process a mixture of pig-iron and scrap is charged into the furnace and melted. Nothing is added to form a slag, as the combustion of the silicon and manganese, together with some iron that is oxidized, and some sand from the bottom, affords a sufficient supply. The slag is about half silica (SiO_2), while the other half is composed of oxides of iron and manganese. When the mass is melted it is fed with iron ore, and the oxygen in the ore oxidizes the excess of carbon until the required composition is attained, whereupon the steel is tapped, the proper additions of manganese being made at the time of tapping. Melted spiegel iron, so generally used in Bessemer practice, is not used in open-hearth work, but the manganese is added in the form of a rich ferromanganese, which is generally thrown into the ladle as the heat is tapped. Sometimes a spiegel iron is used, but this is put into the furnace a little while before tapping and allowed to melt.

It is necessary for the highest success of the operation that the slag should be kept within certain limits in regard to its chemical composition, for if it contains too much silica it is thick and gummy, and the operation will be much retarded, while if it contains too much oxide of iron it will be sloppy and the metal will be frothy and over-oxidized. It would seem at first sight that there would be considerable difficulty in regulating the composition of a slag that is constantly receiving iron ore and constantly absorbing silica from the bottom. Moreover, the amount of ore is not constant nor the rate at which it is added, for on some heats scarcely any ore is thrown in, on others there may be 500 pounds added in three or four hours, and on others there may be 3,000 pounds used in the same period of time.

As a matter of fact, there is very little difficulty in maintaining a very regular chemical composition if moderate judgment be exercised and the additions of ore are regulated by the temperature of the furnace and the condition of the metal. Many an open-hearth melter has never heard of silica, and yet can keep a constant percentage of it in his slag. This is due to the fact that the slag regulates itself to a great extent. The pig-iron used in the charge always contains silicon and this furnishes silica. If the amount is not sufficient, there will be a cutting away of the sand bottom to supply more. We thus have by the wearing of the bottom an inexhaustible source of supply of silica. In the same way we have a similar supply of iron oxide by the oxidation of the iron of the bath. If iron ore is added, this is the easiest way for the slag to get the oxide, since it simply appropriates it to its own use. Iron ore is a compound of two atoms of iron with three atoms of oxygen, expressed in chemistry thus—Fe_2O_3—, wherein Fe is iron and O is oxygen, and the figures represent the proportions. If the slag contains too high a percentage of silica, and needs more iron oxide, and if under these conditions iron ore is added, then only one of these atoms of oxygen goes toward oxidizing the silicon and carbon of the bath. This leaves two atoms of iron and two atoms of oxygen, and these unite together to form two parts of a different oxide, FeO, or since there are two atoms of each, thus—2FeO.

The extra atom of oxygen has united with carbon and formed a gas in which one atom of carbon unites with one atom of oxygen. In chemistry this action is expressed thus: $C+O=CO$. The symbol C stands for carbon, and O for oxygen, and when united in equal proportions, they form CO, which is the chemical symbol for carbonic oxide.

The whole operation of adding iron ore to an open-hearth bath, when only the extra atom of oxygen is given to the carbon, and the rest of the oxide stays with the slag, may be expressed by the following simple chemical formula:

$$Fe_2O_3+C=2FeO+CO.$$

This concentrates in one line all the explanation we have just gone through.

Sometimes the slag has a sufficient supply of oxide of iron and needs no more. In this case, when ore is added, all the oxygen goes to the carbon of the bath so that there are three atoms of oxygen calling for three atoms of carbon. This leaves the iron alone in its metallic state and it is instantly dissolved in the bath, and the weight of the charge is increased by just so much. The chemical symbol expressing this is as follows:

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

Generally it will happen that the truth lies between these two conditions; that the slag keeps part of the oxide and the rest is reduced, part of the oxygen uniting with carbon and part of the iron being dissolved in the bath, the remainder of the oxide of iron entering the slag.

Still another condition exists whenever iron ore is not added to the bath. Under this state of affairs, it may be necessary for the slag to have more oxide of iron, and there is no place for this to come from except the bath. Therefore, when there is need of oxide of iron, the iron of the bath unites with the oxygen of the flame and goes into the slag.

Thus it is clear that if no iron ore is used, a certain equivalent amount of good stock must be oxidized, and that if iron ore is used the weight of metal tapped will be greater than if it had not been added.

The amount of carbon in the steel, and therefore the tensile strength, depends entirely on the conduct of the operation, but the amounts of phosphorus and sulphur depend upon the kind of stock which is put into the furnace. If a superior quality of steel is required the original stock should contain only small percentages of these elements. Such stock, however, costs more money than common scrap. If an ordinary quality is required then ordinary pig-iron and scrap are used.

It is a common belief that it is an easy thing to distinguish between open-hearth steel and Bessemer steel. It is usually very easy to tell basic open-hearth steel from acid Bessemer, or acid open-hearth from basic Bessemer, but it is impossible by any ordinary means to tell acid Bessemer from acid open-hearth or basic Bessemer from basic open-hearth. Most American metallurgists and engineers, however, agree that open-hearth steel of a given composition is more reliable, more uniform, and less liable to break in service than Bessemer steel of the same composition. And there are many metallurgists and engineers both in this country and abroad who believe that acid open-hearth steel is more reliable than basic open-hearth steel of similar composition. In Chapter XVII. it will be shown that there is mathematical evidence to support this opinion.

There are many who disagree with this proposition, but almost every American who disputes it will confidently assert that open-hearth steel is superior to Bessemer steel, and he will just as unqualifiedly put basic Bessemer steel in a lower place, yet his opinion on these two steels is no more capable of complete logical demonstration than my opinion in favor of acid steel. The reasons for this opinion, founded on an experience extending over a score of years, may not be written in the compass of this chapter or this book.

THE BASIC OPEN-HEARTH PROCESS.

The term basic open-hearth furnace means a regenerative gas furnace, used for melting steel and lined with basic material, usually either magnesite or burned dolomite.

It has been stated in discussing the acid open-hearth that the bottom itself takes very little part in the operation, but that it determines the character of the slag that can be carried. When the bottom of the furnace is made of silica (sand) the slag must be silicious; but when the bottom is basic the slag must be basic. Consequently in the basic open-hearth furnace the charge is composed of pig-iron and scrap, just as in the acid furnace, but, in addition to this, a certain amount of lime or limestone is added. The whole mass of iron, scrap and lime is melted down by the action of the flame. The silicon and carbon of the pig-iron are oxidized, just as in the acid process; the manganese of the scrap and some of the iron are both oxidized just as on the sand bottom; but the silica and the oxides of iron and manganese do not make a slag by themselves, for they unite with the lime that has been added. This gives a basic slag and when the slag is basic the phosphorus in the pig-iron and scrap will be oxidized and enter the slag as phosphate of lime or iron, just as it does in the basic Bessemer vessel. Thus the basic open-hearth furnacewill allow the purification of iron containing phosphorus, and for the same reason, but in very much less measure, sulphur can be eliminated.

After the charge of pig-iron and scrap is melted, iron ore is added as fast as necessary to oxidize the excess of carbon, and when the metal has reached the desired composition it is tapped into the ladle, the additions of manganese being made in the same manner as in the acid furnace.

The principles underlying the reactions in a basic furnace may briefly and incompletely be stated as follows:

(1) Silicon oxidizes readily at a high heat under almost all conditions. Its oxide is sand (SiO_2), which acts as an acid, by which is meant that it will combine if it has a chance with one of the bases or earths, like lime, iron or manganese.

(2) Phosphorus oxidizes readily, but it will not stay in the form of oxide unless the conditions are favorable. Its oxide is phosphoric anhydride (P_2O_5), which acts as an acid like silica; but silica when formed is stable and will stay where it is put, but the oxide of phosphorus must have something to unite with, and this something must be one of the bases or earths like lime, iron or manganese. If oxide of phosphorus is formed and there is no base for it to unite with, the metallic iron robs it of its oxygen, and then we have oxide of iron, while the phosphorus is left alone, dissolved in the bath.

(3) The oxide of phosphorus requires a considerable quantity of bases to unite with. If the quantity is limited, the phosphorus may stay for a time, but will then leave. If a slag contains all the phosphorus it can hold at a certain temperature and the furnace gets hotter, some of the phosphorus will go back into the metal. If, with the same slag the carbon begins to burn faster from any cause, the phosphorus will go back into the metal on account of the reducing action being stronger.

(4) The oxide of phosphorus does not hold on with equal force to all bases. If it is combined with lime it is much harder to pull it back than if it is combined with iron.

(5) Since oxide of phosphorus acts as an acid and combines with a base, it is evident that a slag which is absorbing phosphorus becomes every moment more acid, and thus becomes every moment less capable of further absorption.

(6) It is the rule in slags that a mixture of several different acids and bases will be more active than a slag made of one acid

and one base. Such a complex slag, all other things being equal, will be more fluid in the furnace than a simple slag.

(7) In all furnaces, whether acid or basic, there is more or less of an automatic regulation. In the acid furnace the percentage of silica will be constant, for if there is not enough silicon in the charge to supply the necessary silica, the slag will eat away the bottom until it is satisfied. The total content of the oxides of iron and manganese will be constant, for if there is no ore added, the iron of the bath will be oxidized. If ore is added, the silicon and carbon of the bath unite with the oxygen of the ore and the iron goes into the bath. Thus the slag takes care of itself on an acid hearth.

(8) In the basic furnace the slag takes care of itself to some extent, but the cutting away of the hearth must not be allowed, and if phosphorus is to be eliminated, a sufficient quantity of lime must be added. Given the right amount of lime, there is then a considerable self-adjustment of the slag by the oxidation of the iron of the bath or by the reduction of the iron from the slag. If much lime be added, it will tend to drive the iron back into the bath, although it can never do it completely, while if little lime be added, there will be a greater proportion of iron in the slag.

(9) It is necessary that the slag shall be so basic that it will not attack the bottom. If it is so, it is basic enough to hold all the phosphorus that will be present if the stock contained only a moderate amount—say not over one-half of one per cent. If the stock contained far in excess of this, as often happens, special attention must be paid that phosphorus does not pass back into the steel when a high temperature is combined with violent agitation and perhaps a reducing action, these conditions being often present when the heat is tapped.

SEGREGATION.

Every engineer knows that steel is not homogeneous. Manufacturers have always known it, but they have usually said very little about it. It is a much safer plan to state the facts and let proper allowance be made in the proper place. The tendency among structural engineers is continually toward heavier work. The size of beams and angles and girders is greater now than it was some years ago, and the percentage of the heavy sections is greater. These heavy pieces necessarily mean heavy ingots in order that there shall be sufficient work upon the steel to give it a proper physical structure, and these heavy ingots mean a larger cross-section, and this means that it takes a longer time for the ingot to cool from the liquid to the solid state.

During all the time the ingot is liquid there is a process going on by which the carbon, the phosphorus, and the sulphur are becoming concentrated in the central portion of the mass and rising to the upper portion. During the operation of rolling and shearing off the ends, the worst of the ingot is discarded, but the central portion of what is left is not uniform with the outside portions. It is evident that in most sections this impure portion will constitute the neutral axis and thus its influence be reduced to a minimum. In certain cases, however, as in armor plate and ordnance, great care is taken to reject all contaminated portions. This could be done in structural material, but it would involve much expense, and no engineer would be justified in insisting upon such a course, since contracts are founded upon ordinary commercial practice, and this ordinary practice allows a certain measure of segregation to exist. Mr. A. C. Cunningham, one of our best inspectors, states explicitly in his printed specification that in tests cut from the finished material an increase of 25 per cent. will be permitted in the allowable content of impurities. This is simply stating clearly what other inspectors tacitly accept as a fact.

Perhaps the most troublesome instances of segregation occur in plates rolled directly from ingots. It usually happens that the top surface of the ingot is solid and that a cavity exists beneath. When this is rolled into a plate, it is possible to shear the plate so that this inner cavity is not opened, and we then have a finished plate which has an area of lamination and an area of segregation, and these are not in the center of the plate, but near one edge. The test pieces are almost always taken from the corners, so that they never reach the segregated portion, and there is nothing to mark the dangerous condition of the plate. In plates rolled from slabs there is often a streak of segregation running through the central axis, but there is not the centralization of impurities that occurs in the older method of manufacture.

THE INFLUENCE OF HOT WORKING UPON STEEL.

When an ingot of steel is cast in a mold and allowed to cool it is not a homogeneous mass of uniform strength throughout. Its structure is coarsely crystalline and these crystals do not always have a firm hold on each other. Moreover, there are many small cavities, called blowholes, distributed unevenly but mainly very near the surface, and oftentimes a much larger cavity in the center of the upper portion. There are also shrinkage cracks extending inward from the surface, these cracks being very numerous in the case of steel that is poured at a very high temperature.

When the ingot is heated and rolled all these disturbing factors tend to disappear. The crystals are forced together and come into more intimate contact; the blowholes are crushed out of existence, and although their sides are not always perfectly welded together they at the worst become mere lengthwise seams, which have no influence on the longitudinal strength and scarcely any on the bending or torsional stiffness; the central cavity is cut off when the top is cropped at the hot shears; the cracks are at first opened up by the rolls and are then either worked out into a perfect surface or show themselves in open and staring flaws that condemn the bar and so prevent its use in structural work.

It will be evident that the more work that is put upon the piece the greater will be the tendency to remove flaws and to secure homogeneity. Of course, if an ingot is not alike at the top and bottom no amount of work will make the bar from the upper end like the bar from the lower end, but the effect of the continual working in the rolls will be toward doing away with local irregularities in both physical and chemical condition. For these reasons and particularly on account of the elimination of surface imperfections, the tendency of modern rolling-mill practice is toward the use of larger ingots. In cases where the ingot is rolled into the finished bar at one heat it will be evident that with a large ingot the bar will be finished at a lower temperature on account of the greater time necessary to do more work, and this lower finishing temperature is beneficial. In cases where the ingot is not finished at one heat the use of a large ingot renders it possible to get a clean bloom of large size, and this again makes it probable that the bar will be finished at a low temperature.

THE EFFECT CAUSED BY CHANGES IN THE SHAPE OF THE TEST PIECE.

It is the custom for engineers to specify that steel shall give a certain percentage of elongation, but it is seldom that anything is said as to how and where the test shall be taken. This omission is covered by a general understanding in the trade so that there is seldom any trouble in the case of standard structural shapes. Wherever it is possible the test piece is taken so as to leave two parallel rolled surfaces on the test bar, the other two sides being machined. This can readily be done with plates, beams, channels, angles and similar shapes. In small rounds the whole piece is taken as it comes from the rolls. In the case of plates it is understood that the test piece is to be taken lengthwise of the plate unless stated otherwise in the specifications. In forgings, however, no absolute standard can be given, but it is usual to cut a test from a prolongation of the piece at a short distance below the surface. In many cases this is unnecessary, and it will suffice to forge a small bar from the heat and finish this either at a small hammer or at a rolling-mill. In other cases, like armor plate and cannon, stringent provisions are incorporated in the specifications.

The results obtained from test pieces of different shape are not the same. The general section, whether round or rectangular, makes a difference, and in a rectangular piece the relation of the width to the thickness influences the result. It will be seen that this latter fact is important in cutting strips from angles or flats of varying thickness. Needless to say that the length is the one predominant factor. Just before breaking there is a drawing out of the bar in the immediate neighborhood of the place where it is going to break, and this local stretch will be a greater proportion of the total in the case of a bar two inches long than with a bar ten inches long. In order that records shall be comparative, the length of eight inches is used throughout England and America, except for forgings and castings, in which cases a 2-inch test is often used, as it is both inconvenient and expensive to get the longer piece. In foreign countries the standard length is 200 millimeters =7.87 inches, so that the results are fairly comparable with our 8-inch test.

The general laws may be thus summarized, the data from which the conclusions are drawn being given in Chapter XVI.

(1) A rolled round will give the best results if tested in the shape in which it leaves the rolls. If the outside surface is removed by machining the elongation will be reduced.

(2) The tensile strength of a plate as determined by the grooved (marine) section will be from 6500 pounds to 12,500

pounds per square inch higher than if determined by the parallel-sided test.

(3) Flat bars differ from rounds in having less tensile strength, lower elastic limit, lower elastic ratio, greater elongation, and a slightly lower reduction of area.

(4) In testing flats the elongation increases regularly as the width increases, while the reduction of area regularly decreases.

(5) The percentage of elongation decreases as the length of the test piece increases. The law of change is such that if a piece 8 inches long gives 30 per cent. elongation, a piece of infinite length would give about 24 per cent.

THE INFLUENCE OF CERTAIN ELEMENTS UPON STEEL.

Nothing is more difficult than to state accurately the effect of different elements upon the strength and ductility of steel. Those who have studied and worked over the problem differ among themselves and differ widely. Yet it is a common thing for engineers to write a specification calling for a steel of a certain tensile strength, and limiting the content of carbon, phosphorus, manganese and sulphur. It often happens that such specifications are impracticable, if not impossible. For instance, the tensile strength is allowed to vary between 60,000 pounds and 70,000 pounds per square inch, but it may be that the highest allowable contents of carbon, phosphorus and manganese will actually give a strength of only 65,000 pounds. Now it will be evident that the true allowance of tensile strength is not 10,000 pounds, but 5000 pounds. It is also evident that the manufacturer must keep his phosphorus and manganese at the highest point, a thing the engineer is very far from wishing, but which he has ignorantly made necessary.

The slightest consideration will show that it is a mathematical impossibility for the engineer to put both chemical and physical limits and have them coincide, unless he knows absolutely the effect of each element upon the strength of steel, and no man in the world claims to know that to-day. It is right for the engineer to specify certain parts of the chemical formula, but he must leave room for the manufacturer to attain the physical results. If he specifies the phosphorus limit, he should leave the carbon open, and if he specifies the carbon he should leave the phosphorus and manganese to the manufacturer.

Following are the elements usually found in steel and the general influence they have upon the physical properties. In each case the statements are my own opinions. In a general way they will be agreed to by almost all metallurgists, as far as structural steel is concerned.

Silicon: This element is seldom present in structural steel in quantities greater than a trace, and the effect of these minute quantities may be ignored. It is present in steel castings in amounts up to four-tenths of one per cent., but its influence is not great for better or for worse.

Copper: This element has some influence on the hot properties, but not as much as generally supposed, as its effect is often masked by sulphur, with which it is generally associated. It has no effect on the cold properties as far as known.

Manganese: The most important function of this element is to give ductility while the steel is hot, so that the piece can be rolled into finished form without tearing. Ordinary structural steels contain from .30 to .60 per cent. and within these limits it has very little influence upon either the tensile strength or the ductility. Above this amount it adds to the tensile strength, but does not materially decrease the ductility. It would seem, however, to slightly increase its liability to break under shock, although this is not proven.

Sulphur: This element has just the opposite effect from manganese and makes the steel crack while it is being hot rolled. After the metal is cold it seems to have no appreciable effect upon the physical properties.

Phosphorus: This element has little effect upon the hot properties, but in the cold state it makes the steel brittle and adds to the tensile strength in about the same degree as carbon. In cther words an increase of one-hundredth of one per cent. (.01 per cent.) of phosphorus increases the tensile strength about one thousand pounds per square inch. In ordinary steels the phosphorus is always limited to one-tenth of one per cent. In special steels much lower limits are given.

Carbon: This is the one element used above all others by manufacturers in getting required physical properties. An increase of one-hundredth of one per cent. (.01 per cent.) gives an increase in tensile strength of about 1000 pounds per square inch. It decreases the ductility slightly and regularly. When steel is heated red hot and plunged in water the carbon in the metal unites with the iron in some peculiar way so as to produce a compound of extreme hardness. If the steel contain one-third of one per cent. of carbon a sharp point so quenched will scratch glass. With two-thirds of one per cent. the steel is hard enough to make common cutting tools. With one per cent. it reaches nearly its limit of hardness. This percentage is used for the harder tools, but with higher carbons the brittleness increases so fast that the usefulness of the metal is limited.

Nickel: This element in alloy with steel gives a metal with a high elastic limit and having great toughness under shock. Its principal uses are for armor plate and special forgings.

In Chapter XVII, I have given the results of a mathematical investigation into the influence of carbon, phosphorus and manganese. The method of Least Squares was used to find the most probable values assignable to the factors, and the result will be found in the following formulæ:

FORMULA FOR ACID STEEL.

$$38600+121C+89P+R=\text{ultimate strength.}$$

FORMULA FOR BASIC STEEL.

$$37430+95C+8.5Mn+105P+R=\text{ultimate strength.}$$

In these equations the contents of carbon, manganese and phosphorus are to be given in units of .001 per cent., while R is a factor depending upon the finishing temperature, and it may be plus or minus. The results would indicate that the metalloids have slightly different quantitative effects upon acid and basic steels. The figures have been applied to many thousand heats of steel since these calculations were made, and all the results seem to show the correctness of the conclusions.

Now if acid steel does not follow exactly the same law as basic steel, then it is certain that they are not the same, and if they are not the same, then it is quite possible that one is better than the other, a possibility that is vigorously denied by some people.

I have found that it takes more carbon to give a certain tensile strength in basic steel than in acid steel, and I make the argument that this is a bad thing because every increase in carbon gives a better chance for segregation and lack of uniformity. I do not say that this in itself proves basic steel to be unreliable, for nothing could be farther from the truth, but it does seem to indicate that acid steel may be preferable in some cases.

SPECIFICATIONS ON STRUCTURAL MATERIAL.

It is the custom for engineers to specify just what kind of steel they wish, and just what the physical requirements shall be. Needless to say that it sometimes happens that the engineer does not fully understand all about the different kinds of steel and does not know just what elongation and reduction of area should be obtained in each case. In such a dilemma he often takes the first specification he finds and perhaps adds to it some special idea which has been impressed upon his mind. There are many such specifications used by engineers. Some of them are antiquated and out of date, but they hold their place because the longer they have been in use the more reverence they receive from certain people, and the more proud of his work is the author. His name attached to a set of specifications is a constant advertisement, and it arouses a pardonable feeling of self-satisfaction. These conditions, however, do not serve scientific progress.

Within the last few years considerable advance has been made in getting up standard specifications. In 1895 the Association of American Steel Manufacturers adopted a certain set of specifications, and although it was claimed by some people that it was not the place of the manufacturers to do this, yet the fact remains that the users of structural material eagerly grasped these specifications as filling a long felt want, and they are the basis of ordinary business to-day.

There are two facts which may well be kept in mind:

First: The steel manufacturers in session assembled may be supposed to know something about steel.

Second: It is not for their interest to advocate a bad material. It might be for the interest of one of them to try and pass a bad lot of steel on a single contract, but taken as a whole they can have no incentive to plead the cause of something they think is bad.

The steel makers are not a unit in all matters, but they do agree in some things. Most of them believe that Bessemer steel will do for buildings, highway bridges and similar purposes. They believe that open-hearth steel should be used for railway bridges, for boilers, for locomotive forgings and other purposes where the steel is subject to vibration and shock. They believe that in such open-hearth steel the phosphorus should be lower than in the ordinary run of Bessemer steel, and that the greater the liability to shock the lower should be the phosphorus.

In some other matters they do not agree. They differ in regard to acid and basic steel, and probably always will differ as long as human nature remains as it is. It is my own opinion that acid steel, all other things being equal, is superior to basic steel, but the manufacturers being unable to give an authoritative opinion leave the matter open to the choice of the engineer, stating what the phosphorus shall be in each case. This whole subject of specifications is now under consideration by the engineering societies of our country and especially by the American Society for Testing Materials, and it will be discussed at greater length in Chapter XVIII. No ordinary specification, however, can take account of all the variations which will be found in the physical results of bars of different section, and in the chapter just mentioned I have tried to indicate what allowances should be made to cover these variations. It was not expected when I wrote these specifications that they would come into general use, but the fact remains that they show certain laws which must be recognized by the engineer and the manufacturer. These laws may briefly be stated as follows:

(1) In rounds an increase in diameter is accompanied by a decrease in ultimate strength, a greater decrease in elastic limit, an increase in the elongation, and a decrease in the reduction of area.

(2) In angles an increase in thickness is accompanied by a decrease in ultimate strength, a greater decrease in the elastic limit, and a decrease in the reduction of area, while the elongation remains constant.

(3) In plates a thickness of ⅜ inch to ½ inch should be taken as the basis.

Thinner plates will show higher tensile strength, much higher elastic limit, lower elongation and lower reduction of area.

Thicker plates will show lower ultimate strength, much lower elastic limit, lower elongation and lower reduction of area.

Narrow plates will give higher elongation and higher reduction of area than wide plates.

Tests cut crosswise of the steel will usually show lower ultimate strength, lower elastic limit, lower elongation and lower reduction of area. This is most marked in long narrow plates.

Universal mill plates will show a greater difference between lengthwise and crosswise tests than will be found in sheared plates.

(4) In channels, beams and similar sections, the tests cut from the web will follow the laws just stated for plates of medium width. In pieces cut from the flanges there will be a lower ultimate strength, a lower elastic limit, and a lower reduction of area.

(5) In eye-bars, an increase in thickness will show a lower ultimate strength and a much lower elastic limit. The elongation will decrease as the length increases so that if a length of 15 feet gives a stretch of 15 per cent. a length of 35 feet will not give over 13 per cent.

WELDING.

In the days of wrought-iron, welding was the basis of all forging and of very much structural work. To-day almost all structural members are of steel, as well as a very great proportion of the stock that is in the shop of the village blacksmith. This soft steel will weld, and the average blacksmith and machinist, to say nothing of some engineers who ought to know better, believe that a welded piece of steel is just as good, or practically as good, as a new bar. In Chapter XIX will be found data showing that while a weld is better than nothing, and while it may have half the strength of the natural bar, and may have its full strength, it does not have its toughness and is unfit to use in any place where failure will be dangerous, and where it can possibly be avoided. It is also shown that a weld of wrought-iron is entirely unreliable.

STEEL CASTINGS.

A steel casting is a mass of steel poured directly into finished shape from fluid steel made in the regular way. In this country acid open-hearth furnaces are generally used, but in Germany the basic furnace is sometimes employed. At different periods within the last thirty years the Bessemer converter has been used for this work.

One of the latest forms is known as the Tropenas process. Instead of having the tuyeres in the very bottom of the converter so that the blast goes up through the metal, the air is blown at a low pressure upon the surface of the bath. At a point from four to seven inches above this set of tuyeres is another set, which supplies air to burn the carbonic oxide coming from the metal. This upper row of tuyeres is not operated until the blowing is well under way. The lower tuyeres oxidize the carbon to carbonic oxide (CO), just as happens in an ordinary converter, while the upper tuyeres burn this to carbonic acid (CO_2). In this way there is a great increase in the amount of heat produced and the steel will be much hotter than if blown in the usual way. It is necessary to note, however, that high temperatures are considered very injurious in making steel castings of any size, and the open-hearth furnace is amply capable of turning out steel much hotter than is desired, although it is not as well fitted for making very small charges as a small converter. Further remarks on this subject will be found in Chapter XX.

In the steel foundry, it is the practice to put what are called "sink-heads" on steel castings. These are masses of metal that rise above the rest of the casting and are of such size that they stay liquid while the main body is solidifying, and the metal flows from these heads down into the casting to supply the gap made by shrinkage, and thus prevent the existence of large cavities. These "sink-heads" or "risers" must be cut off by saws or otherwise, and it often happens that the surface so exposed shows a few holes. These holes do not indicate a bad casting, as the fault is purely local.

On the other hand it often happens that the casting is machined in one or more places, and this exposes many minute blowholes. These usually are not serious, and as a rule, it may be assumed that the holes do no positive harm in themselves, but that the strength of the casting is just the same as if an equal number of holes had been bored with a tool. A mathematical calculation on this basis will generally show that these flaws reduce the strength in a very slight degree. Steel makers themselves pay very little attention to blowholes in castings used in their own work.

A steel casting of complicated shape is very likely to be internally strained by the forces at work in the cooling of the mass. Certain parts will be in tension and certain parts in compression. In simple shapes these conditions do not exist to any appreciable extent, but in complicated forms it is well to anneal the whole casting by slow heating and cooling. This process when properly conducted also entirely changes the crystalline structure of the mass and increases its ductility. The improvements invented in the last few years in the way of pyrometers allow this process to be carried out with scientific precision, instead of in the old haphazard method that often did as much harm as good.

INSPECTION.

Nothing is easier than to write in one sentence the self-evident laws that should govern the inspection of steel, for the manufacturer should supply exactly what is required and the inspector should receive nothing else. If the steel does not fulfil the specifications, it is most certainly the fault of the maker, and all the chances and losses of error should have been taken into consideration in making the contract. Moreover, the inspector is only an agent, and he violates his trust in accepting anything that falls outside the limits which, either wisely or foolishly, have been set by his principal.

These facts are patent, and it may seem strange that any misunderstanding can possibly come in their practice; but such trouble does arise, and it will be to the advantage of all concerned if the points of difference are discussed. The main causes of disagreement are as follows:

(1) Dishonesty of the manufacturers.
(2) Open disregard of specifications by the manufacturers.
(3) Bad construction of the specifications.
(4) Conscientiousness and non-discretionary powers of the inspector.

The dishonesty of the manufacturer is a sad fact which occasionally appears in evidence, but where one instance becomes known there are a dozen that escape observation, for cheating is so easy in the majority of cases, even with careful supervision, that the temptation is hard to overcome when large financial stakes are put in hazard by absurd restrictions; but the habit once formed is too easily extended from the protection of self to the defrauding of others. It is a physical impossibility for any one or any ten men to follow the material through the processes of manufacture to see that no false marking is done, and although it is true that the buyer has the privilege of investigating the steel at a subsequent time, every one knows that engineers do not go into the erecting shops and cut pieces out of the angles, each one of which is made to fit some one place in the structure, and then test and analyze the samples. Moreover, a dozen random tests would not show that some pieces were not wrongly marked, or that some of the metal was not entirely outside of the specifications.

It must also be considered that no ordinary tests can distinguish between Bessemer and open-hearth steel, or between acid and basic steel, while it is only the laboratory which can find whether the phosphorus is high or low. It is nevertheless a fraud for the maker to use one when the other is specified, and it is none the less a fraud on the part of the engineer toward all competitors for the contract if any change is made in the prescribed method of manufacture after making the award.

Inspectors should be obliged to make reports based on their own knowledge; they should know how the steel is made, and, when any fraud is suspected, should pick out the bars from which the tests are to be cut, watch these bars and see that no substitution is allowed, take drillings to unbiased and responsible chemists, and by all other means endeavor to stop the deceptions which place the honest manufacturer at a disadvantage, as well as nullify the calculations of the engineer. In so doing it is necessary to enforce the spirit rather than the letter of the law. In order to reduce the friction to a minimum, the inspector should be clothed with some discretionary power, for chemists will differ, and steel will not be absolutely uniform, and different rolled sections will give different results, but the general intention of the engineer can be carried out, and true records made of the metal which is used.

Some engineers require that inspectors shall watch every detail of manufacture by night and day. This provision may be necessary in some cases, but it is sometimes very unjust. A contract is often divided among two or more works, and it may happen that one of these succeeds in overcoming certain difficulties by ingenuity and study. Such an advantage is the rightful property of the originator, and the works making the discovery is entitled to all the gain that may result therefrom.

Under the inquisitory system just mentioned it is impossible to keep secret any detail of manipulation, since the inspectors, who travel from one works to another, will naturally carry such information, and will volunteer any assistance in their power to unsuccessful manufacturers. This may be done from the most commendable motives and it is impossible to condemn the practice, but the result is much more pleasant to Utopian philosophers than to business rivals.

The disregard of specifications by the manufacturer often appears in substituting Bessemer metal for open-hearth, or basic steel in place of acid, or in a defiant attempt to make a steel of a different chemical composition from what is required. Assuming that the physical quality is the final criterion, a steel is furnished which passes the tensile tests, and the claim is made that, since these are filled, the material must be accepted. Astonishing, absurd and untenable as this position is, there are cases where it has been taken and where the material has been accepted. Needless to say that by so doing the engineer places himself in an unfair relation to every works which made a bid on the better quality of material, and needless to say that such a transaction casts a deep shadow of doubt over the intention and the force of every clause in future contracts.

Such a concession is an open acknowledgement that the specifications were written in ignorance or error, and while it would be well if such error were recognized whenever it exists, it would also be well if carefully considered requirements were rigidly enforced. Oftentimes there are details which are plainly the result of carelessness, and these furnish an excuse for righteous wrath on the part of the manufacturer. A case of this kind occurred in filling a large contract embracing a number of foundation bolts and similar forgings. Part of these were to be made of steel running from 70,000 to 80,000 pounds tensile strength, while the rest were to be from 72,000 to 82,000. The cause of this absurdity was a change in management during the progress of the construction with a revision of the specifications, and while the requirements for a certain portion were allowed to remain unaltered, new regulations were made for exactly similar bolts and rods for the rest of the work. In this case the reason for the divergence was evidently not in any way the result of intention, but simply an accident, and yet the inspector conscientiously refused to accept steel running 71,500 pounds for one bolt, while for another, intended for exactly the same purpose, he would accept 71,000 pounds. This trouble could possibly have been remedied by a short consultation with the engineer, but in this case he was three thousand miles away and was himself but a part of a complicated system of red-tape.

The possible mistakes in the specifications call for a certain amount of discretionary power on the part of the inspector, but such power is needed also to settle some small questions of detail arising in the manufacture. Thus, during the construction of a large train shed, it was found that a few angles were needed of a certain special size and section not on hand. The labor and time necessary to put in rolls to make them would have cost many times what the angles were worth, but it was necessary to make a hard fight for permission to use some angles of the same section and the same analysis and character, but which were from one-sixteenth to one-eighth inch thicker than called for. Now, it is perfectly conceivable that in a war vessel, where every pound is figured upon, a conscientious inspector would refuse to accept anything beyond the limit, and it is also conceivable that in the building of a long-span bridge the weights of all materials should be carefully watched; but that the same care is necessary, in the face of great expense and delay, in a small-span train shed, which would never have anything to do but keep the rain from the ground beneath, is one of those preposterous conceits which could only arise from misguided honesty.

A still more striking example occurred in the assembling of the angles and plates composing certain large members where it was necessary to use a few long, narrow pieces not over one-sixteenth of an inch in thickness, as filling pieces between riveted work of perhaps one and one-half inches in thickness. Although this was simply a washer, and although any storehouse could supply perfectly suitable sheets of ordinary steel, the inspector required that the steel be made especially for the place, and that it should be just the same in chemical composition and physical characteristics as the angles and plates with which it was united, although this necessitated the making of special contracts with sheet mills and the delay of the erecting work.

The manufacturer does not like to bother the engineer with all these petty details arising from day to day, as it would be human nature for the busy man to answer after several such questions that contracts were made to be carried out. What the honest business man wants is a thoroughly competent inspector who knows how to make sure that he is getting what is called for; who may examine a turnbuckle with a magnifying glass, but pays less attention to an angle for a hand railing; who hammers a fire-box sheet until he knows it is right, but is a little lenient with a gusset-plate.

The proper way, in most cases, would be to place the whole matter of inspection in the hands of a competent man, who should have full authority to make such concessions or such extra tests as seem desirable during the progress of the work, in order that, on the one hand, the manufacturer is fairly treated, and, on the other, that the material is fully up to the standard required. Under any system, most of the routine work will probably be done by subordinates who are not qualified to decide all questions that may arise, but the chiefs of American inspection bureaus are fully capable of meeting all responsibility. They are specialists, who know much more about the quality and nature of steel than the constructive engineer who deals with the designing and construction of caissons and trusses. In this function of consulting expert to the bridge engineer, these inspectors will find that the conscientious manufacturer is their friend and not their enemy.

In former days the surface inspection of the material was the most important function of the inspector; to-day it is the least of his duties. In fact, it has become such a matter of form that there is a tendency toward its complete abolition. There is much to be said in favor of such a step, for it is acknowledged by all manufacturers that if an imperfection is discovered in any piece of steel, no matter if it has passed through the hands of a dozen inspectors, the defective member must be replaced. This is done without argument, it being recognized that the maker must stand behind his goods.

Granting this condition, it will be evident that it is far better for the manufacturer to reject all unsuitable bars at the mill than to have them thrown out after delivery at distant points, and it will therefore be to his interest to properly inspect all material before shipment. For this reason it is the universal custom at rolling mills to have certain men whose sole duty it is to examine the product as fast as it is made, and separate the defective bars. This is done after the bars are straightened, and before they reach the loading beds, so that there is no further sorting to be done in the shipping yard.

The mill inspection is so carefully done in well-conducted works that it is an unusual thing for an outside inspector to reject bars, and it would be still more thoroughly performed if the manufacturer knew that the responsibility rested with him alone. In the cases where the material is to be passed upon by an outside inspector, the natural tendency is to let doubtful bars go by, since the responsibility of their acceptance is to rest upon other shoulders.

These facts are so well known that some of the best and most careful engineers in the country, including those who are most stringent in their demands concerning the chemical and physical qualities, do not make any surface inspection, but notify the manufacturer that the entire responsibility rests with him, and that a bar showing manifest flaws must be replaced, even though it has passed through every hand and has been placed in position.

Whether this practice be generally accepted or not, it is eminently desirable that the inspection bureaus should arrange to examine the material as fast as it is made, so that the delays and expense of double handling of stock may be avoided. It often happens that such handling costs more than the inspection bureau receives for its work, and it is certainly an equitable request that some action be taken to remedy this loss. The solution of this problem lies in the coöperation of the manufacturer, the inspector, and the engineer, with a realization of the fact that the interest of one is the interest of all.

PART II.

THE METALLURGY OF IRON AND STEEL.

CHAPTER I.

THE ERRANCY OF SCIENTIFIC RECORDS.

SECTION Ia.—*Difficulties in obtaining comparative data.*—The data now available for the study of steel would be sufficient for the elucidation of every problem if it were possible to know every condition surrounding each individual case. Such perfection can never be obtained even in the most carefully conducted experiments, for it has often happened in the history of science that the most careful records of observations have failed to give what after years proved to be a vital factor, while it still more frequently happens that such omissions are due to simple oversight.

Instances of this may be found in the data collected by Prof. H. M. Howe in his great work, "The Metallurgy of Steel." On page 18, he gives a table showing the effect of hardening upon various iron compounds. Test No. 11 is a Bessemer steel with .33 per cent. carbon, 51,259 pounds ultimate strength after annealing, and 19 per cent. elongation. This is, indeed, strange metal, since the strength of the original bar is given as 70,225 pounds, so that the loss of strength in annealing was 18,966 pounds per square inch. These figures are quoted from Styffe and it is quite certain that this investigator must have noticed how far such a change varied from usual experience, and he should have recorded such phenomena as bore upon the subject.

If such omissions can be found in the work of eminent observers, very little can be expected from those who have not been trained in scientific thought, but who rush into print sometimes with the best of motives and sometimes with a purely mercenary object. The columns of the technical papers are full of data which are worthless as guide posts on the road to fact. The errors that can creep into such an investigation arise from different causes. They may come from mixing of test pieces in the shop, the testing-room, and the laboratory, or from miscalculations and mistakes in measuring and copying the figures. Instances of such blunders can be found in every establishment, and the only true remedy is the repetition of the entire work. Even when the utmost care has been exercised, the results must not be translated too literally, for there are variations which are due solely to the cumulative effect of petty determinative errors. Thus, I made the experiment of cutting six tests from the same bar and having them measured, pulled and calculated by the same man. The original piece was a rolled flat, 4 inches wide by 5-16 inch thick. This was cut lengthwise into two strips, 1¾ inches wide by 5-16 inch thick, and these strips were again cut into 18-inch lengths. Six of these, taken from alternate sides of the original bar throughout its length, were tested without treatment. The results are given in Table I-A.

Whether the determinations of sulphur and phosphorus are absolutely correct is of no importance, for it is certain that the total amount of impurity is very small, and the probable variation in chemical composition in different parts of such a bar may be neglected. In regard to the physical condition, it should be said that the piece was made from a billet, which in turn had been rolled from a 2-ton ingot; the bar was therefore more uniform throughout than any two different bars would likely be, and yet we find a variation of 1400 pounds in ultimate strength, 3030 pounds in elastic limit, 9.5 per cent. in elongation, 3.20 per cent. in reduction of area, and 4.54 per cent. in elastic ratio.

TABLE I-A.

Variations in Physical Properties of Pieces of the Same Rolled Bar.

Size of bar, 1¾″x5-16″. Composition, per cent., C (by combustion) .057, P .006, Mn .33, S .019.

No. of Piece.	Ultimate strength; pounds per square inch.	Elastic limit; lbs. per square inch.	Elongation in 8 in.; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
1	46730	33500	31.00	72.00	71.69
2	45560	32760	36.25	70.60	71.91
3	45950	34420	33.50	68.80	74.91
4	45710	32750	34.00	68.80	71.65
5	46960	35780	37.00	69.70	76.19
6	45680	33740	40.50	70.10	73.86
Average,	46098	33825	35.37	70.00	73.37

Pourcel,* citing from one of my own papers, gives results differing but little more than this to prove the non-homogeneity of steel as produced by segregation; by a strange irony of fate, he takes the records which I had confidently published to show that our steel was homogeneous and uniform. Nothing will better indicate the effect of a preconceived thesis upon the reasoning faculty.

SEC. Ib.—*Errors in chemical methods.*—Aside from the disturbing factors in the shop and testing-room, there are great and important errors in the work of the chemical laboratories. This will seem a reckless statement to those not conversant with the limitations of chemical science. The average chemist is well grounded in the belief that his determination of carbon by combustion is absolutely beyond question, and if some other chemist disagrees with him, it is the misfortune of that analyst. Not only is he quite certain of this result, but he regards his color determinations as above all but captious criticism. Such is the position of many a steel-works chemist, and the metallurgical compiler must accept his records as inerrant. It seems pertinent, therefore, to recite the following:

In 1888 the chemical societies of the world arranged among themselves to investigate the methods of steel analysis. At one of the first meetings of the American committee it was found that the different ways of determining carbon did not give concordant results, and a special investigation was instituted to discover the causes of error. The result may be told by quoting the report of Prof. Langley,† one of the committee: "It is perhaps not too much to say that sufficient work has already been done to throw doubt on the accuracy of all recent determinations made with preliminary solution of the steel in double chloride of copper and ammonium."

This opinion has been reiterated in Vol. XX, p. 242, where it is stated that all commercial chlorides of copper and ammonium contain carbon, and that their use in steel analysis gives too high a carbon percentage.‡

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* *Segregation and its Consequences in Ingots of Steel and Iron. Trans. A. I. M. E.*, Vol. XXII, p. 108.

† *International Standards for the Analysis of Iron and Steel. Trans. A. I. M. E.*, Vol. XIX, p. 623.

‡ It should be said that a pure article is now in the market, and that all chemists do not agree that the use of this reagent has caused errors of vital importance.

TABLE I-B.

Variations in the Results Obtained by Different National Committees on the Same Steel.

No. of Sample.	Nationality of Committee.	Composition, per cent.				
		C	Si	S	P	Mn
1	English,	1.414	.263	.006	.018	.259
	Swedish,	1.450	.257	.008	.022	.282
	American,	1.440	.270	.004	.016	.254
2	English,	.816	.191	.007	.014	.141
	Swedish,	.840	.185	.004	.015	.145
	American,	.800	.202	.004	.010	.124
3	English,	.476	.141	.008	.021	.145
	Swedish,	.500	.150	.006	.021	.170
	American,	.454	.152	.004	.015	.140
4	English,	.151	.008	.039	.078	.130
	Swedish,	.170	.015	.048	.102	.130
	American,	.180	.015	.038	.088	.098

Since these reports have been published, the committees have been at work, and in the *Journal of the American Chemical Society,* Vol. XV, No. 8, is given a partial report of progress, while in *The Chemical News,* Vol. LXVII, No. 1766, further results are given. Table I-B shows a condensation of the records thus far made public.

TABLE I-C.

Variations in Results of Determinations of Carbon and Phosphorus.
(Wahlberg; *Journal I. & S. I.,* Vol. II, 1901, p. 42.)

No.	Carbon.							Phosphorus.			
	Combustion.				Color.						
	Av.	Min.	Max.	Diff.	Min.	Max.	Diff.	Av.	Min.	Max.	Diff.
1	.119	.100	.156	.056	.089	.166	.068	.051	.048	.055	.007
2	.119	.105	.150	.045	.093	.158	.065	.013	.012	.015	.003
3	.147	.118	.191	.073	.120	.189	.069	.032	.031	.033	.002
4	.225	.200	.254	.054	.178	.264	.086	.029	.027	.031	.004
5	.474	.455	.489	.034	.480	.500	.020	.025	.025	.026	.001
6	.520	.490	549	.059	.515	.555	.040	.041	.039	.044	.005
7	.569	.533	.613	.080	.530	.585	.055	.027	.024	.028	.004
8	.636	.590	.692	.102	.618	.671	.053	.033	.031	.035	.004
9	.967	.880	1.060	.180	.903	.953	.050	.043	.041	.045	.004
10	.986	.881	1.050	.169	.909	1.035	.126	.024	.023	.026	.003
11	1.115	1.071	1.190	.119	1.077	1.268	.191	.029	.027	.032	.005
12	1.238	1.139	1.313	.174	1.162	1.390	.228	.031	.029	.033	.004

It must be borne in mind that these analyses were conducted under the most favorable conditions which could possibly exist.

The chemists were men of recognized and eminent ability, especially selected as worthy of their important task. Each fully understood that his reputation depended upon his report. He must agree with his co-workers or, if differing, must establish to the satisfaction of the world that his methods were right, or else that there was some disturbing factor previously unknown to the chemical world. He was not confined to any one determination, but could repeat as often as desired, and compare with the work of assistants until the record stood for his highest accuracy. Not content with assuming ordinary risks, many blank determinations could be carried through to make sure of the quality of the reagents; of the effect of varying moisture in the atmosphere; and the many minor conditions that influence solution, precipitation and absorption. With all these abnormal refinements, the carbon determinations vary in one standard from .45 to .50 and in another from .15 to .18. The other elements also show variations, and it must not be forgotten that these results are not separate and extreme instances, but that each is the average of many results and of several chemists. A table of extremes of separate determinations would be most interesting reading.

A very important investigation was made by Wahlberg* into the homogeneity of steel, the analytical work being done at four different laboratories. The chemists were of international reputation, as may be seen from the following list:

J. E. Stead, of Middlesborough.
Baron Jüptner von Jonstorff, of Donawitz.
Royal Technical High School, at Stockholm.
Hammarstroem Laboratory, at Kopparberg.

The results of their labors are given in Table I-C. It is not stated how many duplicate analyses were made, but as the determinations by color are given to three places decimal, it is quite certain that each of these figures is the average of several results. Under these exceptional conditions of extreme care and with the knowledge that the records were to go before the world, the different chemists varied to a degree which most practical men would consider entirely preposterous. The differences are not those arising from segregation, but represent results on exactly the same sample, and yet one of the soft steels is reported to hold .118 per cent. of

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* *Journal I. and S. I.*, Vol. II, 1901.

carbon, while another chemist says it contains .191 per cent. On a little harder steel the reports varied from .200 to .254; on a still harder steel from .590 to .692 and on a spring steel from .880 to 1.060, a variation of 18 points.

These differences are in determinations by combustion. In color work the higher steels varied as much as 23 points, while the difference between the results of combustion and color were as much as .026 in the case of the .20 carbon steels, and as much as .185 in the case of the hardest steels. The phosphorus was reasonably low in all the steels, but the error of analysis amounted to as much as .007 per cent. and was usually about .004. This is not startling, but under the conditions described it is not as satisfactory as might be wished.

Judging from the above data we are justified in doubting any chemical determination. Many records are published on the verbal statements of uneducated metallurgists, whose uncertain memory of facts not originally proven, is befogged by crochety prejudices. Some are taken from laboratory notebooks with too little care in the detection of clerical errors. Others are the results of methods which have been condemned by all chemists save the one using them, while still more have been obtained by methods which, though looked upon as correct at the time the analyses were made, have been found to be inadmissable. Few, very few, have been made by chemists whose work is being continually checked by the parallel results of other analysts of known excellence. Even were this last requirement met, it has been shown that scientific certainty would by no means be obtained.

From the foregoing remarks it may be seen that the comparison of miscellaneous records is perfectly useless and misleading. Even the results of two different well-conducted laboratories and works may not be trustingly placed together. This can be done if the two works in question exchange samples, and find that both obtain similar results from the same metals, but under no other circumstances is the comparison valid.

SEC. Ic.—*Necessity of uniformity in chemical work.*—It may appear that these conclusions put in question the value of chemical work, but such is not the case. The one thing desired above all others in practical manufacturing is consistency of results, and, having this quality, the absoluteness may be dispensed with. A striking example of this happened in my own experience. We discovered about twenty years ago that we had been running with an error of .11 per cent. in all our low carbon determinations, and .13 in all the high steels. Thus steel of .09 carbon had been regularly determined as .20, and .50 carbon as .63. Customers ordered steel, found it right, or found it too hard or too soft, and ordered the next lot accordingly. Years had rolled by and every customer knew just what he wanted, and could learnedly discuss the special nature of .64 and of .76 carbon. The discovery of the error in the standards was a rude shock, and the change to the new order of things was the work of many months, and a diplomatic catering to prejudice, mixed with a very strong disinclination to an open acknowledgment that we had been altogether wrong.

In these later days it is customary to have the standards analyzed by several chemists, and to take an average between results, which always differ. It has also been found essential, whenever color comparisons are to be made, that a standard of nearly the same composition be dissolved at the same time and under the same conditions as the steel under treatment. This refinement was certainly not observed in many analyses of the past.

As before noted, the errancy of the records is not confined to the carbon, for sulphur is another offender; thus in Table I-B three of the samples have only a trace at best, and hence a difference of 100 per cent. will not be discussed, but the results on the fourth sample, showing .038 by one average and .048 by another, is a more important matter. When United States Government contracts specify that sulphur must be below .04, and when steel is rejected because it shows .042 by the analysis of a naval engineer, it is time that the standard methods should not give a variation such as these records show.

The differences in silicon in the results given in Table I-B are unimportant, and the same may be said of manganese, although these determinations do not shed lustre on chemical science, but it is in phosphorus that the most astonishing revelation appears. An error of 50 per cent. in steels of about .02 is bad enough, for contracts are made with that point as a limit, but the fourth sample is a catastrophe. In the structural world the limit .10 is looked upon as the maximum percentage admissible. Some few engineers, who desire a better class of material, specify that .08 shall be the maximum. Yet so great are the errors of the highest chemical research, that this sample (No. 4) is condemned by one committee as unfit for the most common work, while another approves it as of extra quality.

SEC. Id.—*Variations in the parallel determinations of practicing chemists.*—It may be a fall in dignity to leave these determinations of the picked chemists of the world and discuss the results of everyday work, but it is assuredly of vital importance to know how much reliance can be placed upon commercial records. At a meeting of the A. I. M. E., in February, 1894, W. R. Webster recounted an investigation by Mr. Vauclain of the Baldwin Locomotive Works, wherein two pieces of boiler plate were each cut into five parts and sent to five different steel works for analysis. The greatest differences in the results were as follows:

Carbon	0.17 to 0.23	per cent.
Manganese	0.33 to 0.42	" "
Phosphorus	0.041 to 0.055	" "
Sulphur	0.019 to 0.043	" "

In commenting upon these figures, the opinion was expressed by Mr. Vauclain that the divergence was probably due more to irregularity of the steel than to chemical errors. It should be noted, therefore, that both plates had been rolled direct from small ingots.

TABLE I-D.

Comparison of Chemical Results Obtained on the same Steels by the Pottstown Iron Co. and the Pennsylvania Steel Co.

NOTE.—Steels were made by the Pottstown Iron Co.

Heat No.	Carbon, per cent.			Phosphorus, per cent.		Manganese, per cent.		Sulphur, per cent.	
	P. S. Co. Comb.	P. S. Co. Color.	P. I. Co. Color.	P. S. Co.	P. I. Co.	P. S. Co.	P. I. Co.	P. S. Co.	P. I. Co.
1022	.109	.125	.11	.033	.030	.46	.47	.064	.075
1028	.078	.095	.09	.087 .089	.110	.23	.26	.069	.090
1043	.090	.100	.10	.044 .039	.025	.31	.30	.058	.066
1069	.068	.090	.09	.064	.065	.33	.34	.064	.086
1082	.109	.120	.12	.055	.050	.34	.36	.048	.057
1084	.109	.120	.11	045	.040	.45	.46	.039	.038
1097	.094	.110	.10	.075	.075	.31	.34	.087	.098
1099	.146	.145	.13	.053	.065	.66 .67	.68	.057	.069
Av.	.100	.113	.106	.057	.057	.39	.40	.061	.072

Inasmuch as the value of many investigations in this book depend on the accuracy of chemical determinations as made at Steelton, Table I-D will be of interest as comparing the results obtained in the laboratory of the Pennsylvania Steel Company with those of the Pottstown Iron Company. The latter works is chosen on account of the investigations conducted there by W. R. Webster into the physical properties of steel. His work is discussed at length in Chapter XVII.

It will be seen that there is a difference of one point in carbon between the determinations by color and by combustion. This, usually, is of no importance, but in carefully equating the influence of elements, such a difference is of some moment. The manganese agrees very well, being sufficiently accurate for all practical purposes.

The two averages of phosphorus coincide, but the individual records show that this is purely accidental. With three exceptions, the error is not of vital importance, but this is hardly true of heats 1028 and 1043. A comparison of the results throughout the columns shows an erratic character, pointing rather to a general uncertainty than to a pronounced wrong in the chemical system. In sulphur, on the contrary, the difference seems to be fairly uniform, and the separate items, like the average, indicate a fundamental variation in the manipulation.

The variations in results between different laboratories sometimes becomes a matter of great commercial importance, as shown by G. E. Thackray,* who recites a case where the Cambria Iron Company delivered steel running from .074 to .080 per cent. of phosphorus according to its own determinations, while the buyer's chemist found it to contain from .088 to .110 per cent. Having agreed upon an arbitrator the metal was reported to hold between .063 and .087 per cent.

This experience led to the distribution of drillings from two different pieces of steel to many of the steel works and chemists of the country, and the paper just referred to gives the individual records. In the case of one piece of steel, the lowest phosphorus reported was .045, and the highest .055 per cent. In the second piece, the lowest determination was .076, and the highest .091 per cent. In commenting upon these results, Mr. Thackray considers that they are "quite harmonious" and encouraging, although he acknowledges that they "by no means approach perfection, and leave room for further improvement."

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* *A Comparison of Recent Phosphorus Determinations in Steel. Atlanta Meeting, A. I. M. E.,* October, 1895.

SEC. Ie.—*Methods by which metallurgical laws must be deduced.*—If the main causes of error which have been enumerated could be removed, the investigation of the laws that govern the physical qualities of steel would be wonderfully simplified. As it is, the published records include inconsistencies and contradictions which are almost appalling. Taking, for example, the apparently simple problem of determining the effect of carbon upon steel, we find in Professor Howe's book the following paragraph:[*] "While we cannot accurately quantify the effects of carbon upon steel, I believe that for ordinary unhardened merchantable steel, the tensile strength is likely to lie between the following pretty wide limits."

.05	carbon	between	50,000	and	66,000	pounds	per	square	inch
.10	“	“	50,000	“	70,000	“	“	“	“
.15	“	“	55,000	“	75,000	“	“	“	“
.20	“	“	60,000	“	80,000	“	“	“	“
.30	“	“	65,000	“	90,000	“	“	“	“
.40	“	“	70,000	“	100,000	“	“	“	“
.50	“	“	75,000	“	110,000	“	“	“	“
.60	“	“	80,000	“	120,000	“	“	“	“
.80	“	“	90,000	“	150,000	“	“	“	“
1.00	“	“	90,000	“	170,000	“	“	“	“
1.30	“	“	90,000	“	115,000	“	“	“	“

These wide generalizations are of interest as showing the extremes which have been recorded, but in order to deduce a law, it is necessary to compare metals which have been made by the same process, analyzed by the same laboratory, rolled under the same conditions, and tested in the same way. With records so collaborated, the deductions are of the highest value, even though the results are not strictly comparable with those of other investigators.

Not only are carefully recorded experiments to be accepted, but much virtue should be accorded the unformulated generalizations of experience. The advances in metallurgical science are seldom due to special investigations. These are usually the exponents, not the causes, of progress, and they refine, rather than create, the methods of procedure. Not one man in a hundred has ever put down on paper a graphic proof that carbon strengthens steel; by long experience that fact was discovered without the plotting of a curve, and without any careful isolation of this element from all confusing conditions.

Running along in the mind of the practical man is a long series

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[*] *The Metallurgy of Steel,* p. 16.

of results, some of them complicated with high manganese, some with high phosphorus, some with abnormal rolling, some with erratic analysis; but, just as in the wildest resonance of orchestral music a simple air may ring out clearly above the swelling diapason, so are the fundamental facts of science seen by the observant mind amid a multitude of accidental conditions, with a clearness which mathematics may not explain.

Such opinions must not be taken as final, but there is a vast difference between proving the truth in a disputed issue and verifying an accepted theory. Most of the experiments given in this book are merely illustrative of laws which are commonly received in the metallurgical world. They try to value the factors whose existence is already conceded. There are many things in the manufacture of steel which we do not understand. There are still improvements to be introduced and discoveries to be made; but the work is all surveyed; the mysteries have been swept away. The making of steel was once a trick; it was then an art; it is now a business.

CHAPTER II.

THE BLAST FURNACE.

SECTION IIa.—*Iron ores used for smelting.*—Three kinds of ore are used in the making of pig-iron: carbonates, hematites and magnetites.

(1) Carbonate ($FeCO_3$), called also spathic ore, or black-band, or clay-band, or clay iron stone, contains when pure only 48.28 per cent. of iron and is usually roasted to expel the carbonic acid before being charged in the blast furnace. In the United States it occurs widely distributed throughout the coal measures, but it is usually impure and has been driven from the market by richer ores. The most notable deposits of carbonate are in the Cleveland district of England, in Spain, in Bohemia, in Hungary, and in Styria. In most cases it is out of the question to transport spathic ore any great distance. The carbonic acid contained is clear loss, and if the ore is carried in its raw state, then freight must be paid on this waste material. If, on the other hand, it is roasted at the mines, then coal must be carried there to do the work, unless it so happens that the coal is near the mines, in which latter case there is generally no necessity for shipping the ore away.

(2) Hematite (Fe_2O_3) is the ferric oxide and contains when pure exactly 70 per cent. of metallic iron. It occurs sometimes as specular hematite, the fracture presenting a black, shining, crystalline appearance, one of the most beautiful instances of this being seen in the ore from the Island of Elba. More often the color is a reddish brown, or yellow, in which latter case the ore is pretty certain to contain some combined water. The accidental moisture can be driven off by exposure to a temperature of 212° F. (100° C.), but the combined water remains as an integral part of the chemical compound, the percentage of this combined water varying from zero in the specular hematites to over 13 per cent. in the less crystalline varieties. Mineralogists have classified these minerals according to their content of com-

bined water, but it is customary to speak of the purer kinds as "red" or "brown" hematites, while the more hydrous ores are called "soft" hematites or "limonites." This latter term should be applied only to bog-iron ore containing over 20 per cent. of water, but the above classification has been sanctioned by custom and by the Census Bureau.

The best known deposits of hematite are as follows: The Lake Superior region, which alone supplies as much ore as is produced in any other country; Alabama, which has an immense deposit of extremely lean ore; the Bilbao region in Northern Spain; the southeast coast of Cuba; the Minette district of Lorraine, Luxemburg, France and Belgium; the west coast of England; the basin of the Don in Southern Russia; the Ural Mountains; the Tafna beds in Algeria; the newly opened mines in Newfoundland, and the now almost exhausted mines of Elba.

Oolitic ore is a variety of hematite which cannot be called a distinct kind of ore like carbonate, or magnetite, but which is constantly referred to in scientific literature and which must be mentioned on account of its importance. The term "Oolitic" means that it is in the form of small spherical grains, each grain being composed of a kernel of foreign matter surrounded by iron ore. If the foreign matter be silica, the ore is usually worthless, but if it is limestone it may be valuable, even though the percentage of iron be low, for this lime reduces the quantity of limestone needed in the blast furnace, and if present in sufficient quantity, the ore may be "self-fluxing," that is to say, it contains so much lime that it is unnecessary to add any limestone in the furnace. Many ores contain more than enough limestone and must be mixed with others more silicious.

For this reason it is entirely wrong to regard the percentage of iron in such an ore as the sole index of the quality, as the real ground of comparison is the percentage of iron in the sum total of ore and limestone. Thus, if an ore should contain 40 per cent. of iron and sufficient lime to be self-fluxing, it is actually just as valuable as an ore containing 50 per cent. of iron and no lime, but carrying so much silica that one-quarter of a ton of limestone must be added for every ton of ore. In both cases the total of ore and stone gives an average of 40 per cent. of iron. On this account, there is much misunderstanding about the poverty of the ores in certain districts.

One of the principal deposits of oolitic iron ore occurs in Alabama, but it is very high in silica and most of it is worthless until some method is found to enrich it by concentration; another deposit is found in the eastern central part of England; another, and the most important of all, spreads over the junction of three nations and forms the basis of the iron industry in Belgium, France, Luxemburg and Western Germany.

(3) Magnetite (Fe_3O_4) contains 72.41 per cent. of metallic iron when chemically pure, and is regarded as a chemical union of the ferrous oxide (FeO) with the ferric oxide (Fe_2O_3). Its distinctive characteristic is its attraction for the magnet, although, in this respect, it differs in degree rather than in kind from other iron oxides, for it is now proven that the other oxides are quite susceptible to magnetic influence. It is also certain that magnetite and hematite shade into one another so that no line can be drawn between them, and that some ores which have been called hematites are really magnetites. It is the general opinion that a true magnetite requires more coke in the blast furnace than a hematite on account of the greater difficulty in reduction.

The main deposits of magnetite are found in Central and Northern Sweden, the deposits being extremely rich in iron. In this respect they differ widely from very extensive deposits occurring all over the eastern portion of New York, New Jersey and Pennsylvania. These deposits are extremely poor, but are of such extent that great effort has been made to make them available by magnetic concentration. Edison has spent vast sums of money and years of work upon the problem, but it will hardly be a surprise to hear of failure when it is known that the ore treated by him was a hard sandstone rock carrying only 18 per cent. of metallic iron. The work was perfectly successful from a technical point of view in that concentrates were regularly made containing from 60 to 65 per cent. of iron with the phosphorus down to about .02 per cent., but one great difficulty was to brick the fine product, while the greatest was to do the work and compete with the ores of Lake Superior, which every year came cheaper and cheaper to the furnaces of the East.

To separate the magnetic particles from the sand or from the phosphate bearing minerals, the ore must be crushed fine enough to have each mineral in separate particles, and it is perfectly clear that the finer the ore is ground the better will be the product and the purer the concentrate. It is also perfectly clear that under present conditions this finely ground product cannot be used directly in the blast furnace as a large proportion of the burden, and that some means must be found to put it into the form of bricks.

The strength of the brick required depends upon the operating conditions; certain Swedish furnaces have utilized successfully a brick which would not be hard and strong enough to resist the much greater pressure in the high and fast driven furnaces of America. It has been proposed to melt the fine concentrate by passing it between the poles of an electric arc, but this involves the expenditure of so much power per ton of product that it is doubtful if it will come into general use.

Sec. IIb.—*Fuel used in smelting.*—

(1) *Charcoal:* The primitive fuel is charcoal and this is still used in some localities owing to the demand for charcoal iron. Such iron, however, may be left out of the question as far as the manufacture of steel is concerned, except in Sweden and the Ural Mountains, where no other fuel is available.

(2) *Hard Coal:* The term "hard coal" or "anthracite" is one meaning different things in different places. It generally means the "hardest" kind of coal known in the district. In America we have a coal which has been subjected to a severe geological history and has had practically all the volatile matter driven out, leaving nothing but fixed carbon and ash. It is as solid as limestone and is entirely without pores. Such coal is unknown in Europe, except in South Russia, and when "anthracite" is mentioned in foreign writings there is generally meant a semi-bituminous coal.

This hard anthracite above described is found in Eastern Pennsylvania, and is used almost exclusively for household purposes, although the smaller sizes are used for firing boilers. A generation ago it was used in blast furnaces, and now sometimes constitutes a part of the charge, but it does not give good results when used alone. Being non-porous, it cannot burn rapidly and must flake off in layers and if it disintegrates, it will clog the furnace. The statistical records of American blast furnaces always speak of "anthracite" furnaces, but this is misleading, as the furnaces so classified use only a small proportion of anthracite and many of them have used none at all for many years.

(3) *Raw Coal:* In Scotland it is the custom to use raw coal, but this is because there is but a small proportion of volatile mat-

ter, and this enriches the gas from the top without seriously troubling the working of the furnace. In almost all other districts the use of raw bituminous coal has been discarded in modern practice.

(4) *Coke:* The use of coke for smelting is almost universal, and the working of the blast furnace depends on its quality as much as upon the quality of the ore. It is possible, however, to do well even with inferior material. In America the deposits of Connellsville have been so abundant, the cost of transportation so low, and the quality so good that they have dominated the situation in the North and East. The West Virginia beds have come to the front in recent years, but they are of the same high quality. Some furnaces of Eastern Pennsylvania have used the poorer cokes of the central part of the State, but with the exception of Alabama, the great producers of our country have never faced the necessity of using an inferior fuel. In the Cleveland district of England the furnacemen have had the renowned Durham coke, and in the Rhenish provinces of Germany the coke of Westphalia is very good, but in other districts, as in Silesia and the Saar, the coal gives a poor coke, which American furnacemen would call worthless, and yet the fuel consumption is not high and the furnaces run regularly. In Chapter IX the manufacture of coke from inferior coal is further discussed.

SEC. IIc.—*Flux.*—In exceptional cases an iron ore containing no lime may be smelted without the addition of any flux. An instance of this is mentioned by Bell, who gives the slags as having the composition shown in Table II-A.

TABLE II-A.

Slags made by Smelting Ores without Lime.

SiO_2	49.57	48.39
Al_2O_3	9.00	6.66
MnO	25.84	33.96
MgO	15.15	10.23
S	.08	.08
FeO	.04	.06

Omitting these cases, which are merely curiosities, limestone either as part of the ore or as a separate addition is a component part of the charge. Sometimes, as in the case of the Cleveland ore, the earthy impurities would make a perfectly fusible slag without such an addition, but the lime is necessary to carry away the sulphur contributed by the fuel and the ore in order to get an iron free from this element.

Limestone occurs so universally that it is usually possible to get it in a reasonably pure state, but it always contains some silica and oftentimes magnesia. The latter element has been the cause of much controversy. Ledebur* says: "For the production of pig-iron low in sulphur, pure limestones are to be preferred to those containing magnesia."

Bell† confirms this: "Lime has at high temperatures a certain affinity for sulphur, whereas magnesia has little or no action on it."

Firmstone‡ has reviewed these and other condemnatory opinions and argues that magnesia has been treated with injustice and that "under certain circumstances at least the sulphur in the pig is *reduced* by substituting dolomite for limestone containing about 5 per cent. of magnesia." It was found possible to run with a lower percentage of silica in the slag and still have the cinder retain its fluidity. With pure lime and a silica content of 39 to 40 per cent., the cinder "slacked," but with dolomite, the silica could be reduced to 35 per cent., and the furnace worked much better.

Phillips§ regards magnesia as a benefit and says: "It may be regarded as practically settled that as a desulphurizer in the blast furnace, dolomite is quite as efficient as limestone for ordinary grades of iron, and much more efficient for basic iron requiring unusually low sulphur."

The probable explanation of the contradictory character of these opinions was pointed out by Firmstone.|| He refers to various investigators who had shown that a high content of magnesia gives rise to the production of spinel, an infusible and insoluble compound of alumina, lime and magnesia, and he argues that the formation of this compound depends upon the presence of a large proportion of alumina as much as it depends upon the presence of magnesia. From this he reasons that if the ore contain only a small proportion of alumina, a considerable proportion of magnesia will give no trouble, the proportions being so regulated that when the slag from the furnace contains over 20 per cent. of magnesia, it

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* *Kaernther Zeitschrift,* No. 2, 1881, p. 53.

† *Manufacture of Iron and Steel,* p. 58.

‡ *Trans., A. I. M. E.,* Vol. XXIV, p. 498.

§ *Iron Making in Alabama; Ala. Geol. Survey,* 1898, p. 73.

|| *loc. cit.*

shall not contain over 10 per cent. of alumina. Whether this be the whole explanation or not, it is quite certain that furnaces in Eastern Pennsylvania, New Jersey and Alabama have used for many years a limestone containing from 5 to 20 per cent. of magnesium carbonate without any noticeable increase either in the quantity of stone or fuel, and without any trouble from sulphur.

The most objectionable component of limestone is the carbonic acid. In pure stone ($CaCO_3$) this gas constitutes 44 per cent. of the total weight, and the only part of the flux which is of any use is the 56 per cent. of CaO. This gas is expelled from the stone at a full red heat and consequently the action takes place as the stock sinks down in the blast furnace, the exact point depending on the conditions under which the furnace is operating. If the gas merely left the stone and went off unchanged, little harm would be done, but it undergoes decomposition. It has been stated that it does not leave the stone until the temperature is above redness, and at this temperature carbonic acid acts upon the coke. The reaction is as follows:

$$CO_2+C=2CO.$$

Thus each pound of carbon in the carbonic acid, which is to say each pound of carbon in the limestone, absorbs a pound of carbon from the coke and carries it away in the gases. These gases may be used to create heat or power after they have left the tunnel head, and the carbon utilized in that way, but as far as the furnace itself is concerned, this carbon is irrevocably lost. If 750 pounds of limestone are used for each ton of pig-iron made, this stone will contain 90 pounds of carbon and it will carry away 90 pounds of carbon from the fuel, or about 100 pounds of coke. If the proportion of limestone be doubled on account of impure ores, there will be an additional loss of 100 pounds of coke. Thus an ore containing high silica involves a large consumption of fuel, not only on account of the larger amount of impurities to be smelted, but on account of the greater amount of limestone needed and the consequent waste of fuel.

In order to prevent this waste, it has been the practice in some localities and at some furnaces to burn the limestone and expel the carbonic acid before charging into the furnace. This apparently simple answer proves to be at the best an unsatisfactory one, even if it is an answer at all. In the first place, it is impracticable to expel all the carbonic acid and, in cases cited by Bell, the weights of burned lime charged when compared with the usual practice with raw stone indicated that only about half of the gas was driven off by the calcining, so that all the labor and fuel were expended to get only half the hoped for result.

But even this might be economical if the furnace practice showed the gain that theory would call for, but such gain is not always shown, and there are good reasons why it will not appear. When the burned lime is charged into the tunnel head, it is exposed to the action of a gas containing a considerable proportion of carbonic acid (CO_2). This is exactly the gas that has been driven from the stone in the kiln; but at lower temperatures, below a red heat, there is a complete reversal of affinities and caustic lime absorbs CO_2 with avidity. Consequently when this burned lime has been in the furnace for sometime and has sunk downward with the rest of the stock, it has become reconverted into limestone and all the work of the kiln has been undone. This artificial limestone must be broken up again farther down in the furnace, just as if raw limestone had been charged. It is true that energy cannot be lost or gained by any such action, but although this is true theoretically at all times, it is also sometimes true that there is a wrong way of doing things, and the above described action is wrong from every point of view. The upper part of a furnace has a certain amount of sensible heat to spare, and any way of using this heat will be an economy, but the combination of lime and carbonic acid does not absorb heat, but creates it, and it creates it where it does no good at all. When raw limestone is added it is calcined by the excess heat and the result is a lowering of the temperature of the tunnel head gases, and although this is theoretically a loss, it is practically a matter of small moment as far as the absorption of sensible heat is concerned. The loss by absorption of carbon, however, is not a small matter, and as the CO_2 is not driven away from the CaO until it reaches a point where it is impossible for CO_2 and C to exist side by side, it would seem as if there was little hope of preventing the waste of fuel involved in the use of either limestone or caustic lime.

These arguments were elaborated many years ago by Sir Lowthian Bell, but they have not been accepted as final by everybody, and some furnaces in the Cleveland district have made a regular practice of calcining the limestone, or at least a part of it. One of the chief exponents of this system was Charles Cochrane, one of the great ironmasters of Middlesborough and the author of many valuable metallurgical articles. In a paper presented only a few days before his death* he gave the comparison between a furnace running on burned lime and raw stone, and showed by elaborate calculation that calcining resulted in a very considerable reduction in the coke consumption.

The conditions in the Cleveland district offer every opportunity to discover the facts in the case, for although Cochrane's experiments were carried on with the richest ores in the beds, the amount of limestone used was 1560 pounds per ton of iron made. It goes without saying that if the margin of gain is so narrow that it needs rigid investigation to prove its existence in Cleveland, it would be impossible to show any advantage when the amount of stone is only half as great. But it also would seem that if a gain can be proven in the Cleveland district, there would also be a gain anywhere, whether this gain would be visible or not. This last conclusion, however, has limiting conditions. In the first place the burden now used in the eastern part of the United States is arranged to carry as large a proportion of fine Mesabi ores as the furnace can successfully handle. The substitution of fine burned lime in place of lumps of stone would probably decrease considerably this allowable proportion of fine ore. Moreover, the furnaces in America and some of the later furnaces abroad are blown much harder and at much higher pressures than most of those of the Cleveland district, and under these conditions of rapid driving a very considerable proportion of this finely divided burned lime would be carried away by the tunnel head gases through the downtakes into the ovens and under the boilers, and the loss from this source would undoubtedly counterbalance any gain. Possibly for these reasons, and possibly on account of conservatism, the use of burned lime, although quite ancient, seems to make no progress.

SEC. IId.—*Construction and operation.*—It was proven a generation ago that a blast furnace eighty feet high would give better fuel consumption than one fifty feet high, but the changing of a furnace is such an expensive operation, often requiring the complete destruction of existing plant, that many furnaces exist to-day in well equipped plants of Europe and America varying from fifty to seventy feet in height, and some of them are doing excellent work.

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* *Journal I. and S. I.,* Vol. I. 1898, p. 69.

On the other hand many of the newer furnaces in America are one hundred feet high, although the very latest experience indicates that ninety feet is about right. The immense product of the larger American furnaces depends upon the amount of air delivered to the tuyeres, and it is easy to see that with a furnace of given height and given cross sectional area, the delivery of twice the volume of air means that the gases burned in the furnace are in contact with the ore only one-half the time, and consequently there is only half the opportunity for reduction of the iron oxide by these gases. In order to give the same opportunity for reduction with twice the quantity of air we must double the cubical contents of the furnace either by doubling the height or by doubling the cross sectional area, or by enlarging both height and diameter.

There is a limit to the possible diameter of the furnace at the level of the tuyeres, as it is necessary that the blast should penetrate to the center of the furnace, and an increase in diameter necessitates a corresponding increase in the pressure of the blast in order to get this penetration. There is a limit to the diameter above the tuyeres, as it is necessary to have the angle of the bosh just what experience has proven to be best, and there is a limit to the extension of the slope of the bosh outward, as the walls must be drawn in above the bosh to give a small opening at the bell. Were it not for these conditions, the bosh might be indefinitely enlarged by increasing the height of the furnace, the inwall angle remaining constant. Thus in a furnace 80 feet high if the lines are such that the widest part of the bosh is 23 feet in diameter and the tunnel head is 15 feet, and the distance from the tunnel head down to the widest part is 40 feet, then if the diameter of the bosh be increased three feet to 26 feet, and the slope of the inwall be maintained, it will be necessary to increase the height 15 feet to get the same diameter at the tunnel head.

There is a limit to this increase in height both on account of the increased blast pressure required and the crushing of the coke by the weight of the column of stock. Thus all the factors enumerated must be considered as parts of one great problem, and with them must be taken into account the kind of ore used, and whether it is reduced easily or only after long exposure to reducing gases. Disastrous results have followed the introduction of so-called American practice into some European works because only one part of the practice was introduced at a time, and nothing else was made to fit. It is idle to take a furnace that has been running for thirty years on a production of seventy-five tons per day, and suddenly blow three times the amount of air at three times the pressure, and expect three times the product with a reduced fuel consumption and no mishaps. Such things have been done and such expectations treasured, and when the results were bad "American practice" was blamed, but it should be known that American practice is an evolution from failures as well as successes; it is the result of changing the blast to suit the hearth and the hearth to suit the blast; of changing the bosh to suit the hearth and the hearth to suit the bosh; of changing continually, and at enormous cost, to strengthen weak points and improve strong ones, until a furnace is obtained that makes six hundred tons per day and economizes both labor and fuel. With a furnace producing such a quantity it is economical to provide expensive machinery for handling the stock, when with a furnace making only one-third this quantity the interest and depreciation on the installation would be greater than the saving.

Such a furnace has its difficulties, for if it makes 600 tons of iron in twenty-four hours, it must handle nearly 1000 tons of ore, 500 tons of coke, and 300 tons of limestone, or 1800 tons of material every day, and it is a problem to get this up to the tunnel head and never have the machinery out of order. Moreover, in the greater part of the United States the ores come from Lake Superior and must be brought down the chain of lakes during the open season from May to November, so that the ores must be stocked in sufficient quantity to last from the late fall until early summer, or about six months supply. This means that a furnace such as above described must have an ore pile containing 200,000 tons of ore within reach, and provision must be made during the summer for unloading this quantity in addition to an equal quantity required by the furnace, and for loading it in the winter, in spite of snow and ice, and carrying it to the hoist. This problem is one which does not confront furnacemen in most European districts, and hence there is no reason for the enormous and expensive installations that may be seen in some American works.

The blast pressure under American practice is about 15 pounds per square inch, equal to one atmosphere, although in exceptional cases it may rise for a short time to two atmospheres, the engines being designed to work at this load. The fundamental point is to deliver exactly the same amount of air to the furnace each minute without any regard to a scaffold or other irregularity of the internal conditions. In ordinary European practice the blowing engines are all attached to one common main, and it is evident that if a furnace is slightly out of order and ten pounds pressure is needed, and if the supply in the main is at a pressure of only five pounds, the furnace in question will receive very little air and cannot be expected to make iron. It has taken a great many years for furnacemen to discover this simple fact, but all up-to-date plants are now constructed so that each furnace has its own blowing engine.

The working of the furnace and its life depend fundamentally upon the preservation of the lines from the hearth to the upper part of the bosh, or in other words, in the region where the stock is melted and where the lining will be eaten away unless precautions are taken. In America it is quite common to use "bosh plates," which are water-cooled bronze plates set into the brick work in such manner that they receive all the abrasion and the melting action of the stock, and thus prevent any change of the bosh. At The Pennsylvania Steel Works at Steelton we have used in place of this construction a continuous jacket of rivetted plate, against which jets of water are constantly thrown. The brick on the inside are only nine inches thick, so that it is impossible for the lining to wear more than this amount without having the stock in contact with the cooled plate, and before this contact happens, there is a deposit of carbon on the plate which protects the iron and acts in place of brick. This construction gives a smooth surface on the incline of the bosh, while the bronze plates gives a serrated surface, which must interfere more or less with the free descent of the material.

The stoves for heating the blast have increased necessarily with the size of the furnaces and the amount of air supplied. According to present American practice, a furnace making three hundred tons of iron per day should have four stoves, each 20 feet in diameter and 85 feet high, while for furnaces of larger capacity the stoves are made 22 feet in diameter and 110 feet high. In some places in America it has been found best to keep the temperature of the blast down to about 1000° F., for with higher temperatures the furnace hangs and slips, probably from the development of an intense heat at too great a distance above the tuyeres and a consequent sticking of the stock to the bosh, but this trouble appears only in the largest furnaces and where the fine Mesabi ores constitute a considerable proportion—say 40 per cent.—of the burden. The temperature is kept down by admitting cold air with the hot blast in the right proportion, this practice having the great advantage

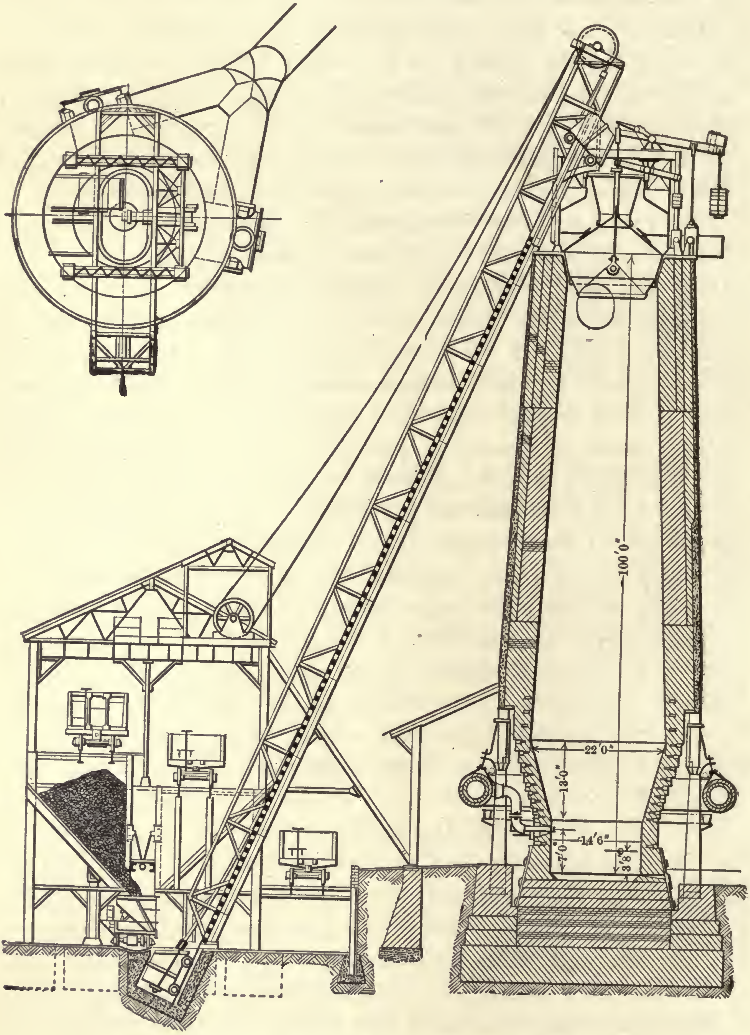

FIG. II-A.—BLAST FURNACE AT JONES & LAUGHLINS, PITTSBURG, PA.

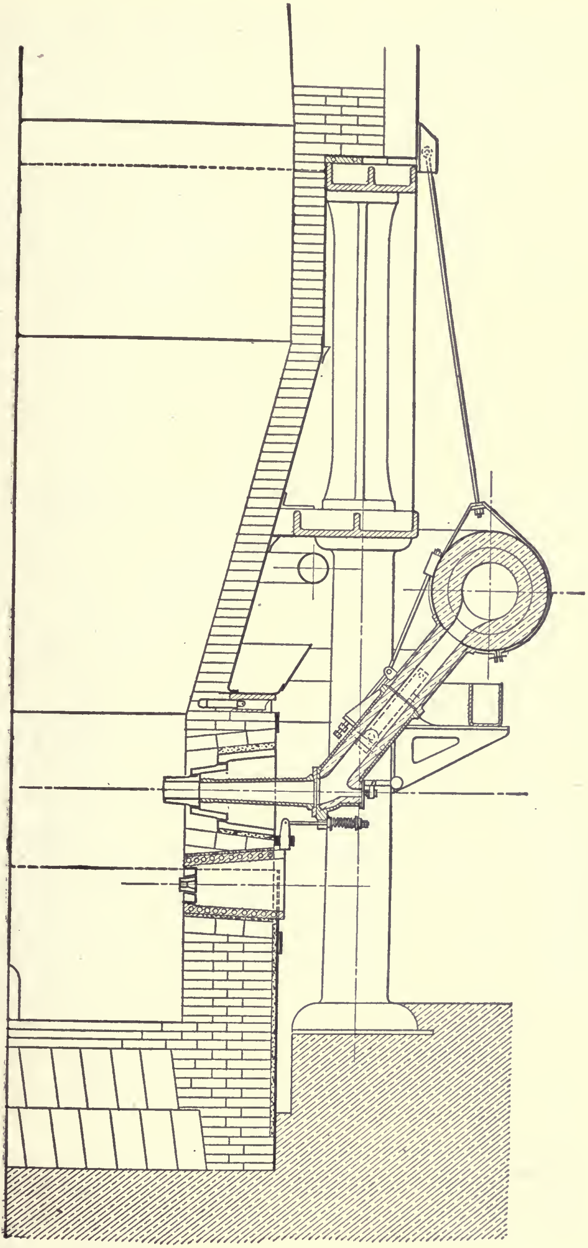

Fig. II-B.—Bosh Construction at Steelton, Pa.

that there is always a reserve supply of heat to call upon, for if the furnace shows signs of growing cold it is only necessary to close the cold air inlet to immediately raise the temperature of the blast. In many parts of America this practice is not followed and the blast is heated to 1400° F.

Fig. II-A is taken from *The Iron Age* and shows the "Eliza" furnace of Jones & Laughlins, Pittsburg, Pa. This is the usual American construction with water-cooled plates set into the bosh walls. Fig. II-B shows the method of constructing the bosh at Steelton, no water plates being used, the lines being preserved by a casing of rivetted steel plates on which water is sprayed constantly. The lining of this casing is made very thin, as it is inevitable that any lining, no matter how thick, will wear down very close to the water cooled sheet, and if the brick work be put in very thick, the lines of the furnace will be materially altered after it is worn away, while with a thin wall, preserved by the cooling, the lines remain nearly constant. This construction gives a smoother interior surface for the descent of the stock, for in the first method of horizontal water-cooled plates, the bricks wear away between the coolers and the interior surface is thus a series of small terraces and corrugations, while under the second method no such conditions can exist.

Fig. II-C gives a drawing of the Bertrand blast furnace top used at Kladno, Bohemia, which is intended to overcome the carrying of dust into the down takes. The ore at Kladno is roasted and then leached to remove sulphur and goes to the furnace in a fine state and saturated with water, but this moisture did not prevent considerable trouble from flue dust, and Mr. Bertrand devised this method of avoiding it. From personal, but very limited, observation I believe that it settles the dust problem at Kladno quite perfectly, and it seems important to consider it in connection with Mesabi ores and also in the use of furnace gas for gas engines, but it must be remembered that at Kladno the saturated ore tends to give a very cool top and consequently the iron work is not subjected to the higher temperatures obtained in some other furnaces. The method of operation is as follows:

The ore falls from the bell, B1, on the distributing bell, B2, and thence down the annular space around it, the gases from the stock finding outlets through the hollow arms, A, all these gases finally reaching the concentric passage, C, from which it goes to the down takes. The arms, A, are open at the bottom, but the ore is maintained at such a level that this opening is sealed by the stock, so that there is no current of gas immediately above this level and the ore and coke fall into a dead space, the only dust being what arises from the slow descent of the column as it passes below the opening in the under side of the spokes marked A. It may be objected that this construction does not give a good chance for explosion doors to take care of the slips. It is generally considered necessary in America to give ample area for the exit of gases in case of such

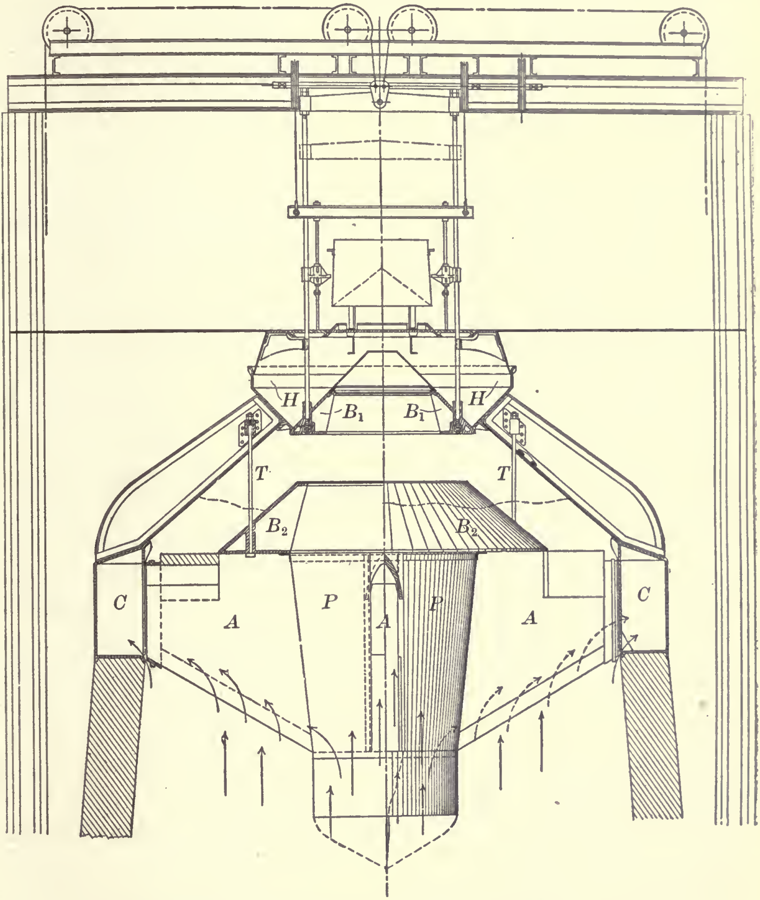

FIG. II-C.—BERTRAND BLAST-FURNACE TOP.

slips, but it is interesting to note that the well known American engineer, Mr. Julian Kennedy, has taken the opposite view, and considers that such openings do much harm by relieving the pressure and thereby encourage a rapid passage of the gases through the furnace, with consequent ejection of the stock. He believes that the true solution is to hold the top securely and allow no explosion doors, thus preventing such rapid escape and keeping the stock in the furnace. This theory has been partially tested in some recent furnaces, but the results are not yet conclusive.

SEC. IIe.[1]—*Chemical Reactions in a Blast Furnace.*—A blast furnace may be looked upon as a colossal gas producer, in which there is a column of coke 70 ft. high ranging in temperature from a white heat at the tuyeres to a black heat at the tunnel head. As soon as the air strikes the white-hot coke there is an immediate formation of carbonic acid, followed by an instantaneous reaction, by which the carbonic acid so produced unites with more carbon to form carbonic oxide. This reaction is consummated very quickly and with thoroughness, so that if the furnace held only coke, the gas coming from the top would be almost entirely carbonic oxide and nitrogen, but the furnace contains also iron oxide, and this complicates the matter very materially, for the carbonic oxide reacts upon the oxide of iron, forming carbonic acid and metallic iron. The reactions between carbonic acid (CO_2), carbonic oxide (CO), carbon, ferric oxide (Fe_2O_3), ferrous oxide (FeO) and spongy iron (Fe) are dependent upon the temperature and upon the exact composition of the gases. The phenomena were thoroughly investigated by Bell many years ago, and Fig. II-D as well as the following discussion is founded on his experiments.

Carbonic oxide begins to reduce Fe_2O_3 at about 250° C. (480° F.), but the action is not rapid until a temperature of 400° C. to 450° C. is reached (say 800° F.), when the Fe_2O_3 is converted into Fe_3O_4, or after longer exposure, to Fe_6O_7. Following are some of the chemical relations between carbonic oxide and the usual iron oxides in the order in which they occur in the blast furnace:

$$(1)\ 3\ Fe_2O_3+CO=2\ Fe_3O_4+CO_2.$$
$$(2)\ Fe_3O_4+CO=3\ FeO+CO_2.$$
$$(3)\ FeO+CO=Fe+CO_2.$$

Each of these is exothermic—i.e., it produces heat.

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[1] I am indebted to Mr. J. W. Dougherty, superintendent of the Pennsylvania Steel Co., at Steelton, for a careful supervision of this section.

FIGURE II-D.

Blast Furnace Reactions as Determined by the Temperature.

Note.—The word "complete" means *practically* complete.

1000°C	$CO_2+C=2CO$
950°	
900°C	
850°	
800°C	$CaCO_3=CaO+CO_2$ $FeO+C=Fe+CO$ (complete)
750°	
700°C	$FeO+C=Fe+CO$ (begin)
650°	
600°C	Carbon deposition ceases $Fe_3O_4+CO=3FeO+CO_2$ (complete)
550°	$CO_2+C=2CO$ (begin)
500°C	
450°	$3Fe_2O_3+CO=2Fe_3O_4+CO_2$ (complete) $Fe+CO_2=FeO+CO$
400°C	$Fe_2O_3+3C=2Fe+3CO$ (begin) $3Fe_2O_3+CO=2Fe_3O_4+CO_2$ (rapid)
350°	
300°C	$Fe+CO_2=FeO+CO$ (begin)
250°	$2Fe_2O_3+8CO=7CO_2+4Fe+C$ (begin carbon deposition) $3Fe_2O_3+CO=2Fe_3O_4+CO_2$ (begin)
200°C	

Carbon begins to reduce Fe_2O_3 at about 400° C. (750° F.). The reactions between carbon and the usual oxides are as follows:

(4) $Fe_2O_3+3\ C=2\ Fe+3\ CO$.
(5) $Fe_3O_4+4\ C=3\ Fe+4\ CO$.
(6) $FeO+C=Fe+CO$.

Each of these reactions is endothermic—i.e., it absorbs heat.

The carbonic acid (CO_2) formed by the reduction of iron oxide by carbonic oxide (CO), or by carbon, is an oxidizing agent, and by a change in temperature there may be a complete reversal and undoing of the reduction just performed, according to the following reactions:

(7) $2\ FeO+CO_2=Fe_2O_3+CO$.
(8) $2\ Fe+3\ CO_2=Fe_2O_3+3\ CO$.

The first creating a large amount of heat and the second absorbing energy.

These reactions depend upon both the temperature and the dilution of the gas with carbonic oxide. At high temperatures the action is strong and considerable carbonic oxide must be present to avoid reoxidation. The main landmarks of the relations may be thus summarized:

(a) Carbonic acid (CO_2) begins to oxidize spongy iron at 300° C. (570° F.).

(b) Carbonic acid (CO_2) begins to unite with carbon at 550° C. (1020° F.), and the reaction is complete at 1000° C. (1830° F.).

(c) The reduction of metallic iron depends upon the percentage of carbonic acid (CO_2) in the gases, but the critical content of CO_2 depends upon the temperature, as follows:

At a white heat a gas containing $CO_2=10\%$, $CO=90\%$, will not reduce metallic iron from the oxide.

At a full red heat a gas containing $CO_2=32\%$, $CO=68\%$, will not reduce metallic iron.

At a low red heat a gas containing $CO_2=60\%$, $CO=40\%$, will not reduce metallic iron.

A mixture of $CO_2=50\%$, $CO=50\%$, passed over spongy iron at a white heat oxidizes it to FeO, while if passed over Fe_2O_3 reduces it to FeO.

It is essential to remember that the reactions in the upper part of the blast furnace are not made up of simple processes of reduction like reactions (1) to (6) or oxidations like (7) and (8). While these actions are progressing there is a deposition of carbon according to relation (9),

$$(9)\ 2\ Fe_2O_3+8\ CO=7CO_2+4\ Fe+C,$$

It is stated by high authority that carbon deposition cannot take place without a contemporaneous oxidation of metallic iron by carbonic acid (CO_2), or by carbonic oxide according to the relation (10) or (11),

$$(10)\ Fe+CO=FeO+C,$$
$$(11)\ 2\ Fe+CO_2=2FeO+C,$$

but it is very difficult to understand how these reactions can possibly take place in the upper zone of the blast furnace, since at the temperatures existing at the point under discussion the reactions (1) and (9) are the only ones possible, and it follows therefore that no metallic iron can exist except through reaction (9), which calls for carbon deposition, and this reaction produces metallic iron instead of oxidizing it. It may be perfectly true that at higher temperatures the great bulk of carbon deposit is dependent upon, or at least is associated with, an oxidation of metallic iron by carbonic acid (CO_2) or carbonic oxide (CO), but the testimony indicates that the first of the carbon deposit is formed where the temperature is insufficient for the formation of metallic iron save by the simultaneous formation of impregnating carbon. Moreover, if metallic iron were formed it could not be oxidized by carbonic acid (CO_2), since reaction (12) does not begin until a temperature of 300° C. (510° F.) is reached and does not become rapid until a still higher altitude is attained.

$$(12)\ Fe+CO_2=FeO+CO.$$

On the other hand, it is well known that carbon deposition does not take place with rapidity until the temperature is from 400° C. to 500° C. (say 840° F.), and this would indicate that such deposition might depend upon reaction (12) between metallic iron and carbonic acid (CO_2), but it may also depend upon the reduction of iron oxide by carbon, as shown in reactions (4), (5) and (6). These latter reactions are all endothermic—i.e., they absorb heat, while the reduction of iron oxide by carbonic oxide (CO) is exothermic—i.e., it creates heat.

Reaction (4) begins to take place at about 400° C. (750° F.), so that at this temperature a supply of metallic iron is provided, and since carbonic acid (CO_2) is able at this point to oxidize metallic iron according to reaction (12), it follows that there may coexist all the factors necessary for any reactions, since by interchange there may be present Fe_2O_3, Fe_3O_4, FeO, Fe, CO and CO_2. Two of the reactions occurring are (13) and (14),

$$(13)\quad 2\,FeO+CO_2=Fe_2O_3+CO,$$
$$(14)\quad 2\,Fe+3\,CO_2=Fe_2O_3+3\,CO,$$

the first creating a large amount of heat and the second absorbing energy.

Some interesting experiments on carbon deposition were carried on by Laudig.* He passed blast furnace gas over different ores, the gas containing about 7.5 per cent. CO_2, and 29 per cent. CO, the temperature being just above the melting point of zinc. The following list shows the results obtained, the figures being the weight of carbon deposited in per cent. of the weight of ore:

	Min.	Max.
Old range soft hematites	4.48	35.13
hard hematites	2.16	12.88
blue ores	1.56	4.72
brown ores	0.98	24.92
magnetites	nil	nil
Mesabis	10.20	36.40
Scale and cinder	0.08	0.74

It was assumed by Laudig that the reducibility and value of an ore depended upon two conditions:

(1) That it should be of such a character that carbon would be deposited throughout the mass;

(2) That it should not be too readily disintegrated or too much increased in volume by this action.

Cases were cited in tests on some of the Mesabi ores where the mass increased to four or five times its volume after exposure to the gas, thus explaining the choking and scaffolding encountered when smelting these fine varieties. I believe that much remains undiscovered in this field. Thus it is a matter of record that Cuban ore

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* *Trans. A. I. M. E.*, Vol. XXVI, p. 269.

has been smelted at Steelton with a consumption of less than a ton of coke per ton of iron, and this was done moreover in a furnace only 65 feet high, the practice being continued for a long time. This ore is mostly magnetite, in hard lumps, containing 10 per cent. silica and from 0.25 to 0.50 sulphur, and on account of this latter impurity it was essential to maintain a good temperature, but this was done so successfully that the iron produced ran from a trace up to .04 per cent. in sulphur. This experience does not agree with the current belief that magnetites are hard to smelt, and it does not agree with the theory about the necessity of carbon deposition since Laudig states that no carbon was deposited in the magnetites, a fact which I have verified by experiments. It is also quite certain that the smelting values of the old range ores do not vary in proportion to their absorption of carbon, and it is well to keep in mind the fact that hematite ores when charged into a blast furnace are very quickly converted into a magnetite, although it is quite possible that this conversion gives an opportunity for the permeating power of the gases which would be absent in the case of magnetites where no such reaction takes place.

I have commented above on the necessity of invoking something beside the oxidizing influence of carbonic acid upon iron to explain the beginning of the carbon impregnation, but the question is so puzzling and it is so difficult to investigate that in the present state of metallurgy there seems to be about as much darkness as light surrounding the matter. It is certain, however, that the subject is of great importance, as it is known that carbonic oxide alone is unable to remove the last traces of oxygen from iron oxide, this office being performed by deposited carbon in the lower region of the blast furnace, and it is also known that carbon deposition ceases at about 600°C and that carbonic acid (CO_2) then acts upon and dissolves carbon, so that in the lower and hotter portions of the furnace there is probably no carbon deposit except what is so to speak associated with the iron, waiting for a chance to unite with it as carbide.

Howe* has reviewed the work of Bell and others very thoroughly in respect to carbon impregnation, and concludes thus:

"The exact nature of the reactions is not known. Metals which like iron are reduced by carbonic oxide, but which unlike it are not

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* *Metallurgy*, p. 122.

oxidized by this gas or by carbonic acid, do not induce carbon deposition as far as known: this suggests that it is connected with the oxidation of iron by one or both of these gases by reactions like the following:

$$\mathrm{Fe+xCO=FeO_x+xC},$$
$$\mathrm{FeO_x+yCO=FeO_{x+y}+yC},$$

rather than to mere dissociation of carbonic oxide, thus:

$$2\,\mathrm{CO=C+CO_2}$$

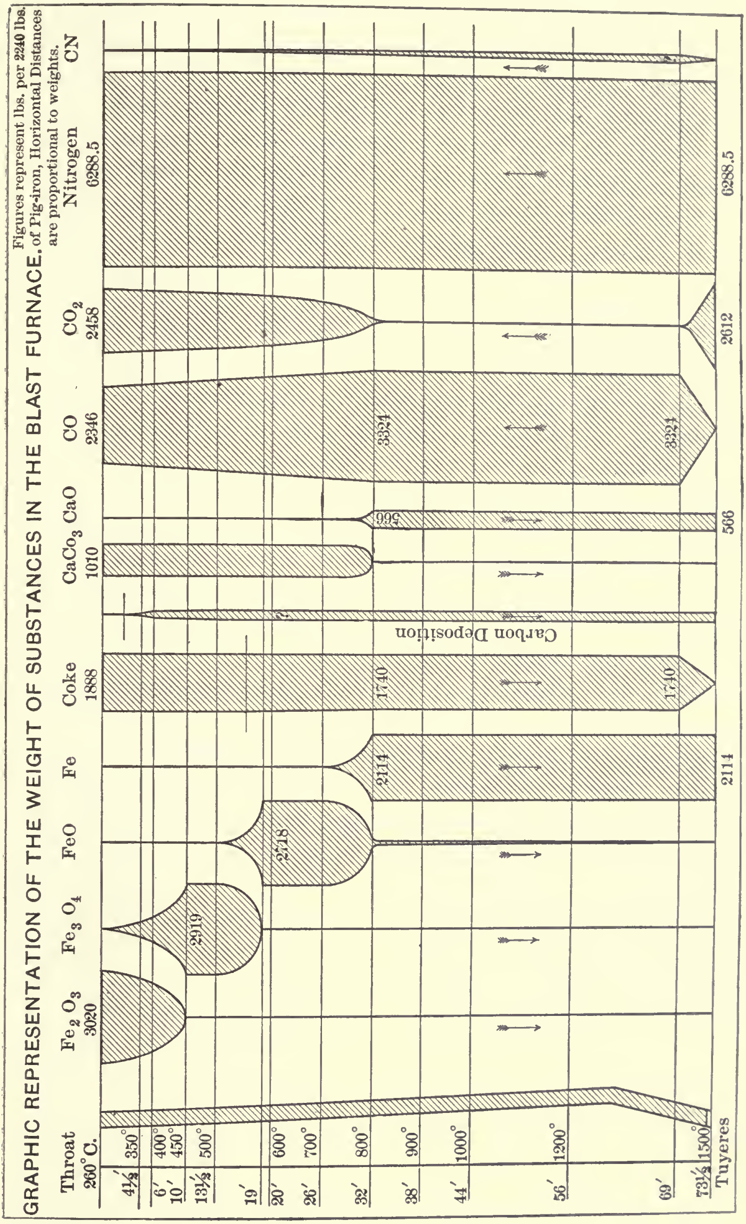
which indeed may be regarded as the resultant of either of these two reactions:"

$$\mathrm{FeO_x+yCO=FeO_{x-y}+yCO_2}.$$
$$\mathrm{FeO_x+yCO=FeO_{x+y}+yC}.$$

The chemical phenomena of a blast furnace have been represented graphically by Bell and also in a book by Prof. Robt. H. Richards for the use of students in the Massachusetts Institute of Technology, but I believe that no attempt has ever been made to show them with quantitative accuracy. From what has gone before and what will appear in the rest of this chapter it may be seen that it is possible to map out the progress of the reactions, after assuming certain working conditions. This task has been performed for me by Mr. John W. Dougherty, Superintendent of The Pennsylvania Steel Company, and the results are shown in Fig. II-E.

It must be understood that the curves are drawn very carefully and express quantitatively the exact relative amounts of each element or substance, as nearly as our knowledge admits, for the special conditions under consideration. The height is taken to be 90 feet, and information is given as to the temperature to be expected at different distances above the hearth, these temperatures being given in degrees Centigrade. The conditions assumed are as follows:

Temperature at tuyeres 1500° C.
Ore=60 per cent. Fe; no water.
Coke=87 per cent. C; 1888 lbs. per ton of iron.
Stone=100 per cent. $\mathrm{CaCO_3}$; 1010 lbs. per ton of iron.
Pig-iron=4 per cent. C; 1 per cent. Si.
Ratio of tunnel head gas by volume, 1 $\mathrm{CO_2}$ to 1½ CO.
Temperature of tunnel head gases 260° C.
Height of furnace, 90 feet.


GRAPHIC REPRESENTATION OF THE WEIGHT OF SUBSTANCES IN THE BLAST FURNACE.

Figures represent lbs. per 2240 lbs. of Pig-iron, Horizontal Distances are proportional to weights.

FIG. II-E.

It is also assumed upon the authority of Bell that the carbon needed for the carburization of the pig iron is deposited in the iron oxide, in the upper portion of the furnace, and that the amount so deposited is just sufficient for the work. In the absence of positive data an estimate is made of the amount of cyanogen present. No data are given on the diagram concerning silicon, sulphur, phosphorus and other similar elements, as it is evident that their graphic representation when shown on so small a scale would be a straight line. In the case of alumina, the amount is considerably greater, but it has not been shown on the diagram, as it undergoes no change and affects no other constituent of the charge until it reaches the zone of fusion just above the tuyeres. It will be readily understood that the isothermal lines in a blast furnace are not horizontal, as they will vary with the irregularities in the rate of the descent of the stock in different parts of the furnace, but it seemed unnecessary to attempt to show these complications.

From this diagram we may learn the following:

At the tunnel head the ore (Fe_2O_3) is plunged into an atmosphere of $CO=24$ per cent., $CO_2=16$ per cent., $N=60$ per cent., and a temperature of about 260° C. (500° F.), and there is immediately a reduction of part of the ore to Fe_3O_4, this action increasing as the ore descends and reaches a higher temperature. By the time a depth of 10 feet is reached, all the Fe_2O_3 has been converted into Fe_3O_4 and the temperature is 450° C. (890° F.).

Before this reduction is completed, and even before it is well under way, there begins the peculiar reaction of carbon deposition by which the gases react upon the ore and deposit carbon throughout the pores of the oxide, and this carbon so deposited remains associated with the iron, finally furnishing the proportion needed for its conversion into pig iron. This carbon deposition begins at a temperature of about 300° C. (570° F.), very soon after the first stages of reduction are under way, rapidly increases until all the Fe_2O_3 is reduced to Fe_3O_4 at a temperature of about 450° C. (840° F.) and then continues at a slower rate until the Fe_3O_4 is all reduced to FeO at a temperature of about 600° C. (1110° F.). The mixture of carbon and metallic iron then descends until the zone of fusion is reached, when the mixture is converted into iron carbide.

As above stated, the gases reduce the Fe_2O_3 and at a temperature of 450° C. the iron is nearly all present as Fe_3O_4. This descends unchanged until at 13½ feet it meets a temperature of 500° C. (930° F.), when it is strongly acted upon and converted into FeO, the transformation being complete when a temperature of about 580° C. (1080° F.) is reached at a depth of 19 feet. This FeO so formed, impregnated with deposited carbon, descends quite a distance unchanged until a temperature of 700° C. (1290° F.) is encountered at a depth of 26 feet, when the last atom of oxygen is taken by the carbonic oxide, and spongy iron begins to form. This reaction is completed when the temperature reaches 800° C. (1470° F.) at a depth of 32 feet.

The limestone comes down through the furnace until it encounters the temperature of 800° C. (1470° F.), at which the last of the FeO is reduced to spongy iron, at which place it is decomposed and the carbonic acid is driven off to rise through the stock, while caustic lime (CaO) descends to the zone of fusion to flux the silicious ingredients of the charge. The carbonic acid (CO_2) so driven off from the limestone plays an important and objectionable part in its passage from its place of birth to the tunnel head. It has elsewhere been stated that at all temperatures above 550° C. (1020° F.) the following reaction occurs:

$$CO_2 + C = 2\ CO,$$

and as the limestone is not decomposed until a temperature of 800° C. is reached it follows that during the passage of this carbonic acid from the point where it is made at a depth of 32 feet until it reaches a temperature of 550° C. (1020° F.) at a depth of about 17 feet, which is to say, during the travel of the gas through a vertical distance of 15 feet, it is constantly reacting upon the coke. Experiments show that a quantity of carbonic acid equal to the entire amount liberated from the limestone is thus destroyed in the upper portions of the furnace, with the production of an equivalent amount of carbonic oxide (CO). The potential energy of this carbonic oxide may be subsequently utilized under boilers or in the stoves, but it is totally lost as far as the economy of the furnace itself is concerned.

It is not strictly correct to say that all the carbonic acid from the stone is decomposed, for alongside of this amount so produced is a certain quantity arising from the reaction between the ferrous oxide (FeO) and the carbonic oxide (CO), and there is no warrant for supposing that a molecule of gas derived from the stone has any history different from a molecule derived from the reduction of the ore, but it may be said for the sake of simplicity, as representing quantitative values, that the reactions in the upper portion of the furnace consist of the reduction of iron oxides (Fe_2O_3, Fe_3O_4, FeO) by carbonic oxide (CO) and the simultaneous oxidation of coke by the carbonic acid (CO_2) of the limestone. With the exception of this last reaction, and the formation of a small amount of carbon deposit, the coke charged at the top goes down through the furnace unchanged in quantity or condition until it reaches the immediate neighborhood of the tuyeres, the presence of so large a proportion of carbonic oxide rendering the oxidation of carbon out of the question.

Below the place where the last of the FeO is reduced, at a temperature of 800° C., at which point the limestone is entirely decomposed, there are practically no reactions whatever occurring, and the whole history is one of heat absorption preparatory to the intense concentration of energy at the tuyeres. The temperature, therefore, rises steadily and regularly as the tuyeres are approached. This rise in temperature is shown upon the diagram as being perfectly uniform throughout the entire height of the furnace, which, of course, is not strictly true, for the bosh region is cooled by water, and, being at a high temperature, the chilling effect at this point must be more rapid than will be found a little higher up, where there is little radiation and no heat absorbing reactions. There is still another zone where the limestone is decomposed, and this portion would show a considerable variation from a regular increase in temperature, while above that point considerable heat is absorbed by the union of carbonic acid from the stone with coke ($CO_2+C=2\ CO$), and a considerable amount created by the reduction of the iron oxides by carbonic oxide (CO). Inasmuch as any attempt to equate these conditions would involve many assumptions, it may be just as well to presuppose a uniform rate of progression.

The reactions in the immediate neighborhood of the tuyeres differ very materially from the reactions occurring higher up, on account of the facilitation of chemical action by the intense temperature. The entering blast is composed of nitrogen and oxygen; the nitrogen passes unchanged through the zone of fusion and through the upper zones of reduction, and escapes in its original state and quantity with the tunnel head gases. A very small and uncertain quantity combines with carbon to form cyanogen, which in turn combines with potassium or sodium to form cyanides, but these are constantly undergoing decomposition in their passage upward through the ore, according to the reaction:

$$2\ KCN + 3\ FeO = K_2O + 2\ CO + 3\ Fe + 2\ N.$$

The oxygen, immediately upon entering, unites with the glowing coke to form carbonic acid (CO_2), but by contact with other pieces of incandescent coke this is all changed into carbonic oxide (CO), and from a distance of about four feet above the tuyeres to the point where limestone is decomposed and ferrous oxide reduced, there is no carbonic acid in the furnace, the entire gaseous atmosphere being composed of nitrogen and carbonic oxide (CO).

As before stated, the coke comes down through the furnace unchanged and unaffected in quality or quantity, save for the oxidation of a small amount by the carbonic acid (CO_2) driven off from the limestone. No other action takes place until it reaches a point about four feet above the tuyeres, when it meets the carbonic acid (CO_2) formed at the tuyeres, and there then occurs the reaction:

$$CO_2 + C = 2\ CO.$$

At the same time other particles of incandescent carbon, possibly only a fraction of an inch away from where the foregoing reaction is taking place, are coming in contact with molecules of free oxygen from the blast and there occurs the following reaction:

$$C + 2\ O = CO_2,$$

the carbonic acid so formed being doomed to immediate destruction on its first meeting with the next molecule of incandescent carbon.

The final result of this combustion is the formation of carbonic oxide (CO) with no admixture of carbonic acid (CO_2), and this carbonic oxide rises in unchanging quantity to the point where it meets unreduced ferrous oxide (FeO). Here begins the formation of carbonic acid (CO_2) from both the reduction of the ore and the decomposition of the limestone, and in spite of the destruction of some carbonic acid (CO_2) by the coke with formation of carbonic oxide (CO) the proportion of carbonic acid (CO_2) in the gases increases all the way to the top.

It need hardly be stated that all the figures relating to vertical distances must be changed for every variation in the height of different furnaces, nor that the temperature of the tunnel head gases is quite different at every furnace, while the horizontal measurements on the drawing must be made to accord with the furnace practice on coke, ore, etc., but it has been deemed worth while to solve one definite problem as an example of the method which seems applicable to all similar investigations.

SEC. IIf.—*The Utilization and Waste of Heat.*—Any discussion of the distribution of heat in a blast furnace must base itself on the investigations of Sir Lowthian Bell. One of the last contributions

TABLE II-B.

Comparison of Furnace Practice at Middlesborough and Pittsburg.

	Middlesborough.	Pittsburgh.
General conditions—		
Height of furnace, feet	80	80
Cubic contents, feet	25,500	18,200
Per cent. of metallic iron in ore	39.0	59.0
Weekly product per 1000 feet cubic content, tons	21.57	128.00
Temperature of blast, degrees cent	704	593
Temperature of tunnel head gases, degrees cent	250	171
Ratio of CO to CO_2 in gases	2.11	2.35
Data per ton of pig iron—		
Coke, pounds	2239	1882
Limestone, pounds	1232	1011
Ore, pounds	5376	3613
Weight of blast, pounds	9761	7974
Weight of tunnel head gases, pounds	13,381	11,211
Slag, pounds	3136	1200
Calories used in the furnace per ton of pig iron—		
Reduction of Fe_2O_3	1.681,887	1.681,887
Reduction of metalloids in pig-iron	212.039	133,655
Dissociation of CO	73,152	74,168
Fusion of pig-iron	335,280	335,280
Evaporation of water in coke	13,970	4,216
Decomposition of water in blast	120,904	118,516
Expulsion of CO_2 from limestone	206,756	157,175
Reduction of this CO_2 to CO	214.579	177,190
Fusion of slag	782,320	299,212
Radiation, cooling water, etc	494,792	298,145
Total absorbed in furnace	4,135,679	3,279,444
Calories in tunnel head gases per ton pig iron—		
Sensible heat	364,000	254.700
Potential as CO	3.810.000	3.137,000
Total in tunnel head gas	4.174.000	3.391,700
Summary per ton of pig iron—		
(a) Calories used in furnace (as above)	4.135,679	3.279,444
(b) Calories in tunnel head gases (as above)	4,174,000	3,391,700
Sum of (a) and (b)	8.309 679	6,671.144
(c) Less calories from blast included in (a)	738,632	626,872
Calorific power produced per ton of iron	7,571,047	6,044,272
Calorific power produced per ton of coke	7,574.400	7,196.000

made by him was a discussion of a paper by Gayley.* In his remarks he compared the working of a typical Pittsburgh furnace with the practice in the Cleveland district in England. In Tables II-B and II-C the results are tabulated, so as to show the way the heat is utilized under two entirely different sets of conditions.

In Table II-B I have calculated what I believe are the correct figures, being merely an expansion of the data given by Bell. In

TABLE II-C.

Distribution of Calorific Energy on the Assumption of the Same Coke for Middlesborough and Pittsburg.

Table II-B shows that the English coke was 5 per cent. better than American coke. Hence with the same coke, the fuel in Pittsburg would have been only 1788 lbs. per ton.

	Equivalent in Pounds of Coke.		Per cent. of total Calorific Value	
	English.	American.	English.	American.
Constant factors—				
Reduction of Fe_2O_3	452	452	20.2	25.2
Fusion of pig iron	90	90	4.0	5.0
Total	542	542	24.2	30.2
Factors beyond the control of the smelter—				
Reduction of the metalloids	58	36	2.6	2.0
Expulsion of CO_2, from limestone	56	41	2.5	2.3
Reduction of this CO_2 to CO	58	49	2.6	2.7
Fusion of slag	210	80	9.4	4.5
Total	382	206	17.1	11.5
Factors more or less under control—				
Dissociation of CO	20	20	0.9	1.1
Evaporation of water in coke	5	2	0.2	0.1
Decomposition of water in blast	34	33	1.5	1.8
Radiation, cooling water, etc	134	80	6.0	4.5
Total	193	135	8.6	7.5
Tunnel head gases—				
Sensible heat	99	68	4.4	3.8
Potential as CO	1023	837	45.7	47.0
Total	1122	905	50.1	50.8
Grand Total	2239	1788	100.0	100.0

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* *Trans. A. I. M. E.*, Vol. XIX, p. 957.

In the figures as given here some changes are made. Following the system in his previous writings, the learned investigator has used a unit of 20 kilogrammes as being readily convertible into 20 cwt. Unfortunately, it is too easily convertible and in one case the figure given for calories produced per ton of iron is really the value per 20 kilogrammes, and a column headed pounds does not refer to pounds at all. These errors have no bearing on the fundamental questions, but attention is called to them to save trouble for others.

Table II-C I have departed from his line of calculation in finding the equivalent amount of coke in the American furnace. The object of the investigation is to account for the larger amount of fuel used in England, and Bell sums up every way in which the lean and silicious ores of Cleveland increase the work to be done, but although he mentions the fact that Connellsville coke contains more ash than the coke of Durham, he makes no allowance for this at all. It is quite certain that a pound of ash in the fuel will have just as much effect as a pound of similar earth in the ore, and it is just as certain that the furnaceman cannot get calorific power out of this ash, and for this reason I believe that the calculation by Bell on the heat developed per unit of coke (p. 958 *loc. cit.*) is entirely misleading. The difference of 7.00 per cent. (not "7½ per cent.") is almost entirely accounted for by the extra ash which the American coke contains, for Durham coke is given as 5 to 7½ per cent. in ash, while Connellsville will run at least 5 per cent. higher.

The exact composition of the gases from the Cleveland furnace is not given, but the ratio is recorded and the weight produced per ton of iron, and from these data I have made calculations of the composition. (In the case of both the English and American furnaces no allowance was made for an unknown quantity of steam in the escaping gases and a certain small error is caused in this way.) By thus determining all the factors, we are able to tabulate the figures in a more logical way. Bell views the gases simply as a vehicle of sensible heat, with the exception of the calorific power returned in the blast, but I believe it is more correct to calculate *all* the potential energy in the coke and find how much is accounted for, either as potential or chemical energy, or as sensible heat. Bell has done this in some cases in his previous writings and showed that in one case 74 per cent. of the entire heating power of the fuel was employed in useful work, but this counted the energy developed in the boilers and in the hot stoves. I believe it is better to keep this separate under the name of "potential heat in gas," as the economical use of such gas is a problem entirely distinct from the metallurgy of a blast furnace. It may or may not be possible to improve radically on the economy of energy in the interior of a furnace, but it is certainly possible to improve on the power plant and the oven plant in use at many places.

The treatment of the energy used in heating the blast is a rather confusing problem. It cannot be neglected, as the hot blast produces an increase in the calories developed in the furnace; and it cannot be treated alone, as this same energy is included in the potential heat of the unburned tunnel head gases. This potential heat becomes kinetic when the gases are burned in the stoves and in the boilers, but it is impossible to make a full account of it and put it all into the equation of the furnace, because only a portion is used to heat the blast, the rest being burned under the boilers and dissipated in losses having no direct bearing upon the calorific history of the furnace proper.

I have tried to cover the general heat equation in Table II-D, which gives on the one side the total heat developed in the furnace and on the other side the distribution of this heat.

TABLE II-D.

General Equation of the Blast Furnace.

	Middlesborough.	Pittsburg.
Per ton of pig iron—		
Calories from formation of CO_2	2,427,000	1,982,000
Calories from formation of CO	1,336,000	1,025,000
Calories potential in gas as CO	3,810,000	3,137,000
Total per ton of iron	7,573,000	6,144,000
Per ton of coke—		
Calories from formation of CO_2	2,428,000	2,360,000
Calories from formation of CO	1,342,000	1,220,000
Calories potential in gas as CO	3,812,000	3,735,000
Total per ton of coke	7,582,000	7,315,000
Distribution by per cent. of total energy—		
Per cent. from formation of CO_2	32.1	32.2
Per cent. from formation of CO	17.6	16.7
Per cent. potential in gas as CO	50.3	51.1
Total	100.0	100.0

The item of potential heat includes all the energy of the escaping gases, except the sensible heat. This potential heat appears later in four places:

(1) Heat utilized in stoves in heating the blast.

(2) Heat utilized in boilers in making steam.

(3) Heat lost in ovens by incomplete combustion, in the stack gases, and by radiation.

(4) Heat lost at boilers by incomplete combustion, in the stack gases, and by radiation.

It would be possible to verify the conclusions if the exact calorific value of the coke were known, but this is not given in either case. Bell assumes that Durham coke contains 10 per cent. of earthy and volatile materials, but some of this volatile matter is hydrogen, which appears as potential heat in the gases. It is probable that the heat value of Durham coke is about 7400 calories per kilogramme, or say 7,500,000 calories per ton. The coke of Connellsville will probably give about 7,120,000 calories per ton.

The figures given in Table II-D, as found by theoretical calculations, show a value for Durham coke of 7,582,000 calories, being about 1 per cent. greater than the foregoing assumption, and for Connellsville 7,315,000 calories, being about 3 per cent. more, while in Table II-B a somewhat different method gave 7,574,000 calories for Durham and 7,196,000 calories for Connellsville. This is a sufficiently close approximation, considering the inaccuracy of the data. The coke, the ore and the stone vary in composition from day to day. The moisture in coke, ore and blast will depend upon the weather; and so, throughout the whole list, it is impossible to make more than an approximation of what we call the general practice, but it is possible, by careful investigations like those conducted by Bell on the Cleveland furnace, to find the values of each factor under an assumed or actual set of conditions, and from these results may be deduced the relative importance of the factors involved. Even if the total calories developed vary somewhat from the heat value of the coke, the ratio of one factor to the whole is not necessarily greatly in error.

We may consider that the Middlesborough and Pittsburgh furnaces represent two extremes of good practice; one with lean ores and slow running, and the other with rich ores and fast running, and from Tables II-C and II-D the following conclusions may be drawn:

(1) Of all the heat energy contained in the coke charged in a blast furnace, almost exactly one-half goes away in the tunnel head gases, a small part as sensible heat, but most of it as unburned CO.

(2) This proportion of heat so lost is about the same whether the furnace is working on lean ores with a high consumption of fuel or on rich ores with a low fuel ratio.

(3) The other half of the energy is used in reducing the iron ore, in melting the iron and slag, in losses from conduction and radiation, and in minor chemical reactions.

(4) The proportion of the total energy used for each one of these items depends upon the special conditions; as, for instance, the proportion needed for the reduction of CO_2 and the proportion needed for the melting of the slag both depend on the amount of limestone needed, and this in turn depends on the impurities in ore and fuel. In the case of the reduction of the ore and the fusion of the pig iron, both of which take a given amount of heat, the proportion which this given amount bears to the total will depend solely upon what the total is, being greater with a small fuel ratio.

(5) The proportion lost in radiation and through the cooling water will decrease as the output of the furnace is increased, either by the use of rich ores or by rapid driving, or both.

(6) The heat needed for the reduction of the ore calls for between 20 and 25 per cent. of all the energy delivered to the furnace.

(7) The fusion of the pig iron requires from 4 to 5 per cent.

(8) The fusion of the slag requires from 4.5 to 9.4 per cent., increasing with the amount of impurities and the quantity of stone.

(9) The heat lost by radiation and in cooling water varies from 4.5 to 6.0 per cent., decreasing with a larger output of pig iron.

(10) The reduction of the metalloids, the expulsion of CO_2 from limestone, and the reduction of this CO_2 to CO, each require from 2 to 3 per cent.

(11) The dissociation of CO, and the decomposition of water in the blast, each call for from 1 to 2 per cent., while the evaporation of the water in the coke takes a small fraction of 1 per cent.

(12) Some factors are beyond the control of the smelter, as for instance all those depending on the limestone, this being determined by the impurities to be fluxed. In the American furnace before described the factors beyond the control of the smelter required only 206 pounds of coke, while in the English furnaces 382 pounds were needed, a difference of 176 pounds. Inasmuch as fifty per cent. of all the energy is lost in the escaping gases, it is evident that these factors alone account for an extra 352 pounds of fuel in the English furnace.

(13) The factors which are more or less under control are practically the same in both cases, giving a total of 7.5 per cent. in Pittsburgh and 8.6 per cent. in Cleveland.

(14) The loss in the tunnel head gases is the only great item presenting any hope for future economies. In the Cleveland practice the ratio of CO to CO_2 was 2.11. In Pittsburgh it was 2.35.

It has been stated by Bell that a ratio better than 2 to 1 cannot be hoped for, but instances are given elsewhere showing that much better practice is possible.

SEC. IIg.—*Metallurgical Conditions Affecting the Nature of the Iron.*—The composition of the slag and the temperature of the furnace are the two great forces at work determining the quality of the product and much remains to be learned concerning their mutual relation. A slag is necessary for two reasons:

(1) To carry away the silica and earthy matters contained in the ore and fuel.

(2) To carry away the sulphur contained in the ore and fuel.

It must be liquid enough to be fluid at the temperature of the furnace and run freely from the cinder notch, and it must be viscous enough so that it does not act too readily on the linings and destroy them. In other words, acids and bases must be in such proportion that they are mutually satisfied with each other, and it is plain that this satisfaction depends in great measure upon the temperature, since a high heat renders a slag active that might otherwise be inert.

It is rather difficult to determine just what constitutes an acid and a basic slag, as the function of alumina is not thoroughly understood. It is stated by Elbers* that "if the percentage of silica be low, it acts as an acid and hence increases the fluidity of the slag, but if high it acts as a base and lowers the fusing point." Phillips,* in discussing furnace slags, says, "for every-day practice and with slags of 33 and 36 per cent. silica the alumina is considered as silica. In calculating furnace burdens the error thus caused is comparatively slight."

It is seldom that an increase in the proportion of lime in the slag gives trouble by erosion of the walls, since a hot furnace usually protects itself by a deposit of hard carbon upon the inner surface of the bosh and hearth, but trouble does arise in other ways. If the slag is too basic it will not run out, and therefore fills the hearth, while if it is too acid it will not absorb the sulphur. If the ore and fuel contain only a small amount of this impurity the slag may be able to dissolve it, even though the composition vary through very wide limits, but if sulphur be present in excess it may be necessary to keep the slag within very narrow bounds to make it capable of

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***Berg- und Hüttenmannische Zeitung,* Vol. XLVII, p. 253.

***Ala. Geol. Survey,* 1898, p. 45.

holding the sulphur in solution, and it will often happen that it will be necessary to increase the amount of slag so as thereby to have more latitude. With rare exceptions, the ores used in the large iron districts of the world contain only a small proportion of sulphur, but the coke almost always carries a very considerable quantity varying from one-quarter of 1 per cent., which is very low, to over 2 per cent., a fair average of good coke being about 1 per cent., so that, ordinarily, the question of removing sulphur resolves itself into handling the sulphur in the fuel. It may often happen that special provision must be made to accomplish this; thus some of the Lake Superior hematites contain so little silica that they do not produce sufficient slag to carry away the sulphur from Connellsville coke, and it is found necessary to mix them with more silicious ores in order to produce a greater volume of cinder. Some ores contain sulphur up to 2 per cent., as, for instance, the Cornwall deposit in eastern Pennsylvania. Part of this can be expelled by roasting, but although the ore is rich in silica, it is found advisable at times to still further increase the volume of cinder to carry away the double burden of sulphur in ore and coke.

When much sulphur is present in either coke or ore it may be removed by running the furnace very hot, thereby making possible a very basic slag, but it is difficult to do this without making an iron high in silicon, and this is considered a disadvantage in America, as with rapid work in the Bessemer a content of 1 per cent. of silicon is quite sufficient. High silicon can be used, however, if necessary, and if plenty of scrap be added and plenty of blast supplied, the blow is not very long. At Steelton we have many times put a mixture into the vessels containing 3 per cent. of silicon and have blown the heats in about twelve minutes, when low silicon iron would take about nine minutes, no difference being found in the life of the linings or the bottoms.

The amount of silicon reduced, and hence the percentage of this element in the iron, depends on several conditions, being aided by:

(1) A rise in temperature; for at high thermal altitudes the oxygen has a greater affinity for carbon than for silicon, and, therefore, carbon can reduce silica with production of silicon.

(2) A decrease in lime additions; for lime tends to hold silica in proportion to its needs, so that the higher a slag is in silica, the less firmly is any one molecule fastened in that slag.

(3) An increase in the total amount of silica present; for, when

all other things are equal, the greater the exposure, the greater is the opportunity for its reduction, so that if one furnace working on ores low in silica makes three-quarters of a ton of slag to every ton of iron, and another furnace working on ores high in silica makes one and one-half tons of the same composition, the tendency will be toward twice the percentage of silicon in the second iron that would be found in the first.

It will be noticed that one of the conditions favorable to the production of high silicon pig iron, viz., high temperature, is also favorable to the elimination of sulphur, while another condition—an acid slag—is opposed to it.

This complication gives rise to variations in practice whereby these factors are arrayed against each other for the attainment of certain ends. Thus it is possible to make:

(1) An iron with high silicon and low sulphur, by running the furnace at a high temperature with a slag sufficiently basic to hold the sulphur, but not basic enough to keep silicon from being reduced.

(2) An iron with low silicon and low sulphur, by using a lower temperature with a somewhat more basic slag, or a high temperature with a much more basic slag.

(3) An iron with low silicon and high sulphur, by using a low temperature with a slag not sufficiently basic.

(4) An iron with high silicon and high sulphur, by using a high temperature with a slag not sufficiently basic.

c Manganese is another element which is found in many ores, and which occasionally plays an important part in the operation. A content of only 1 or 2 per cent. in the ore will nearly all be carried away in an ordinarily acid slag, but if a greater quantity of lime be added, there is less demand for metallic oxides in the cinder and the manganese is reduced and alloyed with the iron. A high temperature seems to favor this reaction, but part of this effect may be due to the corresponding increased fluidity in the extra-basic slag.

The specifications of high temperature and a limey slag, which favor the presence of manganese in the pig iron tend also toward the elimination of sulphur. When the slag is made more basic, as it should be in the production of spiegel, to prevent the loss of oxide of manganese in the cinder, the conditions are evidently opposed to the reduction of silicon, so that high-manganese iron generally contains low silicon, and almost always low sulphur. It is possible, however, by special care, to make a silico-spiegel containing as much as 11 per cent. of silicon and 18 per cent. of manganese, this alloy being used as a recarburizer in steel making.

Table II-E shows the composition of blast furnace slags as taken from various sources.

SEC. IIh.—*The blast.* (a) *The amount of air required.*—The usual way of measuring the amount of air that enters the furnace is to calculate the cubical displacement of the pistons in the blow-

TABLE II-E.

Composition of Blast Furnace Slags.

	Slag.							Iron.		Remarks.	
	SiO_2	Al_2O_3	CaO	MgO	FeO	S	Total not including S.	Si	S		
1	33 10	14.92	40.76	9.67	......	......	98.45	3.37	tr.	Cuban ore, hot furnace.	
2	32.27	14 57	41.02	10.30	......	......	98.16	3.18	tr.	" " " "	
3	24 26	11.53	40.25	13.28	......	......	98.32	4.81	.01	" " " "	
4	32.68	13.50	43 28	9.44	......	......	98.90	1.25	.06	" " warm.	
5	32.28	9.38	46.95	9.52	.....	......	98.13	0.70	.11	" " cool.	
6	34.50	7.94	46.47	10.47	......	......	99 38	0.69	.05	" " "	
7	34.98	12.05	41.33	9.62	....	......	97.98	2.60	.03	Spanish ore, hot furnace.	
8	34 70	11 44	41 27	9.96	......	......	97 37	2.32	.02	" " " "	
9	33.68	11.93	45.96	6.69	......	......	98.26	1.27	.02	" " " "	
10	29.86	12.04	45.20	11.41	......	.....	98.51	1.27	.02	" " " "	
11	28.95	12 04	49.30	8.46	.....	......	98.75	.57	tr.	" " cool furance.	
12	30 62	10.47	49 13	7 49	......	......	97.71	.26	.02	" " " "	
13	32.55	11.13	47.16	6.61	......	.....	97.45	.15	.03	" " " "	
14	30 08	11 44	46 36	8.76	......	......	96.64	.58	.03	" " " "	
15	31.46	11.50	44.85	10.41	......	......	98 22	.20	.07	" " " "	
16	36.08	12.85	41.69	7.25	0.54	1 62	98.41	2.15	.020	Lake ore and part anthracite coal; mostly Connellsville coke.	Hot furnace.
17	37.19	12.65	35.47	11.32	0.90	1.70	97.53	1.92	.029		Fairly hot.
18	36.86	10.74	42.46	6.62	0.63	1 54	97.31	1.50	.028		" "
19	32.06	11.97	42.46	10.25	0.63	1.76	97.37	1.59	.032		" "
20	33.57	10.65	44.11	8.55	0 81	1 74	97.69	0.94	.017		Normal.
21	35.38	11.76	38.19	12.32	0.90	1.60	98.53	1.13	.040		"
22	36.35	10.21	40 10	10 95	0.99	1.28	98.60	0.66	095		Cool.
23	33.70	12.56	38 12	11 60	0.32	0 96	98.30	0.50	.101		"
24	35.11	14.21	22 48	22.38	......	......	100.12	1.37	.048	Lake ore and Connellsville coke.	Av. of 8 weeks
25	35.10	14.75	27.95	22 28	......	......	100.08	1.85	.038		" 7 weeks
26	35.84	14 34	32.71	17.46	......	......	100.35	1.60	.034		" 7 weeks
Averages for hot furnaces—											
	33.21	13.67	40 68	11.08	......	......	98.64	3.79	tr.	Cuban ore.	
	34.84	11.75	41.30	9.79	.....	......	97.68	2.46	.025	Spanish ore.	
	31.77	11.98	45.58	9.05	......	......	98.38	1.27	.020	" "	
	35.55	12.05	40.52	8.86	0.68	1.66	97.66	1.79	.027	Lake ore.	
Averages for moderate or cool furnace—											
	33.15	10.27	45.57	9.81	......	......	98.80	0.88	.07	Cuban ore.	
	30 73	11.32	47 36	8.35	......	......	97.75	0.35	.03	Spanish ore.	
	34.75	11.30	40.12	10.86	1.26	1.40	98.29	0.81	.063	Lake ore.	
	35.35	14.43	29.69	20.71	......	......	100.18	1.61	.040	" "	

NOTE—All slags are from Steelton furnaces except Nos. 24, 25 and 26. The ore mixture was the same in all the cases where Spanish ore was used.

ing cylinders, but this is not accurate, as the losses from leaks and from inefficiency of inlet and exit valves cannot be measured. It may be well to calculate the theoretical amount of air indicated by the results obtained on tunnel head gases. In Section IIi will be found Table II-I, which gives the weight of nitrogen and oxygen contributed by the blast per ton of pig-iron under different conditions of furnace practice. Selecting practice D as representing a consumption of 1900 pounds of coke per ton of iron and a good efficiency as shown by the ratio in the tunnel head gases of 2CO to $1CO_2$, we find by calculation that such a furnace when making iron at the rate of 300 tons per twenty-four hours will require about 19,700 cubic feet of air per minute.

The correctness of this result is indicated by the figures obtained by Bell,* who calculates in an entirely different way and gives the weight of the air blast as 103.74 kg. per 20 kg. of iron, a ratio of 5.187 kg. to 1 kg. of iron=5270 kg. per 2240 pounds of iron, which, for a furnace making 300 tons in 24 hours, is at the rate of 1098 kg.=849 cubic metres=29,983 cubic feet per minute. It is to be noted that the consumption of coke in Middlesborough was 22.32 units per 20 units of iron=2500 pounds per ton of iron, while I have assumed for American practice a consumption of 1900 pounds, and correcting for this, the figures according to Bell would indicate that 22,790 cubic feet of air was supplied per ton of iron, which is a moderately close agreement to 19,700 cubic feet, the result just obtained by entirely different methods of calculation, and under radically different conditions.

(b) *The heating of the blast.*

In the foregoing calculation it has been shown that in round numbers a furnace making 300 tons of pig-iron per day will receive 19,700 cubic feet or 558 cubic metres of air per minute, equal to 803,500 cubic metres per 24 hours. It will produce 3551 cubic metres of tunnel head gases per ton of iron (see Sec. IIi) equal to 1,065,000 cubic metres in twenty-four hours and about one-third, or 355,000 cubic metres of this gas will be sent to the stoves. The specific heat of the air is .307 calories per cubic metre and the blast must be warmed from its natural temperature to a dull red heat, say 1300° F. or 700° C. so that the heat required for this operation will be

$$803{,}500 \times .307 \times 700 = 172{,}670{,}000.$$

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* *Manufacture of Iron and Steel,* p. 204.

The gases from the tunnel head enter the stoves quite a little warmer than the atmospheric temperature, say about 170° C. (300° F.), and their sensible heat will be utilized in heating stoves. The specific heat of tunnel head gas is about .320 calories per cubic metre, so that the sensible heat thus carried to the stoves will be

$$355{,}000 \times .320 \times 170 = 19{,}312{,}000,$$

and the net amount which must be supplied by the combustion of the gas will be the total amount to heat the blast minus this sensible heat carried in by the tunnel head gases, which, is therefore,

$$172{,}670{,}000 - 19{,}312{,}000 = 153{,}358{,}000 \text{ calories.}$$

It has been assumed that one-third of the tunnel head gas is sent to the stoves, and it is shown in Table II-I that Gas D has a calorific value of 823 calories per cubic metre, after allowing for a small proportion of hydrogen. The theoretical value, therefore, of this will be

$$355{,}000 \times 823 = 292{,}165{,}000 \text{ calories.}$$

Thus we find that the gas furnished to the stoves has a theoretical heating value of 292,165,000 calories, while the heating of the blast calls for only 153,358,000 calories, showing an efficiency of 52 per cent. The low temperature of the gases, their varying quality and the difficulty of properly regulating the quantity of air for combustion will account for this low percentage of efficiency, while the presence of large quantities of dust in the gas render impracticable the use of small passages for the more perfect absorption of the heat.

In this calculation no account has been taken of the moisture in the atmosphere, or of difference between summer and winter temperatures. This matter will be discussed later.

It may be interesting to compare the results of calculations by Bell,* although conducted on entirely different lines, and by entirely different methods. He states that the heating to 500° C. of the blast for 18.83 kg. of pure carbon in coke required 11.345 calories. In the foregoing paragraph it has been found that heating the blast for 300 tons of iron to 700° C. required 153,358,000 calories, or

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* *Iron and Steel Manufacture*, p. 143.

511,193 calories per ton. It is shown in Table II-I, Section IIi, that under the practice assumed, giving Gas D, there will be 768 kg. of carbon in the tunnel head gases per ton of pig-iron. If a rough allowance be made for the heating to 700° C., instead of 500° C., it will be found that 18.83 kg. will require:

$$\frac{18.83}{768} \times \frac{500}{700} \times 511{,}193 = 8952 \text{ cals.}$$

Thus Bell gives 11,345 calories, while our figures show 8952 calories. We have not made any allowance for oxygen contained in the gases, nor for moisture, but have taken simply the quantity of air theoretically necessary to burn the carbon to a gas containing a low ratio of CO to CO_2. After allowing for various losses and for leaks, it is probable that this amount in practice would be increased 20 per cent. and that a furnace making 300 tons of pig iron in twenty-four hours will call for over 23,000 cubic feet of air per minute, under which assumption our figures would agree with those given by Bell.

It has just been shown that when the blast is heated to 700° C. it contains over 500,000 calories per ton of iron produced, and it was shown in Section IIf that under American practice the full value of the coke charged represented 6,000,000 calories per ton of pig iron, of which one-half is utilized in the furnace itself, the other half escaping in the gases. The heat in the blast, therefore, represents 17 per cent. of all the heat that escapes from the tunnel head, and as the amount utilized is just equal to the amount escaping, it follows that the heat in the blast represents also 17 per cent. of all the heat utilized in the furnace. If this is true when the air is at 700° C., it is possible to say that each 100° C. in the blast represents 2.4 per cent. of the fuel utilized, or if the coke consumption is 1900 pounds per ton, it represents 46 pounds of coke, so that it would seem that an increase of 100° C. (180° F.) in the temperature of the blast should save 46 pounds of coke per ton of iron.

Such a conclusion, however, is not warranted by either theory or facts. It was long ago explained by Bell that the great gain in hot air is found in the first increments of heat, and that when a temperature of 700° C. is reached the gain by further superheating is comparatively slight. It is hardly necessary to pursue the calculation on theoretical lines, as many assumptions must be made, and because general experience has corroborated the foregoing statement.

In calculating the amount of fuel needed for any metallurgical operation it is necessary to consider two things:

(1) The amount of energy needed.

(2) The intensity of heat required.

A pound of coal produces a certain amount of energy and heat when burned and this amount is constant whether the coal is burned slowly or fast. It is the same whether it is burned in an open grate by natural draft or in a furnace under forced blast, but under forced draft the coal burns in a shorter time, and this means that there is a greater amount of heat produced per unit of time, and since the loss by conduction and radiation is about the same, it follows that this rapid combustion produces a higher temperature. If only low temperatures are required, as, for instance, in the evaporation of steam in boilers, the efficiency of the coal is about the same whether the fires be forced or not, but when cast iron or copper or other difficultly fusible substances are to be melted it is almost necessary to use a blower. Thus making the arbitrary assumption that a coke fire without blast will give a temperature of 1000° C. and that a fire with blast will give 1400° C., it is evident that no increase in the amount of fuel or length of time will melt a substance requiring a temperature of 1200° C. unless forced blast be used, but that with forced blast the melting can easily be accomplished.

In the same way the use of hot blast renders possible a higher temperature than with cold blast, and with this high temperature the blast furnace may readily smelt what was done with difficulty and with a great quantity of fuel when cold blast was used, but by the very same course of reasoning it will be clear that, once a sufficient temperature is attained, any increase beyond this may be of comparatively little value.

It has been shown in Section IIe that at the moment the hot blast of air strikes the glowing coke a certain amount of carbonic acid (CO_2) is formed, but that this is immediately transformed into carbonic oxide (CO), so that the first reaction and the equation may be written as follows:

$$\text{1 kg. C} + \text{4.45 c.m. air} = \text{1.87 c.m. CO} + \text{3.25 c.m. N}$$
$$= \text{5.39 c. m. products of combustion.}$$

The burning of 1 kg. of carbon to CO produces about 2450 calories when the carbon and the air are both cold, but the production of energy is much greater with hot carbon and hot air, just in accordance with the extra energy in these two factors, and it is possible to find the temperature that will be created under any set of conditions by dividing the total number of calories by the sensible heat of the gaseous products of combustion. This calculation is not perfectly simple because the specific heat of these products varies with every change in temperature. Table II-F gives the specific heat of the common gases at different temperatures.

TABLE II-F.

Specific Heat of Gases at Different Temperatures, between 0° C and t° C.

Formulae........ $\begin{cases} \text{N, CO and O} = 0.306 + 0.000027\,t \\ CO_2 \qquad 0.374 + 0.00027\,t \end{cases}$

Temp.	Specific.		Temp.	Specific.		Temp.	Specific.	
	N, etc.	CO_2		N, etc.	CO_2		N, etc.	CO_2
0	.306	.374	800	.328	.590	1600	.349	.806
200	.311	.428	1000	.333	.644	1800	.355	.860
400	.317	.482	1200	.338	.698	2000	.360	.914
600	.322	.536	1400	.344	.752	2200	.365	.968

We are thus confronted with the fact that we should know the resulting temperature in order to find the specific heat, and should know the specific heat to find the temperature. This may be done quite readily by the method of successive approximations, but I am indebted to Prof. J. W. Richards for a method by which accurate results can be obtained by direct processes, and with assumptions which give rise to unimportant errors. I have adopted his method and have worked out the answer for the range of available temperatures. It will suffice to explain the details of one calculation, by which we find the temperature produced by the combustion of the carbon at the tuyeres of the blast furnace, with air at 700 degrees Centigrade.

The specific heat of carbon above 1000 degrees C. is 0.5, but below 1000° C. it is less, so that the total heat in 1 kg of C. at t° (when t° is above 1000°) is approximately 0.5—120. Assuming that the heat value of 1 kg of carbon is 2450 calories, the calculation for a temperature of 700° C. will be as follows:

Heat in air 700x4.45x0.325=	1012
Heat in carbon..............................	0.5 t— 120
Heat in carbon and air.......................	0.5 t+ 892
Heat of combustion..........................	2450
Total heat in 5.39 c. m. of products......	0.5 t+3342

Heat per c. m... $623.8+0.0928\,t$

Therefore .... $t=\dfrac{623.8+0.0928\,t}{0.306+0.000027\,t}$

from which we have:

$$0.2132\,t+0.000027\,t^2=623.8$$
$$t=2273^\circ\ \text{C.}$$

In this calculation no allowance has been made for the dissociation of the water vapor in the air, but taking the amount usually present in the atmosphere, it is found that from 200 to 300 calories will be absorbed per kg. of carbon, and this will reduce the temperature at the point of combustion about 115° C., so that it is necessary, to subtract this from each result. It is not supposed that this will by any means give accurately the temperature of the zone of fusion, but it is believed that it is an approximation; and it is still further believed, what is of great importance, that the results in Table II-G are comparative and show the relative temperatures caused by changes in the temperature of the blast.

TABLE II-G.

Temperatures Produced by Burning Carbon with Air at Different Temperatures.

Temp. of air.		Resulting temperature.	
0° C.	(30° F.)	1559° C.	(2840° F.)
100° C.	(210° F.)	1641° C.	(2990° F.)
200° C.	(390° F.)	1724° C.	(3135° F.)
300° C.	(570° F.)	1808° C.	(3290° F.)
400° C.	(750° F.)	1893° C.	(3440° F.)
500° C.	(930° F.)	1978° C.	(3590° F.)
600° C.	(1110° F.)	2062° C.	(3740° F.)
700° C.	(1290° F.)	2146° C.	(3895° F.)
800° C.	(1470° F.)	2232° C.	(4050° F.)
900° C.	(1650° F.)	2316° C.	(4200° F.)
1000° C.	(1830° F.)	2400° C.	(4350° F.)

It will be found by inspection that the increase in temperature is constant for each increment in the temperature of the blast, which is to say that the same increase in the resulting temperature of the zone of fusion follows the heating of the blast from 600° to 1000° as from 0° to 400°; but, as before pointed out, an increase in temperature of the zone of fusion has nothing whatever to do with the amount of heat produced in the furnace as a whole, and the calculation as to how much saving is effected is very complicated and admits much difference of opinion. There can be no question of how much heat is contained in a given amount of air, or in the air for a given amount of coke, but it is a question whether this should be compared with the total value of the fuel, or with the amount utilized in the furnace proper, or with the amount developed in the neighborhood of the tuyeres. Moreover, any one of the assumptions is wrong, for it is necessary to take into account the fact that the fuel can never be reduced below a certain point on account of the necessity of having free carbonic oxide in the tunnel head gases to act upon the ore. The exact proportion of this gas necessary is much lower than formerly supposed, but there is *some* limit, and as this limit is approached each gain is made at a greater sacrifice. Experience has shown that there is a practical limit in heating the blast, and in practice it is usually from 1000° F. (540° C.) to 1400° F. (760° C.).

In further elucidation of this point I give the following remarks of Prof. J. W. Richards on reading the manuscript of the foregoing discussion:

NOTE BY PROF. J. W. RICHARDS.

The conclusion is correct that the increase in the temperature of the zone of combustion is proportional to the increase in the temperature of the blast.

I have made a formula for the temperature at the point of combustion, using the temperature of the blast as a variable, and by differentiating and taking the first differential coefficient have obtained the relative rate of increase of the two temperatures, from which it appears that when the temperature of the blast is 0° C. the rate of increase in the furnace is 0.86° for 1° in the blast and at 1000° it is 0.85°.

Theoretically, therefore, the maximum temperature attainable increases about 85° for every 100° increase in the blast. Actually, however, the temperature of the whole zone of fusion depends on the ratio of burden to the coke burned, or rather to the heat available in the zone, and as the furnace is burdened heavier when hot blast is used, the temperature of the whole zone of fusion, and of the fused materials, will be lower than theory would call for.

The heat developed by combustion and absorbed mostly by the CO and N raises these gases to a certain temperature. As they ascend they cool off by transmitting their heat to the ingredients of the pig-iron and slag. The maximum temperature to which the burden can be heated at the zone of fusion is the heat which the CO and N lose in ascending through the furnace, divided by the calorific capacity of the pig-iron and the slag-forming materials. Whatever be the temperature of the gases, these conditions will determine the maximum temperature of the fused materials. This explains why in the use of hot blast, the temperatures of the fused iron and slag are not proportional to the theoretically calculated temperature of the gases, for, as stated above, more burden is carried with the hotter blast.

(c) *The Vapor in the Atmosphere.*—The vapor in the atmosphere is everywhere recognized as seriously interfering with the operation of a blast furnace, but accurate information on the subject is not always obtainable. The Pennsylvania Steel Works is situated only three miles from a station of the United States Weather Bureau, at Harrisburg, Pa., and I have obtained the data, from this source, of a district one hundred and fifty miles from the ocean and still farther from any great fresh water lake. The district is not mountainous, and has an annual rainfall of about 40 inches, which is about the same as most places in the northern and eastern portion of the United States.

The average humidity throughout the year, for three successive years, was 68 per cent., 75 per cent. and 76 per cent., and this percentage did not vary as much as might be supposed in different parts of the year. Selecting January, April, August and November in one year as typical months, there were eight days in January and one day in November when the humidity was 100 per cent., or, in other words, when the atmosphere was saturated, while in April the highest humidity was 96 per cent. and in August 93 per cent. The minimum figures showed one day in each month as follows: January, 40 per cent.; April, 33 per cent.; August, 54 per cent.; November, 40 per cent. There were 17 days in January when the humidity was 80 per cent. and over, April having 6 days, August 9 days and November 11 days. There were 3 days in January when the humidity was 60 per cent. or less, April having 13 days, August 4 days and November 9 days. Thus August has less than the average number of days of high humidity and much less than the average of low humidity, while November shows a large proportion with high humidity and a large proportion with low humidity. In other words, the humidity in August remained steadily at about the average, while in November it varied widely, but averaged about the same as in the summer. The early spring-time showed the largest number of days with a low humidity, while January had the largest number with high humidity. These facts are recorded, as they differ quite a good deal from popular belief.

A general error arises from confounding the *percentage* of humidity with the *amount* of vapor. One cubic foot of air at 32° F. (0° C.) will hold, at 100 per cent. humidity, only .000304 pounds of water per cubic foot, while at 92° F. (33° C.), it will hold .00225 pound, or seven times as much, and it follows that a cubic foot of air at 90° F., with only 50 per cent. humidity, will carry between three and four times the vapor that will be held in saturated air of only 32° F. In the previous discussion it has been shown that a blast furnace, making 300 tons per day, will need over 20,000 cubic feet of air per minute, or about 100,000 cubic feet per ton of pig-iron. It will be shown in Table II-I, Section IIi, that a furnace producing gas (D) which has been the basis of previous calculations, requires 806 kg. of oxygen per 1900 pounds=862 kg. of coke, equivalent to 750 kg. of carbon. This proportion is somewhat different from that in the tunnel head gases as the limestone contributes carbon and oxygen, and the ore contributes oxygen, but at the base of the furnace the weight of oxygen will almost exactly equal the weight of carbon. This precludes entirely the formation of any CO_2 so that the higher oxide must be formed higher up in the furnace by the action of the ore. Therefore, the heat reaction arising from the setting free of oxygen from the steam will consist simply of the union of 8/9=0.89 kg. of oxygen with sufficient carbon to form CO.

$$.67 \text{ kg. C.} + .89 \text{ kg. O},$$

which will produce 1650 calories. It would seem, therefore, that the true refrigerating effect of the decomposition of H_2O will be the heat absorbed in setting free 1/9 kg. of hydrogen, which will equal the heat produced by burning 1/9 kg. of hydrogen$=\frac{30000}{9}$ =3333 cals. minus the heat produced by the union of the oxygen with carbon=3333—1650=1683 calories.

There is, however, another point to be considered. We may view the reaction not in the light of the dissociation of steam, but as the oxidation of carbon, and this carbon, had it not been burned by water, would have been burned by air, and in this case would have produced a positive gain in heat. It may be correct and it may be a fallacy to view this hoped for heat as part of the problem. If we do so view it, it would tend to counterbalance the heat produced by the oxygen of the steam, but it cannot entirely counterbalance it since the steam carries no nitrogen with it, while the oxygen of the air carries a heavy load of inert matter. The question is very puzzling, but the answer is of considerable importance. In Table II-H the refinements just elaborated have been omitted and the dissociation of one kilogramme of steam is considered to absorb the same amount of heat as the oxidation of the hydrogen contained therein.

TABLE II-H.

Vapor in the Atmosphere as Affecting the Blast Furnace.

Degrees Fahr.	Cubic Feet of Air Needed per Ton of Pig Iron.	Pounds of Water in One Cubic Foot of Saturated Air.	Pounds of Water in Air Needed per Ton of Pig Iron	Calories Absorbed in Dissociating this Steam. 1 kg.=3333 cals. 1 lb.=1510 cals.	Pounds of Coke Represented by this absorption. 1 kg. coke=4200 cals. 1 lb. coke=1900 cals.	
					100 Per Cent. Humidity.	40 Per Cent. Humidity.
32	100,000	.000304	30.4	45,900	24	10
42	102 000	.000440	44.9	67,800	36	14
52	104,000	.000627	65.2	98 500	52	22
62	106,000	.000881	93.4	141,000	74	30
72	108,000	.001221	131.9	199,200	105	42
82	110,000	.001667	183.4	276,900	146	58
92	112,000	.002250	252.0	380,500	200	80

From this it will be seen that a saturated atmosphere of 92° F., which sometimes exists during the day in America, calls for an expenditure of 200 pounds more fuel per ton of iron than dry air at 32° F. It also shows that at low temperatures, it matters very little whether the air is saturated or not, as the content of vapor is so small in either case, and it shows that a saturated atmosphere of 60° F. will demand no more fuel than a dry air of 85° F., as the content of vapor is the same in either case. A summer temperature of 90° F. means that the blowing engines must run one sixth faster to give the same wind, and that the coke consumption will be from 70 to 200 pounds higher per ton of iron than on a moderately cool winter day.

NOTE: On reading the manuscript of the foregoing discussion, Professor J. W. Richards offers the following:

The carbon burnt to carbonic oxide at the tuyeres produces the heat of formation of carbonic oxide, no matter where the oxygen comes from. If the oxygen comes in as air, the above heat is generated and is available; if part of the oxygen comes in as steam, the above heat is also generated but not all is available, and a deduction must be made for the heat required to decompose the steam and set the oxygen free. The chilling effect of the steam is therefore 29,000 calories per kilo of hydrogen thus liberated.

To keep the zone of fusion at the same temperature while this chilling effect is being produced, requires that more carbon be burnt there per unit of burden to be fused; therefore the chilling effect at the tuyeres can only be counteracted by either decreasing the burden or increasing the fuel ratio. If the burden is considered constant, then more carbon must be burnt at the tuyeres, enough more to make up for the chilling effect; and since carbon burns at the tuyeres only to carbonic oxide, the extra amount to be burnt at the tuyeres will be the chilling effect in calories divided by the heat effect (generated and introduced in hot blast) per kilo of carbon consumed at the tuyeres. Assuming that coke contains 90 per cent. of fixed carbon, of which 90 per cent. is burned at the tuyeres, and that the hot blast brings in one-half as much heat as is generated by combustion, one kilo of coke will represent $(90 \times 90 \times 2{,}450) \times \frac{3}{2} = 2{,}977$ calories, and the increased amount of coke required is equal to the chilling effect divided by 2,977 (using kilos and kg. calories).

Sec. IIi.—*Tunnel head gases.*—The volume and the quality of the tunnel head gases are becoming more and more a matter of moment as progressive steel works managers are no longer content to merely raise sufficient steam at the furnace for the furnace itself, but are making all the steam possible and supplying power to other departments. The question also appears important in view of the development of gas engines driven by blast furnace gases. Needless to say that no provision is ever made at furnaces to measure the volume of these gases. A rough calculation can be made from the amount of air blown, but this in turn is generally an unknown quantity. Furnacemen habitually speak of the number of cubic feet blown, when they mean the cubical displacement of the air pistons, without knowing accurately the amount lost by leaks in the piston packing, at valves, at tuyeres, and at joints. With engines in fair condition and blowing against ordinary pressures, this way of speaking does very well to compare one furnace with another, but it will hardly suffice as a basis for a determination of the gas produced at the tunnel head.

The composition of the gas varies considerably, but usually within well defined limits. It is composed almost entirely of five substances, nitrogen, hydrogen, carbonic acid, carbonic oxide and steam. In any complete investigation of the blast furnace the weight of this steam must be taken into consideration, for it carries off a considerable amount of sensible heat, and in burning the gas either in the stoves or under boilers allowance must be made for the sensible heat carried away by this steam in the products of combustion going to the stack, but except as a vehicle of sensible heat it hardly affects the work on hand. In determining the composition of the gases, steam is seldom taken into account, for it condenses in the cooling tubes and therefore does not appear in the volumetric operations.

Moreover, the amount of water present varies so greatly and depends so much upon accidental or temporary conditions that it is impossible to say what is a fair average. In wet weather the coke and the ores may both be saturated, while in dry weather they may both contain very little moisture, so that the quantity of water or steam present in the gases will vary through a wide range. When it is considered that, as above stated, the effect of this moisture is very slight, it may be well to ignore its presence altogether.

Hydrogen is present in very variable quantity and the experiments of Bell shed very little light on the conditions surrounding its creation. The moisture in the blast is without doubt all dissociated in the zone of fusion, but most of the hydrogen caused thereby is oxidized again in the upper parts of the furnace. A certain amount of hydrogen comes from the small proportion of volatile matters in the coke. From these and possibly other causes the gas is usually found to contain anywhere from five tenths of one per cent. to three per cent. of hydrogen by volume. The weight of this hydrogen, however, is so small that it represents a very small amount of oxygen and in the following calculation no attention will be paid to the reaction by which it is produced. It will, however, be assumed that the tunnel head gases contain five-tenths of one per cent. of free hydrogen, since the heating power of this small quantity is worthy to be taken into account.

The nitrogen which constitutes about sixty per cent, by volume of the total gases comes from the blast and from nowhere else. The carbon comes from the coke and from the carbonic acid in the limestone. The oxygen comes from the blast, from the ore and from the carbonic acid in the limestone. Most of these factors are known accurately and it is possible to calculate just what the volume of tunnel head gases will be when the weights of the different materials going in at the top are known, as the weight of the carbon in the coke and the stone is known accurately and all this carbon, with the exception of what is combined in the pig iron, must be contained in the gases. Thus if we know the ratio of CO_2 to CO in these gases we may know just how much carbon exists as CO_2, and how much as CO, and from this we may calculate the weights of these two gases and the amount of oxygen.

Taking then the total amount of oxygen thus determined and subtracting the oxygen added by the ore and the stone we have the amount of oxygen added in the blast. The amount of oxygen in the stone is easily found as it is only necessary to account for the oxygen in the carbonic acid, since the oxygen combined with calcium will remain in combination with the slag. The amount in the ore is also accurately known, for no matter how poor or how rich the ore may be, every ton of pig iron contains about 95 per cent. metallic iron, provided it is a low phosphorus pig iron, the remaining five per cent being carbon and silicon, and this 95 per cent. of metallic iron existed in the ore in the form of iron oxide, either as ferrous or ferric or magnetic oxide. In either case the amount of oxide per unit of iron can be determined. In the present case it is assumed that hematite ore is used and the iron is of course in the form of Fe_2O_3.

Calculating in this way I have given in Table II-I the amount of tunnel head gases made under different methods of practice. Thus, for instance, in practice *A* it is assumed that 1600 pounds of coke and 600 pounds of stone are used per ton of iron and that the gases contain 1.5 per cent. CO to 1 per cent. CO_2.

In practice B, 1600 pounds of coke and 1000 pounds of stone are used with the same ratio of 1.5 and so on up to practice I which represents conditions with a very lean and very sulphurous ore requiring a hot working furnace with large lime additions calling for 3000 pounds of coke and 2000 pounds of stone, this assumption not being theoretical at all, but being matched in practice. It is assumed that the ratio in this case is 2.5. Calculating these different conditions we find the volume per ton of iron with the heat value per cubic metre and by multiplying these together, we get the heat value of the gases per ton of iron. It will be seen that the heat value per cubic metre changes very little, for the percentage of CO stays reasonably constant and it is the percentage of CO_2 that varies, but the value of the gases varies very nearly in proportion to the amount of fuel used and consequently a furnace using a large proportion of fuel has a chance to recover some of the energy that is wasted in the large quantity of gases escaping from the tunnel head, since these gases can produce a large amount of power if properly used.

It has been stated by Bell that we cannot hope that the tunnel head gases will contain a ratio of less than 2 of CO to 1 CO_2, but

TABLE II-I.

Volume and Composition of Tunnel Head Gases under Different Conditions.

Assumptions: Coke=87 per cent. carbon; Limestone =97 per cent. $CaCO_3$; Pig Iron=95 per cent. Fe and 3.75 per cent. C. Tunnel Head gas contains 0.5 per cent. H.

Practice.	Ratio CO_2 to CO.	Per Ton Pig Iron Lbs.		Carbon Per Ton Iron.				Carbon in Gases Per Ton Iron, Kg.		Weight Per Ton Iron, Kg.		Oxygen Per Ton Iron, Kg.			
		Coke.	Stone.	In Coke and Stone, Lbs.	In Pig Iron, Lbs.	In Gases, Lbs.	In Gases, Kg.	As CO_2	As CO.	CO_2	CO.	In Gases.	From Ore.	From Stone.	From Blast by (difference.)
A	1.5	1600	600	1464	84	1380	627	251	376	920	877	1170	415	88	667
B	1.5	1600	1000	1512	84	1428	649	259	390	950	910	1211	415	147	649
C	1.7	1900	1000	1773	84	1689	768	284	484	1041	1129	1402	415	147	840
D	2.0	1900	1000	1773	84	1689	768	256	512	939	1195	1368	415	147	806
E	1.7	2200	1000	2034	84	1950	886	328	558	1203	1302	1619	415	147	1057
F	2.0	2200	1000	2034	84	1950	886	295	593	1082	1384	1580	415	147	1018
G	2.25	2500	1000	2295	84	2211	1005	809	696	1133	162	1752	415	147	1190
H	2.5	2500	1000	2295	84	2211	1005	287	718	1052	1675	1722	415	147	1160
I	2.50	3000	2000	2850	84	2766	1258	360	898	1320	2095	2157	415	296	1446

Practice	Weight of Nitrogen Per Ton Pig Iron Calculated from Weight of Oxygen. Kg.	Volume of Gases Per Ton Iron; Cubic Metres.			Composition of Gases; Per Cent.			Volume and Heat Value Per Ton Iron.		
		CO_2.	CO.	N.	CO_2.	CO.	N.	Volume Cubic Metres.	Heat Value; Cals. Per Cu. M.	Heat Value Per Ton Iron. Cals.
A	2208	467	702	1752	15.99	24.03	59.98	2921	736	2 150,000
B	2148	482	728	1705	16.54	24.97	58.49	2915	764	2,227,000
C	2780	528	903	2206	14.52	24.83	60.65	3637	760	2,764,000
D	2668	477	956	2118	13.43	26.92	59.65	3551	823	2,922,000
E	3499	611	1042	2778	13.79	23.51	62.70	4431	720	3,190,000
F	3370	549	1107	2675	12.68	25.56	61.76	4331	782	3,387,000
G	3939	575	1299	3126	11.50	25.98	62.52	5000	794	3,970,000
H	3840	534	1340	3048	10.85	27 23	61.92	4922	826	4,066,000
I	4786	670	1676	3798	10.90	27.28	61.82	6144	818	5,026,000

there are plenty of instances in America where the results show a better record than this. Thus Whiting* records the continuous operation of a furnace where the ratio was 1.5. He does not give the percentage composition of the gases, but as he gives all the other data, I have calculated that it probably ran as follows:

CO_2 15.8 per cent. CO 23.7 per cent. N 60.5 per cent.

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* *Trans. A. I. M. E.*, Vol. XX, p. 280.

At one of the large steel works in America known for its low fuel consumption, I am told that the average composition of the gases gives CO_2 14.5 per cent., CO 27 per cent, and N 58.5 per cent. This is a ratio of 1.88.

At a 65-foot furnace at the Pennsylvania Steel Works the average composition of the gases for one and a half hours showed as follows:

CO_2 13.7 per cent. CO 23.7 per cent. N 63.1 per cent.

giving a ratio of 1.7 per cent. Samples taken on three other days gave very nearly the same ratio, one being less and the other two somewhat more.

By referring to Table II-I it will be seen that practice A approaches very close to the data given by Whiting and according to his figures it is probable that he used about 1650 pounds of coke per ton of iron and about 600 pounds of stone, his ratio being 1.5. The large steel works referred to with a ratio of 1.88 corresponds very closely to either practice C or D, while the furnace at the Pennsylvania Steel Works, with a ratio of 1.7 corresponds very well with practice C.

It will be found that in every case the heat value of the gases gives approximately 50 per cent. of the heat value of the fuel charge, which was the conclusion arrived at in another section.

In making these calculations, it is recognized that certain errors are unavoidable and that certain conditions have been omitted that have an influence on the result. Thus there is a certain amount of silicon produced from the silica of the ore and coke and this silicon when it is reduced gives up its oxygen to the gases. In the same way a small proportion of calcium oxide is reduced, the calcium uniting with the sulphur as sulphide and the oxygen escaping with the gases. A certain amount of water may be decomposed and the hydrogen escape in the form of free hydrogen, while the oxygen goes off in the gases, and the oxygen formed by these three reactions is not accompanied by any nitrogen, while in our calculation we have assumed that the oxygen not coming from the ore and the stone was accompanied by the proper atmospheric proportion of nitrogen.

But these refinements are not really necessary for a practical determination as the results are much more accurate than would be supposed at first glance. The carbon comes from the stone and from the fuel and from them alone, and the important point in all investigations of tunnel head gases is to find the amount of carbon escaping as CO_2 and as CO. It is a matter of very little moment how much or how little nitrogen accompanies these two gases, for the only gas of any interest after it leaves the tunnel head is the carbonic oxide. If a wrong calculation is made concerning the nitrogen, the figures will merely show that this percentage of carbonic oxide is either too high or too low. If our error shows too low a percentage of carbonic oxide we shall have a reduced calorific value per cubic metre and a larger volume, while if our calculations have erred in the other direction, we shall have too high a calorific value per cubic metre and too small a volume. In either case the product of the two, which will give the value of the tunnel head gas per ton of iron, will be a constant.

Having thus found the heat value per ton of iron escaping in the waste gas we may find the horse power represented by that gas, and it is shown in Table II-I that according to the amount of fuel used the value will vary through very wide limits, according to the amount of fuel used. It is always best to assume that there will be progress in fuel economy, and this is the same thing as saying that there will be less and less heat value per ton of iron escaping in the tunnel head gases. Taking therefore the minimum, which is practice A in the table, we have 2,150,000 calories produced per ton of iron, which is equivalent to a total production of 645,000,000 calories in a furnace making 300 tons of iron in twenty-four hours. It is an accepted fact that one horse power used steadily throughout 24 hours represents 61,080 British thermal units or 15,394 calories, so that the total energy represented by the tunnel head gases will be 645,000,000, divided by 15,394 or about 42,000 horse power if every unit of force could be put into action. As a matter of fact fully one third of the gas goes to the stoves, leaving about 28,000 horse power for the boilers. It is a well known fact that the best boilers, when fired with coal under the most favorable conditions, can absorb 80 per cent. of the energy in the fuel, but it is seldom that good boilers, under ordinary conditions, utilize more than 70 per cent. In blast-furnace work, the results are often much worse than this, since the gases vary very much and it is impossible to supply the air in just the right quantity. Moreover, the gas does not burn readily at all times and it is impossible to avoid either a loss from unburned carbon or a carrying away of heat by an excess of air. The dust also deposits on the surface of the boiler and retards the absorption of heat, while the low temperature of the gases as they enter the fire chamber preclude the best utilization of energy.

From all these causes it is probable that the boilers at some plants do not appropriate more than sixty per cent, of the energy supplied to them, and this reduces the effective energy to 17,000 horse power, and as a compound steam engine utilizes only 10 per cent. of the energy delivered to it in steam, it follows that such an engine can develop 1700 horse power from a blast furnace making 300 tons of iron per day. The modern blowing engines for such a furnace will require not over 1500 horse power, and there will therefore be a slight excess of steam if the foregoing assumptions are correct, and a considerable excess if the boilers are more efficient than before assumed.

It will be granted that actual results prove the calculations just elaborated, and that the available engine power is almost exactly as shown. This indicates that the figures are correct, and they may be summarized as follows:

(1) From 3000 to 4000 cubic metres or 106,000 to 141,000 cubic feet of tunnel head gases are made per ton of pig-iron, when the fuel consumption is from 1600 to 2000 pounds per ton of iron.

(2) About one third of the gas is needed to heat the stoves.

(3) The boilers absorb and utilize only from 60 to 80 per cent. of the real heating value of the gases going to them.

(4) The blowing engine absorbs only ten per cent. of the energy in the steam going to it.

(5) If a gas engine be used, its efficiency must be compared not with the steam engine alone, but with the boiler and steam engine together.

(6) With a higher coke consumption, the heating value per cubic metre will be increased somewhat and in addition the total volume of gases will be increased nearly in proportion to the weight of fuel.

(7) The heat value of the tunnel head gas is about 50 per cent. of the total heat value of the coke, whether the consumption of fuel is high or low.

(8) This calculation takes no account of wasteful furnaces or of those running on exceptionally bad ores, or on coke containing a large amount of hydrocarbons. Thus in Stahl und Eisen, Nov. 1, 1901, Lürmann gives the composition of gases from different fur-

naces in Germany. A Westphalian furnace gave a ratio of 2.9 with 4.0 per cent. hydrogen; one in the Minette district a ratio of 2.75 with 3.0 per cent. hydrogen; one in Silesia gave a ratio of 5.5 and another contained 6.3 per cent. of hydrogen. With very poor ores the value of the tunnel head gases must be much greater than with a rich burden and if they are entirely utilized the power obtained from them will atone in some measure for the greater amount of fuel needed to smelt the leaner mixture. For this reason the use of gas engines is more important in the Minette district of Germany than in the United States.

SEC. IIj.—*The Utilization of the Tunnel Head Gases.*—(*a*) *Use of the potential heat in stoves and boilers.*

It must always happen that in the combustion of the tunnel head gases a great deal of heat is lost. One cause of this is the low temperature of the gases as they enter the combustion chamber of either the boiler or the oven and, as a consequence, the flame is very long and, as it is cooled by contact with the surfaces to be heated, either some CO will go to the stack unburned, or there will be a considerable excess of air, giving a certain amount of free oxygen in the escaping gases together with its attendant nitrogen; sometimes there will be both a certain amount of CO and an excess of air.

Under ordinary conditions of fuel consumption it is possible to calculate quite accurately how much heat is lost by either or both of these conditions, for a piece of coal or coke, if burned with just the right amount of air, must ultimately give a certain percentage of CO_2 and a certain percentage of nitrogen, and it makes no difference whether this combustion is all done in one place, as for instance the shallow fire of a cook stove, or whether it is partially done in a gas producer and completed in a heating furnace. In either case the final result will be the same.

In the blast furnace we have certain complicating circumstances, for oxygen is supplied by the ore without nitrogen, and carbonic acid is supplied by the limestone, so that the ratio of carbon to oxygen in the ultimate products of combustion is entirely different from the ratio that will result from the combustion of carbon under usual conditions, and it will be evident that this ratio will depend upon the amount of limestone used per ton of coke, and upon the amount of air. In this way the composition of the gas will vary in different districts, and with different furnaces, for if one uses 2300 pounds of coke per ton of iron the amount of carbon to a pound of oxygen in the products of combustion will be greater than in a furnace running on the same ores and with the same limestone and using 2000 pounds of coke per ton of iron.

TABLE II-J.

Percentages of CO_2 and O in Products of Combustion when Gases A and I (Table II-I) are Burned with Varying Amounts of Air.

Excess of Air.	Per cent. CO_2		Per cent. free O	
	Gas A	Gas I	Gas A	Gas I
No excess	27.55	25.21	....	....
100 per cent excess	19.75	17.64	5.93	6.30

A little consideration, however, will show that in a furnace using a regular amount of coke and a regular amount of limestone per ton of iron, it matters not at all how complete or incomplete the reactions may be in the furnace, and how much as a consequence the tunnel head gases may vary in composition from day to day, the ultimate products of combustion from the burning of these gases will be the same. It will also be shown in Table II-J that although different conditions of practice give unlike gases and that these may give unlike products of combustion, the variations in these products are so small that they may be neglected in all practical investigations into the question of heat utilization. In this Table II-J, we have taken gases A and I from Table II-I as representing two extremes of furnace practice and two very different types of tunnel head gases. The first line gives the composition when the exact theoretical amount of air is supplied, assuming perfect combustion, while the second line gives the composition when double the needed amount of air is used. It will be seen that as far as practical purposes are concerned the composition of the products is the same for both gas A and gas I, and it is therefore unnecessary to go into the refinement of calculating each individual blast furnace gas to find out what the composition of the products will be, for if two extreme cases give results so closely alike, we may safely assume that all gases will bear a close resemblance.

It will always happen in burning blast furnace gas or any other fuel, that a certain amount of excess air must be added to insure perfect combustion, and for this reason the composition has just been given of the products with a large excess of air. It is very often desirable to know just how much excess is added, and it has been the custom in making experiments in the combustion of coal under boilers to estimate the amount from the percentage of CO_2 in the products of combustion. In the case of burning coal this method is not far in error, for, as before explained, the products of combustion must always be the same for a given excess of air; but blast furnace gas is not constant, and the products of combustion are not exactly the same for different gases. A very much better exponent of the amount of excess air present is the percentage of free oxygen. This, of course, varies somewhat with different gases, but in Table II-J it is shown that a certain percentage of excess air gives about the same percentage of free oxygen in the products of combustion, even though the initial gases were quite different.

It often happens that a certain amount of CO escapes unburned, whereby not only is there a loss of energy, but the composition of the products of combustion is changed somewhat, as less air is needed for what combustion takes place and therefore the volume is decreased and the ratio of the different components is altered. It also will happen under these circumstances that a given percentage of free oxygen will represent a slightly different percentage of excess air than when no free CO is present, but I have found by calculation that the error thus caused is so slight it may be disregarded. It is necessary, however, to consider the amount of CO which escapes in this way, and in Table II-K are shown the results of calculation on Gas D in Table II-I, which is chosen as being of average composition. The general conclusions to be drawn from these results are as follows:

(1) The products of combustion of all tunnel head gases are of approximately the same composition, and, therefore, the volume and weight produced per unit of coke charged will be the same.

(2) The percentage of CO_2 in the products is not a good measure of the amount of excess air.

(3) The percentage of free oxygen in the products is a good measure of the amount of excess air.

(4) When CO escapes unburned the composition of the prod-

ucts is altered not only by the presence of CO, but on account of the smaller amount of air needed for the imperfect combustion.

(5) This alteration in composition is not sufficient to affect materially the accuraey of the estimation of the amount of excess air from the percentage of free oxygen present, since the change in the proportion of oxygen is not great enough to invalidate the result.

(6) The proportion of the unburned CO in the products is a measure of the proportion of the original CO escaping.

(7) In thus estimating the proportion of CO lost in the products it is unnecessary to make any allowance for the percentage of excess air, since this does not cause sufficient variation within usual limits, to seriously affect the accuracy of the result.

(8) The presence of CO in the products indicates a loss of combustible matter amounting to the proportions of the original energy shown in Table II-K.

TABLE II-K.

Loss of Heat by Presence of CO in Products of Combustion.

Per cent. CO in products.	Proportion of energy lost.
0.65 to 1.00	5 per cent.
1.00 to 2.00	10 per cent.
2.00 to 2 80	15 per cent.
2.80 to 3.80	20 per cent.
3.80 to 5.00	25 per cent.

The lower percentages apply to cases where no excess air is present, and the higher to those where there is 100 per cent. excess.

The unburned CO in the products of combustion represents a certain loss of heat without any regard to the temperature at which these products escape to the stack, but in addition to this there is a cerain loss of heat from excess air, this loss depending entirely on the temperature at which the gases escape. If the products of combustion go to the chimney at exactly the same temperature as the air and gas entered the combustion chamber, or if they escape at the temperature of the atmosphere, then there will be no loss of heat, no matter how much air is used in excess; but the products of combustion always do escape at a higher temperature and, by virtue of this, they carry away a certain amount of sensible heat, and that loss is greater just in proportion to the temperature of the escaping gases, and therefore each cubic metre of air which is admitted in excess of the theoretical requirements carries away in the chimney a certain amount of sensible heat for every degree of temperature.

Referring to Table II-I in Section IIi, giving the composition of different tunnel head gases, we may take Gas D as representing a very fair coke consumption and a very good carbon ratio. This gas is as follows:

CO_2 13.43 CO 26.92 N 56.95

Calculating this gas as burning with different amounts of air we have Table II-L. The volume of the products does not increase exactly in proportion to the volume of air supplied, because there is a certain constant shrinkage due to the combustion of the original CO. Perfect combustion, without any excess of air, produces a certain volume of gases and any excess of air beyond this dilutes the gases by an exactly similar amount, and this excess air carries with it a certain amount of sensible heat. It is possible to calculate the loss carried away by this excess air alone; but the method adopted in this table is to give the total loss as carried away by the products of combustion, including the excess air. It will be seen, for instance, that when the gas is burned with just sufficient air and the products escape at 200° C.=390° F., the products of combustion carry away 12.5 per cent. of all the heat produced, while when 100 per cent. excess air is present, which is to say that air is supplied in double the quantity theoretically necessary, the products of combustion at 200° C. carry away 17.4 per cent. of all the heat supplied. At 600° C., which is just below a red heat, the combustion with the theoretical amount of air indicates that the products of combustion carry away 41.8 per cent. of all the heat produced, while with 100 per cent. excess air the products carry away 56.9 per cent. Thus 100 per cent. excess air means an additional loss of 5 per cent. when the products escape at 200° C. and 15 per cent. when they escape at 600° C. By comparing these results with the figures which have been given in Table II-K, it will be found that as long as the products escape to the stack at a moderate temperature, a very large excess of air is to be preferred to the escaping of a small quantity of CO; thus it was shown that the presence of less than one per cent. CO indicated a loss of 5 per cent. of all the heat value, while Table II-L indicates that the escaping gases at a temperature of 400° C. carry away 26.6 per cent. of all the heat with no excess air and 30.6 per cent. of all the heat when 40 per cent. excess air is present, thus showing that 40 per cent. excess air is responsible for a loss of only 4 per cent. of the heat produced. Consequently it would be necessary to have 50 per cent. excess air and a stack temperature of 400° C. in order that the loss from such excess air should equal the loss from the presence of one per cent. of CO in the products of combustion.

TABLE II-L.

Data on Products of Combustion of Gas D (Table II-I).

NOTE—The specific heats of the gases were calculated for 0° and 600° and for no excess of air and for 100 per cent. excess. Intermediate points are interpolated. Calorific value of gas = 823 cals. per cu. m.

Excess of air; per cent.	Per cent. of free oxygen in products.	Per 100 volumes of gas burned.		Per cent. of total heat generated which is carried away by the sensible heat of the products when these products escape at different temperatures; also the specific heat of the products at these temperatures.					
		Volume of air Supplied.	Volume of products.	200°C (390°F)		400°C (750°F)		600°C (1110°F)	
				Specific heat of gases.	Per cent. of heat lost.	Specific heat of gases.	Per cent. of heat lost.	Specific heat of gases.	Per cent. of heat lost.
0	0.00	64	151	.342	12.5	.362	26.6	.380	41.8
20	1.64	77	164	.340	13.5	.360	28.6	.377	44.8
40	3.05	90	176	.338	14.5	.357	30.6	.373	47.8
60	4.27	103	189	.337	15.5	.354	32.6	.369	50.8
80	5.33	116	202	.335	16.5	.351	34.6	.366	53.8
100	6.26	128	215	.333	17.4	.349	36.5	.363	56.9

It will be found that the gases often contain both an excess of air and a certain amount of CO. If the mixture during its combustion could be passed through an indefinite length of hot passages, it would hardly be possible that free oxygen and free CO could remain uncombined in any large proportion, but there is a limit to the completeness of combustion under practical circumstances, as in burning a gas under boilers the flame comes in contact with cold metallic surfaces which check or retard combustion in the same way that a cold piece of iron put in a candle flame will stop the chemical action and will cause carbon and carbonaceous compounds to be deposited upon the metal. In this way a certain amount of carbon and oxygen escape from the stack without uniting one with the other. The way to prevent this is to cause combustion to be more thoroughly accomplished before it comes in contact with the water cooled surface.

It is necessary to note that in comparing analyses of products of combustion we should add together the losses shown by the excess air and the unburned CO; thus we may have a loss of seven per cent. caused by excess air as indicated by free oxygen, and at the same time a loss of two per cent. indicated by the presence of a certain proportion of CO.

Summarizing the foregoing conclusions and interpolating in the tables we may say that of all the heat produced, the losses in the products of combustion will be in round numbers according to the following schedule:

Ten per cent. will be lost by any one of the following conditions:

(a) By the sensible heat of the products of perfect combustion escaping at 160° C.=320° F. when no free oxygen is present.

(b) By the sensible heat of the products escaping at 120° C. =250° F. when they contain from 6.0 to 7.0 per cent. of oxygen showing 100 per cent. excess air.

(c) By the presence of from 1.3 to 1.9 per cent. CO.

Twenty per cent. will be lost:

(a) By the sensible heat of the products escaping at 300° C. =570° F. when no free oxygen is present.

(b) By the sensible heat of the products escaping at 250° C. =480° F. when they contain from 6.0 to 7.0 per cent. of oxygen showing 80 per cent. excess air.

(c) By the presence of from 3.0 to 4.0 per cent. CO.

Thirty per cent. will be lost:

(a) By the sensible heat of the products escaping at 450° C. =840° F. when no free oxygen is present.

(b) By the sensible heat of the products escaping at 330° C. =630° F. when they contain from 6.0 to 7.0 per cent. of oxygen showing 100 per cent. excess air.

(c) By the presence in the products of 6.0 per cent. of CO.

Forty per cent. will be lost:

(a) By the sensible heat of the products escaping at 600° C. =1110° F. when they have been burned with the theoretical amount of air.

(b) By the sensible heat of the products escaping at 440° C. =820° F. when they contain from 6.0 to 7.0 per cent. of oxygen showing 100 per cent. of excess air.

It will be understood that a large percentage of loss may occur by a combination of any two of these factors, as for instance, when the products contain both free oxygen and unburned CO, under which conditions the total loss is the sum of the two factors.

(b) *The Use of Sensible Heat of Gas in Stoves and Boilers.*— When the tunnel head gases are taken directly to the stoves or to the boilers without scrubbing, all the sensible heat of the gas is used as the temperature of the resulting combustion is just that much higher and its efficiency just that much greater. When the gas is scrubbed, this sensible heat is lost and there is an additional disadvantage in the water vapor that will be carried to the stoves or boilers. When the gases are taken directly from the tunnel head to the combustion chamber there is considerable steam present, but it is in the form of a gas, and if this is subsequently dissociated with absorption of heat, the hydrogen produced is again oxidized into steam and therefore there is no heat lost, but in the passage through a scrubber there is a considerable quantity of water carried along in the shape of fog and all this moisture must be converted into steam in the stove or in the boiler.

It may very likely be advantageous in many cases to scrub the gas in spite of this for there is no doubt that if the scrubbing were perfectly successful, in other words if every particle of foreign matter were to be eliminated, there would be a great advantage in having a clean gas, for instead of the crude apparatus in use for burning these gases, we could then substitute something in the form of a Bunsen burner and get almost perfect combustion in exactly the place wanted, but the great difficulty is that we cannot remove the last traces of the sublimate and these clog the action of any Bunsen burner or anything approaching its structure. The future will doubtless see a very much better arrangement for burning these blast furnace gases than now exists, and it is possible that thorough scrubbing will be a prerequisite to the introduction of such methods.

It has already been stated that Gas D, in Table II-I, represents a very good fuel consumption and a good carbon ratio, and it was shown that when a furnace is running under these conditions it produces 3551 cubic metres of gas per ton of pig-iron. Calculating the amount of air needed to burn this we find that 2060 cubic metres are called for theoretically, while with 100 per cent. excess of air, just double that quantity, or 4120 cubic metres, will be required. It is shown in Section IIh that a furnace producing such a gas requires 2687 cubic metres of air per ton of iron to be supplied by the blowing engines, and it is clear, therefore, that if the tunnel head gases are burned with 30 per cent. excess air, the amount of air needed for their combustion in the stoves and boilers equals the amount of air required from the blowing engines. It is probable that more than this proportion of excess air is generally used so that the air needed for combustion exceeds the amount supplied in the blast.

It is probable that few furnacemen appreciate this fact, or will even believe it. If one-third of the gas is taken to the stoves then the stoves are receiving more than one-third of the amount of air delivered by the blowing engines, and if the boilers are receiving two-thirds of the tunnel head gases then the air inlets at the combustion chamber are receiving two-thirds as much air as the blowing engines deliver to the tuyeres. It is almost out of the question to pre-heat all this air for, by the nature of the case, if the volume of air required by the tunnel head gases is as great as the volume required by the furnace, it would require as large an outfit of stoves as is required by the furnace, and there is no available place for the heat to come from except from the combustion of the gases themselves, and this would be wasting at one end and gaining at the other. It will be shown later that the introduction of gas engines may render possible the preheating of this air by the heat of the waste gases escaping from the cylinders of the engines.

(c) *Use of tunnel head gases in gas engines.*

It is a well-known fact that blast furnace gas can be used in gas engines for developing power, and it is just as well known that a given amount of gas will develop about twice as much energy in a gas engine as it will if burned under boilers and the resultant steam be used in a steam engine. High authority has stated that the available power is 3.6 times as great, under practical conditions. I prefer for purposes of illustration to make the conservative assumption that the gas engine will give twice the power.

It is highly probable that there will be less irregularity if the gas is burned in gas engines than if it is burned under boilers, because the real calorific power of blast furnace gas does not vary as much as is generally supposed. It does often for a considerable period possess a strong disinclination to burn under a boiler, this being particularly noticeable when the furnace is very hot, for the furnacemen then say that the gas is "gray" and that it is "poor," because it will not burn with a clear flame; but this gas is of the same composition as free burning gas, and if it is mixed with a proper amount of air in the cylinder of a gas engine and ignited by an electric spark, it should give the normal amount of energy.

In Section IIi it was shown that under certain assumptions of rather low fuel the tunnel head gases contained sufficient energy to produce 42,000 horse power if every unit of force could be utilized. It was also stated that under usual conditions at least one-third of the gas was used in heating the stoves, leaving an equivalent of 28,000 horse power in the gas going to the boilers, but that owing to the losses in boilers and engines we found that very little more power was developed than was necessary to run the blowing engine. It is possible to increase this surplus somewhat by having a better boiler plant than was assumed, and it has been shown that a furnace using a greater proportion of fuel will furnish a much greater surplus of power, but it was considered best to presuppose a reasonable economy of fuel with a fair outfit of boilers. In order to compare a given set of conditions where steam engines are used with similar conditions where gas engines are installed, it will be assumed that the gases available after the stoves are supplied contain 28,000 horse power. If the plant is equipped with an extra good boiler plant, the steam will represent 75 per cent. of the energy in the gas, or 21,000 horse power, and if good compound engines are used it will be possible to develop from this about 2100 horse power, so that if the blowing engine calls for 1500 horse power there will be a surplus of 600 horse power available for pumping and for outside uses.

If it is supposed that just enough steam is produced to run the blowing engines and the surplus gas is diverted to gas engines, and if it is supposed that twice as much surplus power is developed in this way, it follows that each 300-ton furnace will furnish 1200 excess horse power. This increase is important, and seems to fill the minds of many men as one of the coming economies, but as a matter of fact it is merely the beginning, for the first step in true economy is the operation of the blowing engine by gas, since in this way instead of developing a total of 2100 horse power there will be a total of 4200 horse power, and after subtracting the 1500 necessary for blowing there will remain a surplus of 2700 horse power for outside uses. Thus the use of gas engines for auxiliaries only gives just double the amount of power available for outside uses, but the use of gas for blowing engines gives four and one-half times as much surplus as furnished by a steam plant.

This calculation presupposes that the steam engine utilizes 7.5 per cent. of all the energy contained in the gases supplied to the boiler, and that the gas engine utilizes 15.0 per cent. The best steam plants do better than this, but it must be considered that blast furnace gas is not the most desirable kind of fuel and that the operation of a blowing engine against a varying load does not present the best conditions for steam economy. For the same reasons the efficiency of the gas engine is taken considerably below what has been done under favorable conditions.

Taking the figures just found it is shown that for each 300 tons of pig-iron produced there will be a surplus of 2700 horse power, and in a steel plant making two thousand tons of pig iron per day this is equivalent to 18,000 horse power, which is ample to run all the converting plants and rolling mills necessary to finish this quantity of pig-iron into rails, or into the ordinary forms of finished material. In order to utilize this source of supply to the best advantage, it will doubtless be necessary to install a central electric station in which all the gas is used to develop electric power which is then distributed to motors that drive the rolling mills. If this plan can be carried out, no boilers will be used in the entire steel works, the only fuel being that used for heating.

The importance of this problem has been long recognized and it may be well to record the steps that have been taken to reach a solution, and then explain why the introduction of gas engines is so long delayed. The historical facts may be thus summarized:

In May, 1894, B. H. Thwaite applied for a patent in England which was granted in May, 1895 (No. 8670), for a method of purifying blast furnace gas for use in gas engines; acting along the lines laid down by Thwaite, the first gas engine driven by furnace gas was set to work in February, 1895, by James Riley, manager of the works at Wishaw, Scotland. This motor was a success and was in operation four years later. At this time the importance of the work was understood, calculations being made on the saving to be expected, and from that time until now, various gas engine builders have experimented in this field. With one exception the cleaning of the gas has been considered necessary, this exception being the Cockerill Co., which announced that the gas could be used in its engines without scrubbing, but the results have not been entirely satisfactory and the washing of the gas is now looked upon as a necessity by the company at Seraing. In 1899 it was promulgated far and wide that the whole problem was solved and American engineers were looked upon as being behind the times for not equipping their plants with gas engines. During that year I visited every gas engine in Europe which was operated by furnace gas. Every builder was anxious to show his engine as an example of successful construction, and most managers of works were willing to exhibit their plants as evidence of their progressiveness, but nevertheless I put on record in an official report the following conclusions:

(1) That there was not a thoroughly satisfactory installation in existence.

(2) That some engines then in operation and construction were structurally weak, while others were too complicated and would easily be deranged by dust.

(3) That in spite of all assertions, the gas must be cleaned to give good results, and that no method then in use did wash the gas satisfactorily or sufficiently.

(4) That gas engines could be made simple in construction, and strong in design; that some way would soon be found to wash the gas; and when this was done, gas engines would come to stay.

Having confidence in the future, we operated a gas engine at Steelton for some months in the year 1900, but the dust gave rise to troubles which might easily be obviated with a different type of construction. This was the first engine in America driven by furnace gas, and the only other engine up to the present time is one of small size operated in the early part of 1902 by the Maryland Steel Co., very satisfactory results being obtained.

I believe that history has proven the correctness of the above judgment of European engines in 1899, an opinion shared by other American engineers who saw the facts just as clearly and decided to wait. Those who rushed into the breach, on the Continent, deserve the thanks of the engineering world, but they have paid dearly for their glory. At times when the papers have been giving drawings and pictures of new installations, and when these plants have been held up as examples for American engineers to follow, these same plants, almost before the ink on the pictures was dry, have been shut down with their cylinders cut to destruction, or with parts crippled by breakage.

TABLE II-M.

List of Gas Engines Driven by Blast Furnace Gas in Operation May 15, 1901; from *Dutreux, Journal Le Genie Civil,* 1901.

Name of Maker.	Kind of Engine.	Germany.	Luxemburg.	France.	Belgium.	Austria.	England.	Spain.	Russia.	Italy.	Total.	Total for Each Type.
Cockerill, Seraing	Delamare	3,900	6,000		7,600		600		700		18,800	33,650
Participation francaise	"			5,000							5,000	
Société alsacienne	"	3,000						600			3,600	
Wetter on Ruhr	"	2,400								1,200	3,600	
Breitfeld, Daneck & Co	"	600	600			850				600	2,650	
Otto, Deutz	Otto	10,045	3,200						55		13,300	16,600
Comp. Francaise des Moteurs Otto	"			3,300							3,300	
Oechelhauser	Oechel'r	12,800				2,000			1,500		16,300	16,300
Nurnberg	Nurnberg	6,740									6,740	6,740
Koerting. Hanover	Koerting	,105									5.105	5,105
Dubuisson, Eveno & Co.	Letombe			990				1,740			2 730	2,730
Thwaite	Thwaite			250			2,000				2.250	2,250
Pierson (Crossley)	Crossley			250							250	250
Total		44,590	9,800	9,790	7,600	2,855	2.600	2,340	2,255	1,800	83,625	83,625

It was not until the latter part of 1901 that the gas engine could be called a success, breakages having been so frequent that builders were obliged to replace with stronger constructions while the destructive work of dust has led to the development at Dudelingen and Differdingen of the cleaning device where the gas is drawn into a centrifugal fan provided with an internal spray of water. Table II-M gives a list of the engines now in operation in Europe, while America has none. It is not a proud position that American engineers have occupied in waiting for others to do the work, but it may safely be stated that we are richer than if we had been building gas engines.

A most important point which bears upon the matter to-day is the fact that up to the present time a thoroughly well built gas engine, with its scrubbers, its reserve units, and reserve producers, has cost so much more than a steam engine that the fuel saved would no more than pay the interest and depreciation on the extra investment. These conditions are changing and the price of engines will inevitably decrease as makers adapt their shops to the new work and as the risks of loss in starting new machines becomes less formidable. It is now expected that before many months, one of the new American plants will follow the lead of some of the foreign works and will offer something more than mathematical calculations on the benefits of blowing engines driven by gas. In view of the possibility of such developments it may be well to review briefly the fundamental principles of gas engine construction.

When the piston of a steam engine arrives at the end of its stroke, the valves open and a connection is thereby made directly with the boiler, and with what may be considered an inexhaustible supply of power. That is to say, a steady pressure is immediately put upon the piston head, and no matter how fast or slow the piston moves, this pressure follows, like a perfect spring, just as far as desired. In practice, the cut-off is about one-third the length of the cylinder, and during that time, and for that space, the pressure in the cylinder and against the piston is nearly equal to the pressure in the boiler, while beyond that point, the piston is carried forward by the expansive force of the steam and finally at the end of the stroke by the momentum of the flywheel.

The point of cut-off in modern engines is controlled by the governor, so that the amount of steam admitted to the cylinder is exactly in proportion to the work to be accomplished. In older and more wasteful types the same end is reached by the throttle valve, which indirectly regulates the pressure of the steam admitted, but in either case the initial pressure, by which is meant the maximum pressure at the beginning of the stroke, can never exceed the boiler pressure, unless we imagine a completely disordered condition of valves, whereby the cylinder is filled with steam at high pressure on the wrong side of the piston, creating a great compression.

A gas engine differs radically in its principles from this description. It is a cannon, with its projectile fastened to a crank shaft, and this cannon is required to explode every second and keep exploding indefinitely, without getting hot or deforming even a valve.

In addition to the structural problem concerned in this statement, there are certain thermal and chemical questions:

(1) There must be something corresponding to a governor, whereby the speed is controlled, and this must regulate either the amount of gas entering on each stroke, or the number of admissions per minute. The latter plan, the "hit or miss," is a common one, it being arranged that when the engine runs over a certain speed, the gas valve fails to open, and the fly wheel does the work.

(2) In using gas of poor quality, like producer or blast furnace gas, it is necessary, in order to get much power out of an engine, that the explosive mixture should be compressed before ignition.

(3) The pressure obtained after ignition will evidently depend very much upon the pressure before ignition and as the cubical content of the exploding chamber is a constant, it is evidently impossible to have a constant pressure before explosion, if there is any variation in the volume of gas and air added. It is for these and other reasons that the "hit or miss" system has been generally adopted.

(4) The "hit or miss" system is wrong, because it produces irregularities in speed of revolution. Supposing that the engine is a mere shade too fast and the admission "miss," then the whole cycle must be completed of perhaps two complete revolutions before another explosion can occur, and the flywheel must do all the work in that time. If the work is variable it may reach its maximum during this idle period and the speed decrease far below what would be allowable for many purposes, as for instance, in the production of an alternating current.

(5) The above mentioned period of two revolutions is not true of all engines, but in order to understand any gas engine it is necessary to keep in mind this original Otto cycle.

(a) Explosion, high initial pressure, forward stroke of piston, ending with a cylinder full of dead products of combustion which will not condense, but must be removed before the next supply of gas enters.

(b) The backward stroke of piston sweeping out the dead gases.

(c) Forward stroke of piston, sucking in a new supply of gas and air in measured quantities.

(d) Backward stroke of piston with all valves closed, compressing the mixture of gas and air just admitted, the resultant back pressure being dependent upon the cubical content of the space left for the exploding chamber, and the amount of gas and air admitted.

Thus in a single cylinder engine, working on the Otto cycle, there is only one impulse for two complete revolutions, and this impulse is an explosion throwing a great strain on all the working parts.

(6) The very high pressure caused by the explosion is accompanied by a very high temperature, and it is difficult to make valves which will stand the work, while cylinders are always water jacketed and even pistons are sometimes so cooled.

(7) If too high a back pressure be attempted, the explosive mixture may spontaneously ignite before the piston reaches the end of the stroke, with the production of enormous strains on all parts of the mechanism.

(8) If too low a pressure be used the gas may fail to ignite, and the igniters be covered with dust, which is pretty sure to cause other failures to ignite in subsequent admissions.

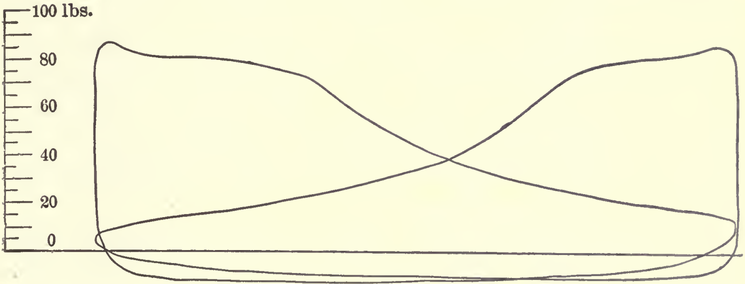
(9) The presence of mineral dust in blast furnace gas increases these difficulties, not simply by the wear on sliding surfaces, but by the interference with all valve adjustments and seats, giving rise to leakages and back explosions.

(10) The limitations just described concerning the admission of varying amounts of gas and air, and the control of compression, render it impossible in most engines to get good fuel economy under varying loads, although some of the later types attempt to attain this end.

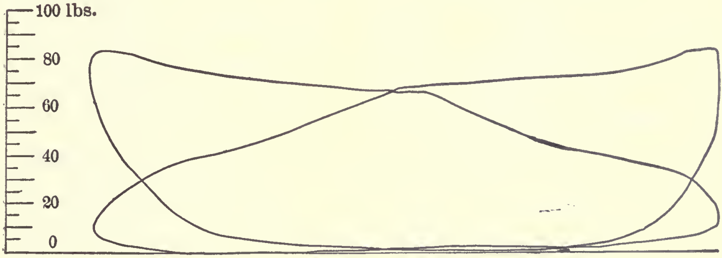
With a modern steam engine rated at 1000 horse power, the consumption of steam is nearly proportional to the load whether the engine is developing 1200 or 800 horse power, while the waste will not be prohibitory even if the load falls to 500 or rises to 1500 horse power.

On the other hand most gas engines, under such variations,

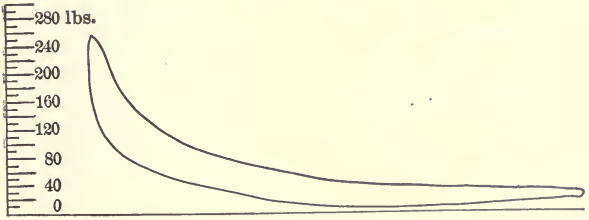
Fig. II-F.—Indicator Cards from Gas and Steam Engines.



32″ x 48″ CORLISS CONDENSING ENGINE.



40″ x 48″ PORTER-ALLEN ENGINE.



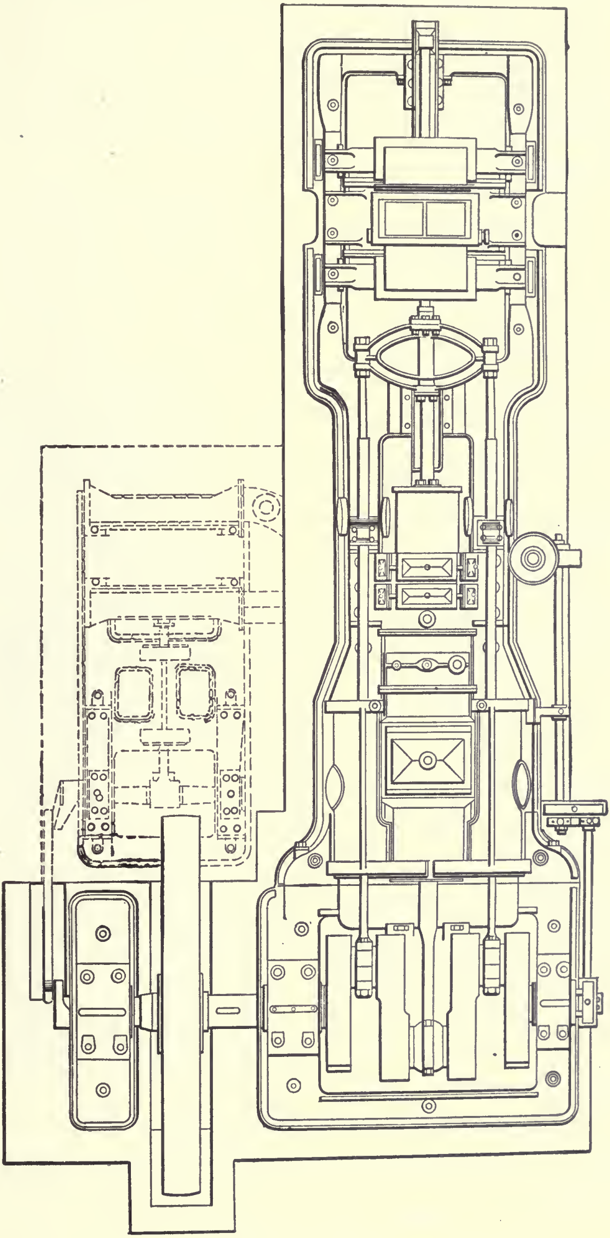
15″ x 22″ THREE-CYLINDER WESTINGHOUSE GAS-ENGINE.

show a much greater consumption of fuel than with their normal load, and they give an unsatisfactory speed regulation. It may also be said that no overload is practicable, for the rating is the maximum capacity. The indicator cards given in Fig. II-F, will exhibit the difference between the work of a steam engine and an ordinary gas motor. The term "ordinary" gas motor is used as the Letombe engine aims to overcome this difficulty; under a light load this engine takes a small quantity of gas and a very large quantity of air, say to a total volume of 100, and compresses the mixture to a pressure of say 300 before ignition. Under a full load it takes a larger amount of gas and the proper amount of air to give the best explosion, the total volume being say 70, and this is compressed to a pressure of say 200. These figures are not accurate, but they will illustrate the principle of getting a higher compression for the poorer mixture, and thus always obtaining a sharp explosion.

(11) In a gas engine there is probably an accentuation of a condition existing to some extent in heavy steam engines. When the weight of the reciprocating parts is very great, the force of the steam at the beginning of the stroke is absorbed by the inertia of the reciprocating parts and the effect upon the crank pin may sometimes be negative. It would seem probable that in a gas engine this condition should be more strongly marked, as the parts are very heavy and the ratio of crank to connecting rod is larger than in the steam engine.

From what has been said it will be seen that there are many difficulties, but the foreign engineers have struggled with them. The greatest bugbear is the old four cycle system, giving only one impulse in two revolutions, thereby reducing the horse power of the engine and giving a variable speed. The most radical departure is in what is known as the Oechelhauser motor, first installed at Hörde and shown in Fig. II-G. In this construction the cylinder is open at both ends and is a true cylinder throughout, save the opening near either end for gas, air and exhaust. There are two pistons working in opposite directions, the piston rods projecting out through the two open ends. When they are nearest together the space between them is the ignition chamber, and the explosion forces one piston in one direction and the other in the opposite way, nothing being exposed to the force of this explosion save the smooth walls of the cylinder and the heads of the pistons. When the pistons reach the end of their stroke they uncover passages in the walls of the cylinder which connect with the exhaust and then with both air and gas, the latter being under pressure. Air is blown through from one end to the other to wash out the

FIG. II-G.—OECHELHAUSER GAS ENGINE.



dead products of combustion, and furnish air for the next explosion, and then a measured quantity of gas is forced in. All this is done quickly and then the two pistons on the return stroke close these openings and pass over them and slide toward each other, compressing the mixture between them ready for the electric spark. An impulse on every revolution is thus obtained and the valves are removed from all heat and all shock.

The one inherent fault in this type of machine is the system of crank shaft and connecting rods. It is evident that both pistons must be connected with the same shaft, and this makes necessary that one piston rod must be supplied with a cross head and two very long connecting rods, and that the main shaft itself be of a very complicated construction with a number of bearings. The earlier engines of this kind were not strong enough and the later examples have been made much heavier. The Koerting engine, shown in Fig. II-H, is designed to take an impulse on each and every stroke, a compressor being used to force the gas and air into the cylinders.

(d) *Preheating the air going to stoves.*

Under steam engine practice the sensible heat of the tunnel head gases is completely used except what is lost by radiation, for a warm gas entering the stoves or boilers means a correspondingly increased production of heat. When the gas goes to scrubbers on the way to the gas engines, this sensible heat is wholly lost, and it may be worth while inquiring whether this heat can be used to preheat the air going to the stoves.

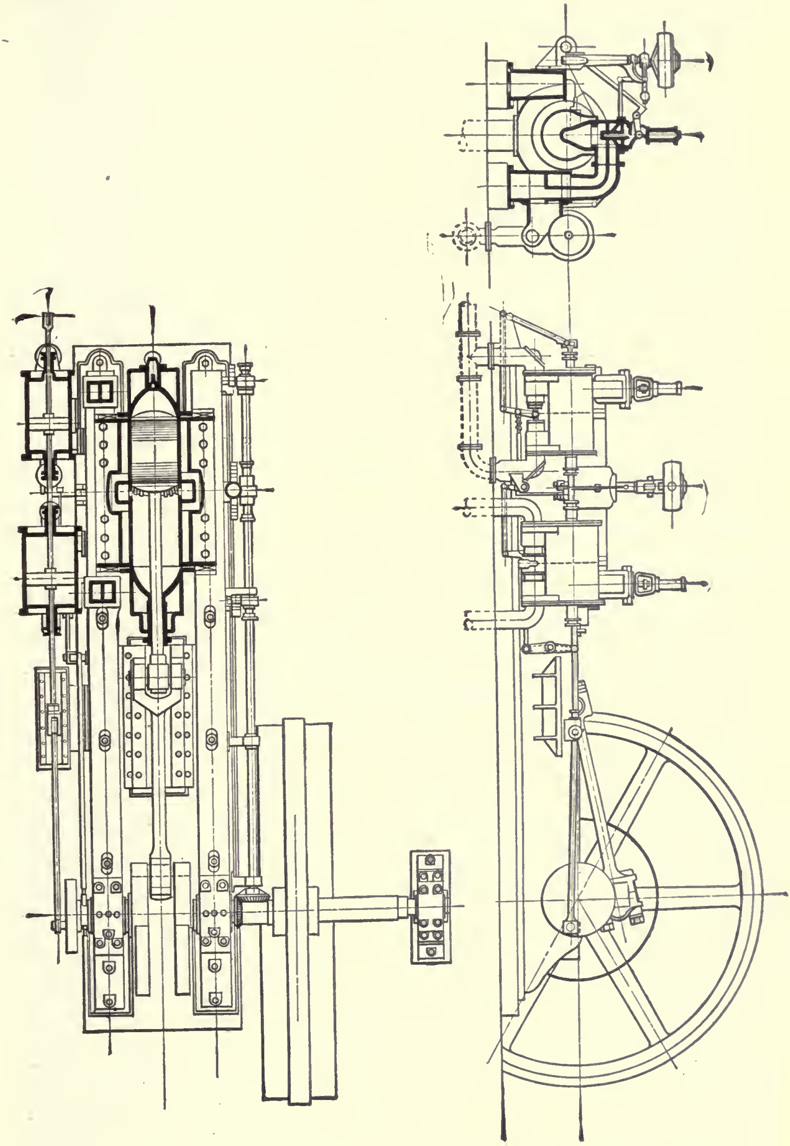
If one third of all the gas goes to the stoves and 3551 cubic metres of gas are made per ton of iron, then 1284 cubic metres of gas go to the stoves per ton of iron, and if 30 per cent. excess air be added, then about 1060 cubic metres of air must be supplied. The other two-thirds of the gas will go to the gas engines and we will, therefore, have the sensible heat of about 2270 cubic metres of gas available for heating 1060 cubic metres of air. Assuming that the air be heated to practically the same temperature as the gases, i. e. from 16° C=60° F. to 120° C=250° F. the heat thereby given to the air will be

$$1060 \times .307 \times 104 = 33880 \text{ calories}$$

while the total heat created by the combustion of the gas in the stoves will be

$$1284 \times 823 = 1{,}057{,}000,$$

FIG. II-H.—KOERTING DOUBLE-ACTING GAS ENGINE.



so that the gain from thus preheating the air is a little over 3 per cent. of the total heat produced in the stoves. If the tunnel head gases were much hotter the gain would be correspondingly increased, but with a cold top the gain will not warrant any expenditure of capital.

It is quite possible, however, that the exhaust from gas engines can profitably be employed in this work. If two-thirds of the gases are used in engines the products of combustion will far exceed the volume of air going to the stoves, and if these products escape at a high temperature the air for the stoves could be heated very nearly to that temperature by a suitable system of pipes and a great improvement made in the efficiency of the ovens, while the amount of gas needed by them could be decreased.

SEC. IIk—*The Relation Between the Physical and Chemical Qualities of Cast Iron.*—The pig iron used in the great steel works of the country is valued entirely according to its chemical composition, and little or no account is taken of it's physical appearance, commonly known as its "fracture," save as a rough and ready way of estimating in advance its chemical formula. Within comparatively few years there has been a strong movement among pig-iron users and manufacturers to adopt the same system throughout the general trade, but it is difficult to alter the prejudices of generations, and it is hard for uneducated foundrymen to cast away all their knowledge of fractures gained by years of observation, and rely on tables of analyses with mystic decimals showing the proportions of elements of whose very existence they have been ignorant.

The matter is not made better by the fact that there are many things not fully understood concerning the relation between the chemical and physical qualities, one instance in point being the superiority of charcoal cast-iron, and the better quality obtained by melting in air furnaces. As long as such phenomena are not fully explained by the scientists, or as long as they disagree in their explanations, so long must the aforesaid foundrymen be pardoned for clinging to their convictions.

The trouble is that most of the deductions concerning cast-iron have been made without complete data, and by men who did not know that the data were incomplete; who, for instance, took no account of manganese since it was not given in the report of the chemist; or who accepted glaring palpable errors like those pointed out by Prof. Howe, where an average of a whole class of iron is reported as containing nearly 15 per cent. of carbon, with one specimen holding over 16 per cent. of graphite. When such absurdities are put into the hands of unscientific foundrymen it is no wonder that the conclusions are slightly erratic.

The most scientific discussion of the constitution of cast-iron has been contributed by Prof. Howe. His opinions are not necessarily right because they are enunciated in scientific language, or because they embody the latest results of microscopic investigation, but they are very likely to be right, as the reader may feel quite sure he is not being misled by any fallacy. In reading any such paper on abstruse subjects, it is easy to be sidetracked and to overlook the continuity of the line of thought, for we are asked to concentrate into a few minutes the work of months, but the investigator who has worked for months or years is supposed to consider every sidelight and every difficulty, and the weight of his conclusions oftentimes depends fully as much upon his reputation for clear thought as upon the extent of his practical experience.

The argument of Prof. Howe is that pig-iron and steel form a continuous series; that, from one point of view, steel is a grade of cast-iron and cast-iron a grade of steel. This is an assumption which needs no justification to the open-hearth melter, who is accustomed to see a bath of pig-iron change by insensible gradations through a thousand intermediate stages from the richest pig to the condition of finished steel.

It is shown in Chapter XV that steel is a mixture or alloy of two components, *ferrite* and *cementite,* but that these two substances combine together in one definite proportion and in one proportion only to form *pearlite.* The proportion is seven parts of ferrite to one of cementite, so that pearlite contains necessarily about 0.80 per cent. of carbon. It follows that steel or iron containing more than 0.80 per cent. of carbon cannot all be pearlite, but that the pearlite which is present will contain, if the metal is cooled slowly, the full quantity of carbon represented by 0.80 per cent. of the mass, and that the rest of the carbon will exist in some other form. Part may exist in combination with the iron as cementite, and part may exist in the free state as graphite. Steel containing 0.90 per cent. of carbon if cooled slowly will be mostly pearlite, but will usually contain a trace of graphite and a certain amount of cementite. Metal containing 4 per cent. of carbon cannot contain any more pearlite than the steel just mentioned, but there will be just so much more carbon to form either graphite or cementite.

The amount of graphite will depend upon several conditions. A hot blast-furnace will give a higher percentage than a cold furnace, and high silicon will also cause the separation of free carbon, while manganese and sulphur will cause the carbon to remain combined. After subtracting the graphite from our calculation, the remaining carbon and iron form a matrix which may be assumed to follow the laws that hold good for all the grades that are usually known as steel.

Thus, as stated by Prof. Howe, cast-iron with 1.25 per cent. combined carbon is really steel of 1.25 per cent. carbon, but weakened and embrittled by graphite. In the same way he regards cast-iron with 3 per cent. of combined carbon plus 1 per cent. of graphite as essentially a mechanical mixture of two substances; (1) 99 parts white cast-iron, containing 3 per cent. of combined carbon, and (2) 1 part of graphite.

The contention that graphite "weakens and embrittles" cast-iron is directly opposed to the views of most practical men, but it seems as if he has made a good argument, for his reasoning is founded on the undeniable fact that ordinary pig-irons, when containing about the same proportion of silicon, manganese and sulphur, carry the same proportion of total carbon, no matter whether they are gray or white. It follows, therefore, that an increase in the proportion of graphite means a corresponding decrease in the proportion of combined carbon, and since one quarter of the total carbon is in the form of pearlite, and since cementite must contain 6.57 per cent. of carbon, it follows that if much carbon exists as graphite, the proportion of cementite present rapidly decreases and the proportion of soft ferrite rapidly increases, with a consequent toughening of the mass. This toughening is usually ascribed to graphite, when in reality the graphite weakens the iron by destroying its continuity, but the injury caused in this way is entirely overshadowed by the fact that as long as it exists as graphite, it cannot at the same time exist as cementite.

Thus an element like silicon will toughen iron because it drives the carbon into the condition of graphite, while manganese will make it brittle, because it causes it to combine. It is a generally accepted theory, although not undisputed, that charcoal pig-iron contains less carbon than coke-iron, and if this is true, the better quality of charcoal-iron could easily be explained by a low proportion of cementite and also a low proportion of graphite, two conditions which can seldom be found in iron. This would also explain why melting charcoal-iron in cupolas takes away its superiority, for the iron absorbs carbon in melting until it is of the same composition as irons made in a coke furnace, so that to retain its quality it is necessary to melt it in an air furnace. It is necessary, however, to consider that the lower proportion of carbon in charcoal-iron is not an established fact, for some authorities, like Stead, aver that the opposite is the case, and Prof. Howe, in a private communication, after reading this manuscript, states that the evidence on this point is inconclusive, and that the lower content may be assumed only as a probability.

Table II-N.

Composition of Various Pig-Irons and Spiegels.

No. of Sample.	Chemical Composition, Per Cent.							Kind of Iron.	Authority.
	Fe	Graphite.	Comb. Carb.	Si	P	S	Mn		
1	92.37	3.52	0.13	2.44	1.25	.02	.28	No. 1 Gray,	Hartman, *Jour. Frank. Inst.*, Vol. CXXXIV, p. 132.
2	92.31	2.99	0.37	2.52	1.08	.02	.72	No. 2 Gray,	
3	94.66	2.50	1.52	.72	.26	tr.	.34	No. 3 Gray,	
4	94.48	2.02	1.98	.56	.19	.08	.67	Mottled,	
5	94.68	. . . .	3.83	.41	.04	.02	.98	White,	
6	. . .	. . . .	4.27	1.10	. . . .	. .	8.11	Spiegel,	Hadfield, *Journal I. and S. I.*, Vol. II, 1889, p. 226.
7	. . .	. . . .	4.78	.52	. . . .	. .	19.74	“	
8	. . .	. . . .	5.63	.42	. . . .	. .	41.82	Ferro-manganese,	
9	. . .	. . . .	6.53	.97	. . . .	. .	80.04	“	
10	. . .	. . . .	7.20	.14	. . . .	. .	80.04	“	
11	. . .	. . . .	3.56	4.90	. . . .	. .	23.90	Silico-spiegel,	
12	. . .	. . . .	2.56	4.20	. . . .	. .	50.00	“	
13	. . .	.33	1.85	10.74	. . . .	. .	19.64	“	
14	. . .	.67	.98	12.60	. . . .	. .	19.74	“	
15	. . .	.90	.30	15.94	. . . .	. .	24.36	“	
16	. . .	2.35	.05	8.77	. . . .	. .	2.42	Ferro-silicon,	
17	. . .	1.85	.06	11.20	. . . .	. .	2.78	“	
18	. . .	1.20	.23	14.00	. . . .	. .	1.95	“	
19	. . .	.55	.11	17.80	. . . .	. .	1.07	“	

In Table II-N are given a few samples of pig-irons and spiegels, showing in a general way the composition of the different grades and the effect of silicon and manganese. Silicon, when present in large proportions, reduces very considerably the total carbon and compels whatever amount is present to be mainly in the form of graphite. Manganese exerts an exactly opposite influence, increasing the total carbon and keeping it in the combined form. Sulphur seems also to keep the carbon combined, but whether it increases the total amount is not certain. Phosphorus probably exerts little influence upon the total carbon content or upon its condition, but in itself and by virtue of its own action it increases the fluidity of the iron, which is a valuable property in the foundry, but increases also its brittleness which is objectionable. Irons with three per cent. of phosphorus are in demand for admixtures with other irons, so as to give an average content of about one per cent., but such a high proportion is not allowable in a great deal of work where the castings are exposed to shock. It is hard to state just what effect silicon, manganese and sulphur have in themselves, as their action is obscured by the influence they have in determining the condition of the carbon and thereby altering the whole character of the metal.

CHAPTER III.

WROUGHT IRON.

SECTION IIIa.—*General Description of the Puddling Process.*—When pig-iron is melted on a hearth of iron ore and is exposed after fusion to the continued action of the flame, there is a rapid oxidation of the metalloids contained in the iron. The silicon, manganese, sulphur and phosphorus unite with oxygen and iron oxide to form a slag, while the carbon escapes with the products of combustion as carbonic oxide and carbonic acid. By the departure of these alloyed elements, the iron becomes very much less fusible, and when the operation is conducted in an ordinary reverberatory furnace the heat is not sufficient to keep the mass liquid. It first becomes viscous, then pasty, and finally is worked into balls, taken from the furnace, and squeezed or hammered into a bloom fit for rolling.

The crude puddle-ball, when drawn from the furnace, is made up of an innumerable number of globules of nearly pure iron, while the interstices between the particles are filled with slag. By the action of the squeezer much of this slag is expelled, and each subsequent rolling removes a further quantity, but it is impossible to get rid of all the cinder, and it forms a skeleton which permeates the entire mass of the finished bar, forming planes of separation between the particles of metallic iron.

It is unnecessary to say that these films must weaken the material by destroying the continuity of the structure and the cohesion of the particles, and in this respect the slag is an injury. In other ways it is of incalculable benefit, for the sulphur and phosphorus are never entirely removed in the process of puddling, and there is usually a sufficient percentage of them left in the product to give bad results if they were able to exert their full effect in producing crystallization, but the network of slag prevents in great measure the tendency to crystallize and thus allows the presence of a considerable proportion of these elements. If bar-iron be melted in a crucible, the slag separates and the impurities have a chance to exert their full force. Some pure irons will successfully undergo this test, but most brands, including many of high reputation for quality, give a perfectly worthless metal after fusion, owing to the high percentages of impurities they contain. The quality of the finished metal, therefore, is not entirely dependent upon its composition, but upon the way in which it has been heated and worked.

The piece of iron made in the first rolling of the puddle-ball is a rough, crude product known as muck bar. For the making of merchant iron, this intermediate product, together with miscellaneous wrought-iron scrap, is bundled into "piles" so as to give a bloom of proper sectional area, and this, after being heated to a welding heat, is rolled into the desired shape. If the pile were square and were made up of similar pieces of equal length, each layer being at right angles to the one below, and if the bloom were rolled equally in each direction, it is evident that the plate would be as strong in the line of its length as of its breadth; but as the bars from which the pile is formed have been made by stretching the material in one way, and as most practical work requires a piece of greater length than width, it will be seen that the finished product will show much better results when tested in the direction of its length than of its width. The result will also depend upon the skill with which the pile has been constructed, upon the perfection of the welding as influenced by the heating and the rapidity of handling, and upon the freedom of the iron from thick layers of slag.

SEC. IIIb.—*Effect of Silicon, Manganese and Carbon upon the Operation of Puddling.*—Aside from these important considerations of content of slag and amount of work, the character of the product will depend upon its chemical composition, and this in turn depends upon the composition of the pig-iron from which it is made and upon the care and skill with which the operation has been conducted. There are five elements commonly found in pig-iron which have an important bearing on the character of the finished material and on the work of puddling, and these will be considered separately.

Silicon.—This element is present to greater or less extent in all pig-irons, and may be regarded as an almost unmitigated evil, since its oxidation produces silica and this is just what is not wanted to produce a basic slag. Moreover, its union with oxygen does not form a gas, and during its elimination the bath lies dead and sluggish. It is true that metallic iron is set free by the absorption of oxygen from the ore, but this gain is more than offset by the iron oxide which is held prisoner by the silica. Some silicon is oxidized during the melting, so that, with a low initial percentage in the iron, the boil begins very soon after melting. With workmen accustomed to high silicon iron, there is danger of considerable waste in using a lower grade, because the latter melts at a higher temperature, and, since there is not enough silica produced from the portions first melted to give a proper quantity of slag, the bare metal is exposed after melting to a hot flame, with the result that copious fumes of iron oxide escape to the stack. The same trouble is sometimes experienced in changing from a pig-iron which has been cast in sand to one which has been cast in chills, but careful practice has shown that this loss in both cases can be avoided by regulating the operation so that all the iron is melted at one time, and by keeping the metal covered with a fluid cinder, better results being obtained, both in time and waste, than with an iron containing a higher percentage of silicon, or one which carries a quantity of adhering sand.

Manganese.—Although acting in the same way as silicon in giving a dead bath, manganese is not quite as objectionable, for its oxide is a base which replaces and saves an equal quantity of iron oxide, and it also aids in the elimination of sulphur.

Carbon.—Unlike silicon, which varies in different forge-irons from 0.25 to 1.25 per cent., and manganese, which is present in all proportions from a trace to 1.5 per cent., pig-iron of all kinds contains a considerable proportion of carbon. Leaving out of the question irons very high in silicon or manganese, and speaking only of ordinary forge-irons, it may be said that the carbon runs from 3.0 to 4.0 per cent. It is often supposed that a mottled or white iron will necessarily be low in this element, but such is by no means a certainty, for the close grain may arise from low silicon which is an advantage, from high manganese which is a disadvantage, or from sulphur which is a decided injury.

Low carbon, moreover, is not such an extremely important matter, for although the elimination of this element lengthens the period of the boil, it must be considered that the carbon facilitates fusion, and that its union with the oxygen of the ore reduces metallic iron without forming any objectionable component of the slag.

SEC. IIIc.—*History of sulphur and phosphorus in the puddling furnace.*—The elements which have thus far been found to be factors in the operation are silicon, manganese and carbon. In the case of reasonably pure irons, like those used in the manufacture of ordinary acid Bessemer and open-hearth steels, these are all that it would be necessary to discuss, for with such irons it would suffice to eliminate these three elements in the presence of any ordinary basic slag, and by balling and working the pasty mass, produce a wrought-iron of good quality. These pure irons, however, are not always obtainable at as low a cost as those containing a greater percentage of phosphorus and sulphur, so that it is necessary to consider the effect of these impurities.

Sulphur.—It was explained in the preceding chapter that the content of sulphur in pig-iron is determined much more by the working of the blast-furnace than by the nature of the ore; but the continual demand for a low-silicon, low-carbon, close-grained iron for the puddler puts the furnaceman between two fires, and the not infrequent result is a pig containing from .10 to .50 per cent. of sulphur. This is materially reduced in the process of puddling by passing away as sulphurous acid in the waste gases and by being carried off in the cinder in combination with iron and manganese.

Phosphorus.—It has also been explained that the content of phosphorus in pig-iron is not determined in any appreciable degree by the furnaceman, for under ordinary conditions almost all that exists in the ore and fuel is found in the product. In the puddle-furnace, on the contrary, this metalloid is under more or less control, and it may be roughly stated that three-quarters of the total content may be eliminated, this broad formula being profoundly influenced by the skill of the puddler and the purity of the reagents. The presence of phosphorus in the ore used for fettling the hearth must necessarily detract just so much from the purifying power of the slag made from it, while the silica in the ore decreases the basicity of the slag and, therefore, its capacity for absorbing phosphorus; needless to say that silicon in the iron, producing silica by oxidation, acts in the same way. A rough sketch of the chemical history of the puddling process is shown by Table III-A, which gives the composition of metal and slag at various stages of the operation.

TABLE III-A.

Elimination of the Metalloids in the Puddling Process.

Nature of Sample.	Composition, per cent.											
	Metal.							Slag.				
	Si	Carbon		Mn	P	S	SiO_2	SiO_2	Fe_2O_3	FeO	MnO	P_2O_5
PIG IRON NO. 1,	2.80	3.12		. .	1.47	.11	. . .	. . .	. . .	. . .	. . .	. . .
Refined,	.12	2.50		. .	.84	tr.	. . .	. . .	. . .	. . .	. . .	. . .
Finished bar,	.19	tr.		. .	.27	tr.	. . .	. . .	. . .	. . .	. . .	. . .
PIG IRON NO. 2,	1.236	3.180		. .	1.494	.111	. . .	. . .	. . .	. . .	. . .	. . .
After melting,	.821	2.830		. .	.913	.096	. . .	. . .	. . .	. . .	. . .	. . .
During the boil	.200	2.800		. .	.582	. . .	. . .	. . .	. . .	. . .	. . .	. . .
" " "	.051	1.170		. .	.519	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Finished bar,	.098	.150		. .	.452	. . .	. . .	. . .	. . .	. . .	. . .	. . .
PIG IRON NO. 3,	1.36	3.20		. .	1.39	.17	. . .	. . .	. . .	. . .	. . .	. . .
Refined,	.07	2.00		. .	.32	.06	. . .	. . .	. . .	. . .	. . .	. . .
Forming into grain,	.04	1.90		. .	.20	.02	. . .	. . .	. . .	. . .	. . .	. . .
Dropping on grain,	.04	1.15		. .	.30	tr.	. . .	. . .	. . .	. . .	. . .	. . .
Finished bar,	.07	.05		. .	.33	.04	. . .	. . .	. . .	. . .	. . .	. . .
		Comb.	Graph.									
PIG IRON NO. 4,	. . .	. .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
After melting,	1.11	0.61	1.75	.78	.36	. . .	. . .	24.04	18.74	51.22	4.42	1.30
Bath growing thicker,	.14	1.89	tr.	tr.	.25	. . .	. . .	27.17	5.28	59.56	5.17	2.12
Coming up on boil,	. . .	1.75	. .	.09	.26	. . .	.74	27.77	4.81	59.95	5.29	2.19
Beginning to drop,	. . .	1.57	. .	tr.	.23	. . .	1.01	27.46	4.19	58.41	55.45	2.22
Dropped; infusible,	. . .	1.10	. .	tr.	.23	. . .	1.37	25.72	4.20	60.61	4.65	2.07
Balling,	. . .	.25	. .	tr.	.25	. . .	.91	15.79	9.21	69.52	2.81	1.66
Finished bar,	. . .	.16	. .	.07	.09	. . .	.28	. . .	. . .	. . .	. . .	. . .

NOTE.—The data on pig-irons Nos. 1, 2 and 3 are taken from investigations by Bell; see *Journal I. and S. I.*, Vol. I, 1877, pages 120 and 122.

Those on No. 4 are from a paper by Louis, *Journal I. and S. I.*, Vol. I, 1879, p. 222, it being stated that after the fourth test it was impossible to get a fair average owing to the viscosity of the mass, and hence the analyses must be considered only approximately representative.

The abbreviation tr. signifies trace, while comb. and graph. stand for combined and graphitic carbon.

SEC. IIId.—*Effect of the temperature of the furnace upon the puddling process.*—The temperature of the furnace has an important bearing on the character of the product, particularly when much carbon is present. Experiments are cited by Stead* showing

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* *Journal I. and S. I.*, Vol. II, 1877, p. 372.

that in the refining process, which corresponds to the first part of the puddling process, the elimination of phosphorus was inversely as the temperature, ranging from 46 per cent. in hot charges to 91 per cent. with cold working, in each case about 96 per cent. of the silicon and 30 to 40 per cent. of the carbon being oxidized. For many years the phenomenon was explained by supposing that phosphorus would not unite with oxygen at high temperatures, and this was deemed to be conclusively proven by the fact that phosphorus was not burned in the acid Bessemer converter. It is now known that the reduction of phosphorus by high heat in the puddling-furnace is due to the very simple fact that carbon has a greater affinity for oxygen as the temperature rises, so that it reduces the phosphate of iron and returns the phosphorus to the metal. Thus there is an inversion of the relative attraction of carbon and phosphorus for oxygen rather than a negation of affinities. These facts are now thoroughly understood in the metallurgical world, and, on the one hand, the refinery produces a dephosphorized high-carbon metal by carrying on the oxidation in a cool furnace, while on the other the basic Bessemer eliminates phosphorus at the highest temperatures by the use of irreducible bases.

It is the practice at most works to remove part of the slag while the metal is high in carbon, the product so made being called "boilings," while the slag which is left in the furnace at the end of the operation and which is sometimes tapped from the bottom is called "tappings." This last cinder is often allowed to remain, or, if tapped, is charged with the next heat in order to furnish a rich slag in the early part of the process, since the fettling of iron ore is so infusible that it cannot furnish a cinder until a high temperature is attained. The removal of the "boilings" during the operation hastens the work, gives less cutting of the bottom, and renders the "balling" easier. It also follows that it aids dephosphorization, for during the first part of the operation the charge is naturally at a low temperature, and the slag, therefore, carries a higher percentage of phosphorus than it would retain if it were kept in the furnace and exposed to a high temperature and the reducing action of carbon. By tapping during the first part of the boil, the greater part of the silica and phosphorus is removed and there is an opportunity to make a new slag richer in iron and of greater dephosphorizing power.

It is the first slag which is generally known as puddle or mill cinder and which is often used in the blast-furnace. It is very variable in composition, as will be evident from Table III-B, which gives analyses from various sources indicating the general nature of the material.

TABLE III-B.

Analyses of Puddle or Mill Cinder.

Where Made.	Authority.	Composition, per cent.				
		SiO_2	Fe	P	Mn	S
Harrisburg, Pa.,	Author.	19.91	49.07	1.10	1.27	....
"	"	11.64	60.86	1.07	....	....
"	"	19.58	55.06	1.81	....	0.24
"	"	21.38	56.04	1.41	3.62	....
Troy, N. Y.,	*Trans. A. I. M. E.,* Vol. IX, p. 14,	13.81	53.44	1.91	....	....
Ironton, Ohio,	*Trans. A. I. M. E.,* Vol. IX, p. 14,	30.00	50.59	0.54	....	....
Marietta, Ohio,	*Trans. A. I. M. E.,* Vol. IX, p. 14,	21.58	51.42	1.40	....	....
Three English Works, "Boilings,"	*I. and S. I.,* Journal, Vol. I, 1891, p. 119,	19.45	53.55	2.76	....	....
Three English Works, "Tappings,"	*I. and S. I.,* Journal, Vol. I, 1891, p. 119,	15.47	59.29	1.71	....	....

Sec. IIIe.—*Effect of work upon the physical characteristics of wrought-iron.*—The influence of the different elements upon the quality of wrought-iron has never been fully discovered owing to the many disturbing conditions, foremost among which is the effect of varying amounts of work upon the finished material. This question arises in the case of steel, but it is much more important in wrought-iron, since the strength of the bar will depend in great measure upon the thoroughness with which the separate pieces forming the mass have been welded and forced together. With well-constructed piles and sufficient reductions, the tests on thick plates are fully as good as on thin sheets.

In Table III-C are given a few averages of results obtained at the Central Iron and Steel Works at Harrisburg, Pa., from plates rolled on their ordinary three-high train, and from those made on a 25-inch universal mill. The better figures for the latter mill are due to the more complete development of fibre by the continuous rolling in one direction.

The width was about alike for similar thicknesses, and no difference was found in the universal plates whether they were 9 or 42 inches in width. The above results are too few for a valid comparison, but they are corroborated by the regular practice at this works where the universal plates are superior to the product of the shear mill. In all these cases, the stock from which the iron was made was the same, and the tensile strength is constant for all thicknesses. Moreover, there seems to be a better elongation as the thickness increases, while the reduction of area is fully as high.

TABLE III-C.

Tests on Wrought-Iron Plates from Shear and Universal Mills.

	Sheared Plates.					Universal Mill Plates.				
Thickness in inches.	Number of tests averaged.	Elastic limit, lbs. per square inch.	Ultimate strength, lbs. per square inch.	Elongation in 8 in., per cent.	Reduction of area, per cent.	Number of tests averaged.	Elastic limit, lbs. per square inch.	Ultimate strength, lbs. per square inch.	Elongation in 8 in., per cent.	Reduction of area, per cent.
1/4	1	32400	51800	11.2	18.9	1	32100	51000	13.0	19.9
3/8	. . .	. . . . .	. . . . .	. . . . .	. . . . .	2	31050	50650	14,6	21.6
1/2	5	31180	49760	14.2	22.0	3	31100	50530	17.3	26.2
5/8	4	30775	50200	15.5	22.5	3	30500	50830	17.2	24.6
3/4	2	30400	49050	16.0	22.4	3	31470	52570	19.0	26.2

With less careful work there is a constant retrogression in quality as the size of the finished piece increases, and this is usually recognized in specifications, as will be seen by Table III-D, which is copied from a paper by A. E. Hunt.*

SEC. IIIf.—*Heterogeneity of wrought-iron.*—The most complete investigation on the subject of wrought-iron is a report by Holley† on the work of a Board appointed by the United States Government to test material for chain cables. It was found that the tenacity of 2-inch bars for chain cables should be from 48,000 to 52,000 pounds per square inch, while 1-inch bars should show 53,000 to 57,000 pounds. This conclusion is reached after very careful reasoning, and it illustrates the profound influence of this one item of reduction in rolling. It will be evident that unless the history of the bar is known, ordinary chemical analysis will fail to give any information as to whether it has been rolled from a pile 4 inches square or from one 7 inches square. In the making of rounds, which was the only shape tested by the Board, there is op-

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* *On the Inspection of Materials of Construction in the United States. Journal I. and S. I.,* Vol. II, 1890, p. 299.

† *The Strength of Wrought-Iron as Affected by its Composition and by its Reduction in Rolling. Trans. A. I. M. E.,* Vol. VI, p. 101.

portunity for very bad practice in beginning to form the piece too early in the operation, for there is a much better chance to work and weld the iron in closed rectangular passes than in the formation of round sections. Usually, a bar which has not received sufficient work will contain an abnormal percentage of slag, and this can be determined in the laboratory; but a slight excess

TABLE III-D.

Average Requirements on Wrought-Iron in the United States.

Kind of Material.	Tensile Tests.				Cold Bending Tests.	
	Limit of elasticity, lbs. per square in.	Ultimate strength, lbs. per square in.	Elongation in 8 in., per cent.	Reduction of area, per cent.	Angle of bend.	Diameter of cylinder around which the specimen is to be bent.
BAR IRON.						
Round bars up to 1½ in. diameter,	26000	50000	18	25	180°	Upon itself until sides come in contact.
Round bars up to 2⅜ in. diameter,	26000	50000	15	20	160°	One diameter of bar.
Square bars up to 1½ in. per side,	26000	50000	18	25	180°	Upon itself until sides come in contact.
Square bars of less than 4½ square inches sectional area,	26000	50000	15	20	180°	Diameter equal to the sides of bar.
Flat bars of less than 4½ square inches sectional area,	26000	50000	15	20	180°	Diameter equal to twice the thickness.
Bars of more than 4½ square inches sectional area,	26000	50000	12	18	140°	Two diameters of bar.
CHANNELS AND BEAMS.						
Test from web,	26000	47000	12	18	140°	Diameter equal to thickness of bar.
Test from flange,	26000	49000	15	20	160°	" " " " "
Angle iron,	26000	49000	13	20	140°	" " " " "
Other shapes,	26000	48000	14	18	120°	" " " " "
PLATE IRON; tests to be taken with the fibre.						
Under 18 inches wide,	26000	50000	15	20	160°	Diameter twice the thickness.
18 to 36 inches wide,	26000	48000	12	16	100°	" " " "
36 to 54 inches wide,	25000	46000	10	10	90°	" " " "
Over 54 inches wide,	25000	46000	8	8	90°	" " " "

does not necessarily imply that the iron has not been well worked, for it may arise from viscosity of the cinder, rendering its expulsion difficult. In any event, it will be seen that, although a certain quantity may benefit the metal by preventing crystallization, anything beyond this must decrease the cohesion of the particles of iron.

In the investigation just mentioned, it was found that the slag varied from 0.192 per cent. to 2.262 per cent. of the total weight of the iron; and it must be remembered that these tests were made on material destined for a service calling for the best product of the mill. Some makers may have supposed that the presence of slag would facilitate welding, but the investigation did not bear this out, for it is distinctly stated in the report that, while "slag should theoretically improve welding, like any flux, its effect in these experiments could not be definitely traced." On the contrary, the iron which was highest in slag (2.26 per cent.) "welded less soundly than any other bar of the same iron, and below average as compared with the other irons."

TABLE III-E.

Variations in the Character of Different Specimens of the Same Brands of Wrought-Iron and of Different Irons as Submitted to the United States Board for Testing Chain Cables.

Subject.	Same Iron.		All Irons.	
	Min.	Max.	Min.	Max.
Carbon, per cent.,	.026 .042	.064 .512	.015	.512
Phosphorus, per cent.,	.065 .095	.232 .250	.065	.317
Silicon, per cent.,	.028 .182	.182 .321	.028	.321
Manganese, per cent.,	tr. .021	.059 .097	tr.	.097
Slag, per cent.,	0.674 1.248	1.738 2.262	0.192	2.262
Ultimate strength, pounds per square inch,	56201 47478	69779 57367	47478	69779
Elongation in 8 inches, per cent.,	11.7 14.1	20.6 32.5	6.5	32.7
Reduction of area, per cent.,	27.7 16.0	59.8 31.5	7.7	59.8

The percentage of slag not only varied in different brands of iron, but in pieces of the same make. This was true also of all the factors investigated. Table III-E shows the variations in the same make of iron, two extreme cases being given under each head. It also gives the maximum and minimum individual records.

SEC. IIIg.—*Conditions affecting the welding properties of wrought-iron.*—These conditions of varying work, percentages of slag, and irregularity of the same irons, not to mention the possible overheating of piles in the laudable effort to produce a perfect weld, complicate so fundamentally the relation between the chemical composition and the physical properties, that it need not be wondered that the committee could not find the exact influence of each chemical component. There was formulated, however, the following very valuable conclusion: "Although most of the irons under consideration are much alike in composition, the hardening effects of phosphorus and silicon can be traced, and that of carbon is obvious. Phosphorus up to .20 per cent. does not harm and probably improves irons containing silicon not above .15 per cent. and carbon not above .03 per cent. None of the ingredients, except carbon in the proportions present, seem to very notably affect the welding by ordinary methods."

Regarding this last clause it should be said that the highest sulphur in any sample was .015 per cent., which is very low; but that copper was present in one instance up to .43 per cent.; nickel up to .34 per cent., and cobalt up to .11 per cent. Moreover, the high percentages of these three elements were coincident in one bar, yet welding gave fair results, notwithstanding that phosphorus was higher than was found advisable. A careful reading of the evidence, however, indicates that the experiments were far from conclusive as to these elements.

This matter of welding power was of special moment in iron for chain cables, but it is also the very root of the entire process, for the integrity of the finished bar depends upon the completeness of the welds between the different particles. In Chapter XIX the welding of iron and steel will be discussed at greater length.

CHAPTER IV.

STEEL.

SECTION IVa.—*Definition of steel.*—Although it seems a perfectly simple matter to give a definition of steel, the task has never yet been accomplished to the satisfaction of all concerned. A true formula must apply not only to all the metals commonly designated by the term, but to all compounds which ever have been, or ever will be, worthy of the name, including the special alloys made by the use of chromium, tungsten, nickel and other elements introduced to give peculiar qualities for special purposes. Moreover it has been shown in Sec. IIk that the latest researches show no dividing line between the softest steel and the ordinary grades of pig-iron.

Prior to the development of the Bessemer and open-hearth processes there was little room for disagreement as to the dividing line between steel and iron. If it would harden in water, it was steel; if not, it was wrought-iron. When the modern methods were introduced, a new metal came into the world. In its composition and in its physical qualities it was exactly like many steels of commerce, and naturally and rightly it was called steel. By degrees these processes widened their field, and began to make a soft metal which possessed many of the characteristics of ordinary wrought-iron, and which was not made by any radical change in methods, but simply by the use of a rich ferromanganese. Notwithstanding this fact, some engineers claimed that the new metal was not steel, but iron. The makers replied that it was made by the same process as the hard steel, and that it was impossible to draw a line in the series of possible and actual grades of product which they made.

The problem rapidly became of great importance, since the filling of engineering contracts and the interpretation of tariff schedules depended upon the application of the one term or the other to the soft product of the converter and the melting-furnace.

At this juncture an international committee was appointed from the leading metallurgical societies of the world, and a list of the members shows us a formidable array of well-known names: Holley, Bell, Wedding, Tunner, Akerman, Egleston and Gruner.

This committee reported in October, 1876, to the American Institute of Mining Engineers, the following resolution:

(1) That all malleable compounds of iron with its ordinary ingredients, which are aggregated from pasty masses, or from piles, or from any forms of iron not in a fluid state, and which will not sensibly harden and temper, and which generally resemble what is called "wrought-iron," shall be called *weld iron.*

(2) That such compounds, when they will from any cause harden and temper, and which resemble what is now called "puddled steel," shall be called *weld steel.*

(3) That all compounds of iron with its ordinary ingredients which have been cast from a fluid state into malleable masses, and which will not sensibly harden by being quenched in water while at a red heat, shall be called *ingot iron.*

(4) That all such compounds, when they will from any cause so harden, shall be called *ingot steel.*

The Institute, in accordance with its rules, declined to promulgate any official opinion on the subject, but did recommend that the proposed nomenclature be used in all future papers presented at its meetings.

It is fortunate that no more positive action was taken in forcing into use a system which was radically wrong. This classification disregarded a primal necessity of business, for it is necessary to have a name for the material while in process of manufacture. As a practical maker of a certain material used in the arts, I wish a title by which to call it. I cannot give orders to make a heat of ——— and wait until it is made, rolled, chilled in water, and tested for hardness before it can have a generic name. The word "steel" was in use for this very purpose in every Bessemer and open-hearth plant in the country and when the name was once given at the converter or the furnace, it clung throughout its history in the rolling mills and shops just as the term is used in the steel works of Germany in defiance of the official classification.

To-day nothing is heard about this proposed nomenclature, its sole panegyric together with an unwilling eulogy having been written by Professor Howe. He opens his great work, published fourteen years after the committee had issued its manifesto, by saying this:* "The terms Iron and Steel are employed so ambiguously and inconsistently that it is to-day impossible to arrange all varieties under a simple and consistent classification." And he adds, with some triumph in the memory of forensic victories, but more pathos over the record of disappointed hopes, that the result would have been quite different "could the little band, which stoutly opposed the introduction of the present anomaly and confusion into our nomenclature, have resisted the momentum of an incipient custom as successfully as they silenced the arguments of their opponents." He closes by completely surrendering to the enemy in these words: "So firmly has this (generic) sense of the word become established that, unfortunately, it were vain to oppose it."

It is a pity that after this acknowledgment of the final judgment of the metallurgical world, he should commend the practice of calling malleable-iron castings by the name of steel,† simply because they coincide with a definition he has just branded as obsolete, for in so doing he sanctions what is to-day one of the greatest frauds in the business. Steel castings are made by pouring melted steel into a flask. This steel must be made either in a crucible, an open-hearth furnace, or a Bessemer converter, for it is impossible to melt scrap in a cupola and have good steel run from the taphole. It is either ignorance or crime to call by the name of steel castings the hybrid metal made by melting a mixture of pig-iron and steel scrap in a cupola, and it is just as far from truth to apply the term to malleable iron. Any definition of steel which gives room for these mistakes writes its own epitaph as erroneous and absurd.

SEC. IVb.—*Cause of failure of certain proposed definitions.*—One reason has already been given why the projected renaissance of a decayed nomenclature was a failure, but although the lack of any other general term to denote the product of the converter was a most formidable obstacle, it is easy to believe that this could have been overcome. The whole structure, however, lacked a foundation, because there can be no satisfactory definition as to what constitutes *hardening.* It will not do to prescribe any test with a file, for there is too much chance for personal equation in such a trial, not to mention the impossibility of having every file of exactly the same hardness. It will not do to make a quench bend, for the success of such a test is determined in too great a

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* *Metallurgy of Steel*, p. 1.

† *Loc. cit.*

measure by certain variable conditions of the preheating not fully understood, and by the manipulations of the smith.

All these points were fully understood by practical men at the time the committee was at work, and the arguments were ably presented by Park and Metcalf.* They asked for a definition as to what constituted hardening, and received the answer that a dividing line is unnecessary. Prof. Akerman† recommends that it be placed where the quenched piece cannot be scratched by feldspar. He recognizes that small variations in many elements other than carbon will determine the amount of hardening, and also mentions the difference caused by the temperature of the water and the way in which the piece is immersed, and whether it is held still or moved. If the learned professor had wished to condemn his case, he could have done little more. Laboratory experiments on quenching and scratching with feldspar are well enough for some purposes, but when these must be performed before the material can have a name, and when such work gives us simply the name and no other information at all, then, surely, the matter presents itself in the form of a *reductio ad absurdum.*

It is true, as argued by Prof. Howe, that many of the common products of metallurgy and art shade imperceptibly into one another; but it is surely extraordinary when the dividing line cannot be drawn even in theory, much less in practice; when, wherever it falls, it must divide, not intermediate, but finished products, used in enormous quantities, and blending into one another by insensible gradations, and when every shade of these variations is the subject of rigorous engineering specifications.

It is customary and necessary in ordering steel to give a certain margin in filling the specifications, and it will be evident, no matter how close this margin is, that if a line could be drawn, it would not infrequently happen that he who ordered ingot iron would receive steel, and he who ordered steel would receive ingot iron.

Many different tests have been proposed at various times for determining the mechanical properties of steels, but although some of them are of value in special cases, the one method of investiga-

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* *Can the Commercial Nomenclature of Iron be Reconciled to the Scientific Terms Used to Distinguish the Different Classes?* Metcalf: *Trans. A. I. M. E.*, Vol. V, p. 355.

† *On Hardening Iron and Steel; Its Causes and Effects. Journal I. and S. I.*, Vol. II, 1879, p. 512.

tion which has become well-nigh universal is to break by a tensile stress and measure the ultimate strength, the elastic limit, the elongation, and the reduction of area. Strictly speaking, none of these properties has any direct connection with hardness, and it is also true that in special instances, as with very high carbons, hardening may reduce the tensile strength by the creation of abnormal internal strains; but in all ordinary steels, it is certain that hardening is accompanied by an increase of strength, by an exaltation of the elastic limit, and a decrease in ductility.

Now, if it is conceded that no practical test defining hardening has ever been devised, and if it can be shown that sudden cooling produces a very marked increase in ultimate strength, an exaltation of the elastic limit, and a decrease in ductility even in the softest products of the converter and the open-hearth furnace, then we are partially justified in assuming that hardening has occurred on the ground that the more easily recognized correlated phenomena continue in unbroken order down the scale of the various iron products. The conclusion is weak in logic, I will admit, but from the standpoint of the engineer of to-day, who grades everything by the tensile test, and who makes "strong" steel and "hard" steel interchangeable terms, I claim good ground for my position in calling steel hardened when it is strengthened.

TABLE IV-A.

Effect of Quenching on the Physical Properties of Different Soft Steels.

NOTE.—Bars were 2"x⅜" flats, rolled from a 6"x6" ingot, and were chilled at a dull yellow heat.

Number of test-bar.		1	2	3	4	5	6
Composition, per cent.	Carbon,	.09	.12	.11	.12	.09	.10
	Manganese,	.44	.32	.43	.32	.39	.16
	Phosphorus,	.011	.004	.010	.004	.017	.010
	Sulphur,	.033	.027	.010	.027	.031	.019
Ultimate strength; pounds per sq. inch,	Natural,	49390	48960	48960	48260	49760	46250
	Quenched,	66080	65670	66300	63640	62280	58380
Elastic limit; pounds per square inch.	Natural,	33220	33390	33010	32340	31040	29830
	Quenched,	47310	und.	und.	50170	46580	40500
Elastic ratio, per cent.	Natural,	67.26	68.20	67.42	67.01	62.38	64.50
	Quenched,	71.60	und.	und.	78.83	74.79	69.38
Elongation in 8 in.; per cent.	Natural,	29.75	31.00	32.50	32.50	31.25	37.75
	Quenched,	18.75	16.25	15.00	17.75	23.75	27.50
Reduction of area; per cent.	Natural,	50.80	52.50	54.10	55.75	49.00	68.38
	Quenched,	56.50	63.27	63.47	64.47	65.15	68.97

The fact that common soft steel is materially strengthened by chilling has been widely recognized for many years, but the extent of the alteration in physical properties in the softest and purest metals is not generally understood. Table IV-A gives a series of tests that I have made, which may shed some light on this point.

As the bars were rolled from a small test ingot, the elongation is much less than the normal, but the consequences of the quenching are well marked. Additional tests were made on another sample of soft basic open-hearth metal. The original piece was a rolled flat, 4 inches wide and 5-16 inch thick. This was cut lengthwise into two strips 1¾ inches wide by 5-16 inch thick, and these strips were again cut into 18-inch lengths, so that the whole bar gave 12 test-pieces. Six of these were taken from alternate sides of the original bar throughout its length and tested without treatment, while the other six were broken after chilling at different temperatures. The results are given in Table IV-B.

TABLE IV-B.

Effect of Quenching the Same Steel at Different Temperatures.

Bars 1¾"x$\frac{5}{16}$"; Composition, per cent.; C (by combustion) .057; Mn .33; P .006; S .019.

Heat treatment.	Ultimate strength; pounds per square inch	Elastic limit; pounds per square inch	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
Natural state; average of 6 bars . .	46098	33825	35.37	70.00	73.37
Chilled at a dull red heat	49740	33800	Broke near jaws.	70.00	67.95
" " dark cherry red	56500	38830		63.80	68.73
" " medium cherry red . .	51100	34570		70.30	67.65
" " cherry red	57240	39060		66.10	68.24
" " low bright red	58200	39930		64.80	68.61
" " bright red	62640	38860		63.10	62.04

There is possibly a mixture of tests in the case of the "dark cherry red" and "medium cherry red," or perhaps an error in estimating temperature, but I give the results as they were recorded. The elongation is not given, for the pieces persisted in breaking near the grips. This may have arisen from the fact that the ends of the bars as they lay in the muffle were not as hot as the middle, and hence did not receive so severe a chilling, but the difference is not enough to invalidate the nature of the results. The reduction of area is lessened somewhat, but this seems to be affected much less by chilling than the other properties, a fact which is also shown in Table IV-A.

The untreated bars show that the metal was of extreme softness, while the chilled specimens prove that each change in the quenching temperature is reflected in the physical condition of the chilled bar.

SEC. IVc.—*The American nomenclature of iron products.*—The classification by hardening is a dead issue in our country. It had quietly passed away unnoticed and unknown before the Committee of the Mining Engineers had met, and the best efforts of that brilliant galaxy of talent could only pronounce a kindly eulogy.

Strictly speaking, some mention must be made of hardening in a complete and perfect definition, for it is possible to make steel in a puddling furnace by taking out the viscous mass before it has been completely decarburized; but this crude and unusual method is now a relic of the past, and may be entirely neglected in practical discussion. No attempt will be made here to give an ironclad formula, but the following statements portray the current usage in our country:

(1) By the term wrought-iron is meant the product of the puddle furnace or the sinking fire.

(2) By the term steel is meant the product of the cementation process, or the malleable compounds of iron made in the crucible, the converter, or the open-hearth furnace.

This nomenclature is not founded on the resolutions of committees or of societies. It is the natural outgrowth of business and of fact, and has been made mandatory by the highest of all statutes—the law of common sense. It is the universal system among engineers not only in America, but in England and in France. In other lands the authority of famous names, backed by conservatism and governmental prerogative, has fixed for the present, in metallurgical literature, a list of terms which I have tried to show is not only deficient, but fundamentally false.

The foregoing discussion has taken no cognizance of the microscopical structure of steel, because the investigations thus far made in this field of research do not give any limits by which we can form a definition. It is rather indicated, as pointed out in Sec. IIk, that there is no dividing line between the softest steel and the hardest pig-iron. In Chapter XV will be found further information on this subject.

CHAPTER V.

HIGH-CARBON STEEL.

SECTION Va.—*Manufacture of cement and crucible steel.*—By the use of reasonably pure ores and by skillful puddling, it is quite possible to produce wrought-iron in which the phosphorus shall not exceed .02 per cent. This bar of soft pure iron may be converted into hard steel by placing it in fine charcoal and exposing it to a yellow heat. By a slow process, called cementation, the carbon penetrates the metal at the rate of about one-eighth inch every 24 hours, so that a bar five-eighths of an inch thick is saturated about 48 hours after it arrives at a proper temperature. This operation is carried on in a large retort where many tons of bars are treated at one time, so that it will always happen that some parts of the furnace arrive at a full heat much sooner than others, and remain longer at that temperature. Consequently, when such a retort is opened, it is necessary to break all the bars and grade them by fracture according to their degree of carburization. The point of saturation is about 1.50 per cent. of carbon, but the average of the whole will be about one per cent.

The steel thus produced is known as blister or cement steel. Its use is limited by the fact that it always contains seams and pits of slag which were present in the wrought-iron, and these defects are of fatal moment in the manufacture of edged tools. To avoid this trouble, cement steel may be melted in crucibles, out of contact with the air, and, being thus freed from the intermingled slag, can be cast into ingots and hammered or rolled into any desired shape. This double process is expensive, and a cheaper and more common method is to put a proper quantity of charcoal into the crucible with crude bar iron, the absorption of carbon progressing with great rapidity when the metal is fluid. This practice is almost universal in America, and it is claimed by men whose word must carry weight in the metallurgical world, that it gives a steel equal in every respect to the older method; but against this must be put the work of firms whose name is synonymous with most excellent product and who, at much extra cost, use a certain proportion of cemented bar for the most expensive steels. It is difficult to say how much of the extra quality is due to the method of manufacture and how much to the strictest care in working and inspecting, and it is also hard to find out whether the conservatism does not arise from the laudable desire to supply old customers with exactly the same metal, in name as well as in fact, that has been furnished them in the past.

In deference to time-honored tradition, it may be well to quote without approval or further dispute the following dictum of Seebohm,* which expresses the ancient doctrines: "The best razor steel must be melted from evenly converted steel. It will not do to mix hard and soft steel together, or to melt it from pig 'let down' with iron, for it will not then possess the requisite amount of body and the edge of the razor will not stand."

A third variation is the melting of wrought-iron with a proper proportion of pig to raise the carbon to the desired point, while in still another, used in Sweden, the charge of the crucible consists of pig and iron ore. The aim of all methods is to obtain a malleable metal containing from .60 to 1.40 per cent. carbon, and free from blowholes. For certain purposes some special element like chromium, or tungsten, may be used as an alloy, but with this exception every other ingredient may be regarded as an impurity.

SEC. Vb.—*Chemical reactions in the steel-melting crucible.*—The best tool steel must be as tough as possible, and, therefore, the phosphorus should not be over .02 per cent. Sulphur, which does not appreciably affect brittleness, but which does decrease forgeability, is not quite so important, but should not exceed .04 per cent. Manganese may be present in larger quantity, and it is not an uncommon practice to put into the pot a mixture of manganese ore and carbon so that metallic manganese may be reduced and confer better forging qualities. If the percentage does not exceed .20 it has very little bad effect; if much above this, it will cause brittleness and liability to crack in quenching.

As in every branch of industry, a simple outline of operations such as is given above may be elaborated indefinitely by the description of the variations in practice which have been developed in different works. Some such details seem absolutely essential to the

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* *On the Manufacture of Crucible Cast-Steel. Journal I. and S. I.*, Vol. II, 1884, p. 372.

originators, but they may be unknown at other equally successful establishments.

There is one feature, however, known as "killing," which is in universal use. Just after the steel is melted there is more or less action in the crucible, since there are several rearrangements to be consummated. Thus, in addition to the iron and charcoal in the pot, there is a small amount of glass or similar material to give a passive slag; there is also a little air, some slag and oxide of iron in the puddled bar, the scale and rust on the surface of each piece of metal, and silica, alumina and carbon from the scorification of the walls. A little time is necessary after fusion for the various reactions to occur between these factors and for the attainment of chemical equilibrium. Aside from these general reactions, the special work of the "killing" epoch is the reduction of silicon from the slag and lining in accordance with the following equation:

$$SiO_2+2C=Si+2CO.$$

The carbon is drawn either from the charcoal, from the metal, or from the walls of the crucible. In the case of graphite pots the supply from the latter source will be more than ample, while even clay pots furnish quite an amount from the coke which is mixed with the clay in their manufacture. This process of reduction goes on until the steel contains from .20 to .40 per cent. of silicon and the metal lies quiet and "dead." The pot is then taken from the furnace by means of tongs, and the contents are cast into ingot form. The crucible lasts from four to six heats, and the weight of a melt is about 80 pounds when the crucible is new, the subsequent charges being regulated according to the strength of the scorified walls, and by the desire to lower the level of the slag line to the less affected portions.

SEC. Vc.—*Chemical specifications on high steel.*—In olden times all springs, tools, dies, and the like, were made from either cement or crucible steel, but in late years large quantities of high-carbon metal have been produced in the Bessemer converter and used for many common purposes, although, ordinarily, the steel made by this process contains too much phosphorus to make it suitable for the best work. The manganese in Bessemer steel is much higher than in crucible metal, and this has a tendency to cause cracks in quenching. Formerly a content of .75 to 1.10 per cent. was not uncommon, but the demands of the trade have forced an improvement in this respect, and it is now customary to keep the manganese below .80 per cent.; it is impracticable to have it much below .50 per cent. on account of red-shortness.

It is possible to make a much better selection of the stock for an open-hearth furnace and to produce a steel which is low in manganese, phosphorus, and sulphur. The relative merits of open-hearth and crucible steel have been the subject of vigorous discussions, but, as in many similar cases, the critics who are loudest in expressing their opinions are the least competent to judge. Oftentimes a comparison is made between a pure crucible steel and an open-hearth metal containing about .07 per cent. of phosphorus and .60 per cent. of manganese, and on the strength of this comparison, and taking the word of some ignorant or untruthful open-hearth maker as to the quality of his product, the conclusion is formulated that crucible steel is undeniably superior. Such generalizations on insufficient evidence constitute the large majority of those made in our tool shops, but it is evident that no comparison is valid unless the steels are of the same composition, and in this latter respect it will not do to accept the unproven statements even of makers who rank as virtuous. To show that this last clause is not meaningless, Table V-A gives analyses of three grades of steel, furnished by one of the large and well-known steel manufacturers of the country. The first column shows the name by which the maker billed it.

Table V-A.

Examples of Commercial High Steels which are not in Accordance with Specifications.

Nature of sample as marked by maker.	Composition; per cent.				
	C	P	Mn	Si	S
"Crucible"	1.00	.04	.33	.02	.025
"Pennsylvania Railroad spring"	.94	.065	.56	.23	.125
"Low phosphorus spring"	.80	.072	.64	.19	.155

Needless to say that the carbon content in these metals is right, for otherwise they would be entirely unsuitable, but each sample shows discrepancies between actual composition and name. Crucible steel may and often does contain as much as .04 per cent. of phosphorus, but no purchaser expects to have that amount when he buys the product of the pot, and when this figure is considered in connection with the high manganese, and above all with the absence of silicon, the natural conclusion is that the metal ran from the taphole of an open-hearth furnace. The second sample was supposed to fill the Pennsylvania Railroad specifications for springs which at that time called for phosphorus below .05 per cent., manganese below .50 per cent., and sulphur below .05 per cent., but a glance will show the liberties that were taken. The "low phosphorus" spring steel contains .072 per cent. of that element, an amount slightly under the average of common rails, but which can by no stretch of words be called "low" for hard metal. The sulphur is extraordinarily high, but where there are no specifications on this element, there is not much ground for criticism, since it has little influence on the cold properties.

Sec. Vd.—*Manufacture of high steel in an open-hearth furnace.*—It is perfectly possible to make regularly, in open-hearth furnaces, a steel of any carbon desired from .05 to 1.50 per cent., with phosphorus below .04 per cent., with manganese below .50 per cent., and with sulphur below .04 per cent.

During the last few years this steel has come into use in enormous quantities and all the car springs used in the country and almost all similar articles are of open-hearth steel. It is to-day being used very extensively under the name "cast steel," a term which is both a truth and a lie. It is the truth because the steel is cast; it is a lie because "cast steel" is a trade name dating back a century, and meaning the product of the crucible.

There are one or two minor points about this material which should be recognized by maker and user. First; there is not as good an opportunity to get a "dead melt" in the furnace as in the pot, and hence there is more liability of blowholes in the ingots and seams in the bar. For making razors, watch springs and other delicate instruments, no expense is too great in the avoiding of minute defects, but when these imperfections are few and not of such vital importance, there must inevitably be a tendency to economize in the cost of the raw material.

Second; a heavy heat of open-hearth steel must be cast in masses which are very large in comparison with the 4-inch ingot of the crucible works, and the chances for segregation are correspondingly increased, although Table V-B will indicate that with proper precautions there is very little danger of trouble from this cause.

TABLE V-B.

Composition of Clippings taken from the Top* and Bottom Blooms of Each Ingot of a High Carbon Open-Hearth Heat, Made by The Pennsylvania Steel Company.

Number of Ingot.	Part of Ingot.	Composition; per cent.					
		Carbon by Combustion.	P	Mn	S	Si	Cu
1	Top	1.009	.030	.30	.027	.14	.10
	Bottom	1.080	.031	.29	.026	.13	.10
2	Top	1.046	.029	.29	.027	.15	.10
	Bottom	1.006	.026	.29	.027	.13	.10
3	Top	1.042	.031	.29	.028	.11	.10
	Bottom	0.933	.030	.30	.029	.14	.10
4	Top	1.090	.032	.28	.028	.09	.10
	Bottom	1.027	.034	.29	.025	.12	.10
5	Top	0.948	.035	.32	.026	.17	.10
	Bottom	1.089	.036	.29	.027	.10	.10
6	Top	1.065	.030	.28	.026	.11	.10
	Bottom	1.086	.033	.29	.026	.11	.10
7	Top	1.073	.030	.29	.025	.11	.09
	Bottom	1.043	.028	.30	.028	.15	.10
8	Top	0.982	.029	.30	.025	.12	.10
	Bottom	0.953	.032	.29	.026	.13	.08
9	Top	1.044	.031	.29	.026	.11	.09
	Bottom	0.915	.032	.28	.027	.13	.10
Test.		1.073	.030	.28	.033	.12	.07

Some very interesting experiments were made by Wahlberg, who took tests from the top and bottom of high carbon ingots made at four well known works in Sweden. The variations in the results obtained by different chemists have already been shown in Table I-C and need not be discussed here. The original paper gives full information, from which we find that one analyst found a difference in the carbon content of the outer skin of the ingot at the top and at the bottom amounting in the four different ingots to the following in per cent.:

.13 .06 .09 .09

The differences at the center of the ingot between top and bottom were respectively .19, .05, .13 and .09 per cent.

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* The piece from the upper bloom was from a point corresponding to one-quarter way from the top of the ingot, and was therefore near the point of maximum segregation. The sample was the usual clipping produced in cutting a billet under the hammer.

There is one important point which is not discussed in the original paper. Wahlberg gives in each case the carbon as "branded" on the bar, by which we may assume that the steel would have been sold as having that particular amount of carbon. It may be well to compare this with the results obtained by the chemists, and Table V-C gives this information, the maximum and minimum in each case being obtained by some one chemist from the top and bottom of the same ingot, and it should be stated that in each case I have selected the chemist whose results gave the widest variation.

TABLE V-C.

Variations in Swedish Steel.

Brand.	Carbon per cent.	
	Maximum.	Minimum.
50	46	49
50	53	61
50	49	55
62	59	69
90	88	106
100	88	105
110	107	119
124	114	131

In the case of the Steelton steels, concerning which the fullest information is given, the variations in phosphorus, sulphur, manganese and copper are trifling, while those of silicon are unimportant. In carbon the difference between extremes is 16 points, and while this may seem to be a great variation in one charge, it will be found that the variations in each separate ingot were less than in the Swedish steel. The average variation between the top and bottom of a Steelton ingot was .07 per cent.

It is necessary to consider that a true comparison is not between one small ingot of crucible steel and a heat of open-hearth metal, but between equal amounts of each. In other words, the question must be asked, whether the irregularities are greater in a lot of ten tons of crucible steel than in ten tons of open-hearth. This cannot be satisfactorily answered, since so much depends upon the care with which the stock is selected, but Table V-D gives some analyses of different bars of one lot of crucible steel, sold under one mark and of uniform size by one of the leading firms in the United

States; it will be evident that uniformity can by no means be assumed.

TABLE V-D.

Variations in Composition between Different Bars of one Lot of Crucible Steel Rounds.

No. of Bar	Composition, per cent.			
	Carbon by color.	P	Mn	S
1	.85	.013	.20	018
2	.85	.011	.20	014
3	1.05	.010	.17	010
4	.98	.013	.21	.012
5	.90	und.	.28	.010

CHAPTER VI.

THE ACID BESSEMER PROCESS.

SECTION VIa.—*Construction of a Bessemer converter.* The acid Bessemer process consists in blowing air into liquid pig-iron for the purpose of burning most of the silicon, manganese and carbon of the metal, the operation being conducted in an acid-lined vessel, and in such a manner that the product is entirely fluid.

The way in which the air is introduced is a matter of little importance as far as the character of the product is concerned. In the earlier days there were many experimental forms of apparatus, the air being blown sometimes from the side and sometimes from the top, while the tuyeres were plunged beneath the surface or raised entirely above it. These forms have given way in all large plants to the method of blowing the air upward through the metal, trusting to the pressure of the blast to keep the liquid from running into the holes in the bottom, but in cases where converters are used for making steel castings the method of side blowing is employed, for it is found that with intermittent work and where there is difficulty in getting the metal hot, the side blast over the surface is an advantage.

The converters vary widely in size according to the desired output of the plant, in exceptional cases holding less than one thousand pounds, but the common size for what are known as "small" plants treats five tons at a time, while in the "large" plants the capacity is from ten to twenty tons. In Fig. VI-A are given drawings of the 18-ton vessels in use at the works of the Maryland Steel Company, at Sparrow's Point, Md.

It is the almost universal practice to rotate the converters on a central axis by means of an hydraulic rack and pinion in order to allow the turning down of the vessel as soon as the charge is decarburized, so that the metal may lie quietly in the belly, the tuyeres being above the metal, as shown in the figure. It is in this way only that a blast from the bottom can be suddenly stopped without fill-

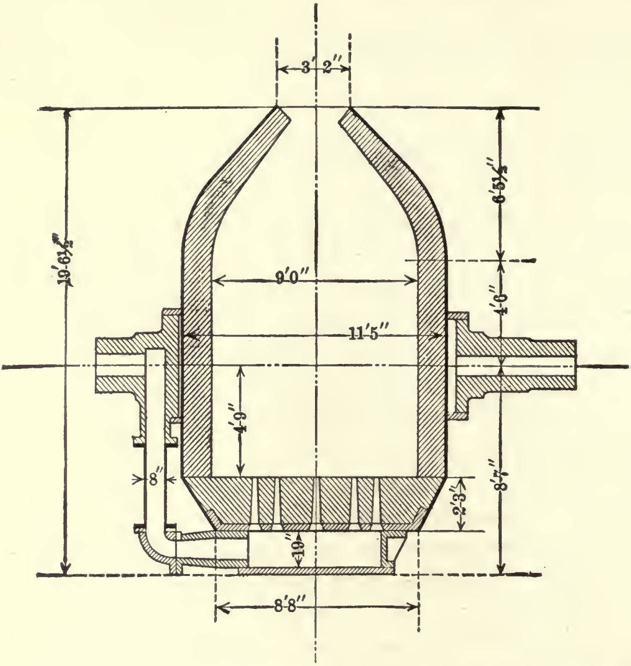

Fig. VI-A.—Section of Bessemer Converter in Upright Position.

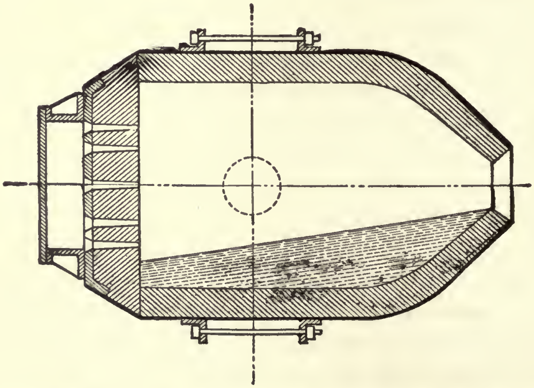

Fig. VI-A.—Section of Bessemer Converter when Turned Down, Showing Bath of Metal.

ing the tuyeres and air box with molten metal. If bottom blast be used with a stationary vessel, the blast must be continued during all the time required to open the taphole and drain out the metal, so that under the best of practice the results will be more irregular than with a rotary form. This fault may be partly overcome by having the blast introduced from the upper surface, but experience shows that the waste of iron is greater, and this extra expense completely wipes away all advantages of a reduced cost of installation.

TABLE VI-A.

Chemical History of an Acid-Bessemer Charge.

Illinois Steel Company, South Chicago, Ill., August 13, 1890, F. Julian. Barometer, 29.79 inches; temperature, 36° C. (96.8° F.); blast pressure, 27 pounds to the square inch. In calculations on volume of air, no allowance is made for leakage or clearance. Weight of pig and scrap, 22,500 pounds. Weight of spiegel, 2500 pounds.

Subject.	Initial Charge.	Time of Blowing.					
		2m. 0s.	3 m. 20s.	6m. 3s.	8m. 8s.	9m. 10s.	After Spiegel.
Carbon	2.98	2.94	2.71	1.72	0.53	0.04	0.45
Silicon	0.94	0.63	0.33	0.03	0.03	0.02	0.038
Manganese	0.43	0.09	0.04	0.03	0.01	0.01	1.15
Phosphorus	.10	0.104	0.106	0.106	0.107	0.108	0.109
Sulphur	.06	0.06	0.06	0.06	0.06	0.06	0.059
Silica	...	42.40	50.26	62.54	63.56	.....	62.20
Alumina	...	5.63	5.13	4.06	3.01	.....	2.76
Ferrous oxide	...	40.29	34.24	21.26	21.39	.....	17.44
Ferric oxide	...	4.31	0.96	1.93	2.63	.....	2.90
Manganese oxide	...	6.54	7.90	8.79	8.88	.....	13.72
Lime	...	1.22	0.91	0.88	0.90	.....	0.87
Magnesia	...	0.36	0.34	0.34	0.36	.....	0.29
Phosphorus	...	0.008	0.008	0.010	0.014	.....	0.010
Sulphur	...	0.009	0.009	0.014	0.008	.....	0.011
Flame	...	Silicon flame.	brightening.	m'der'te carbon flame.	full carbon flame.	flame drops.	.....
Cubic feet of air	...	34502	30628	53481	45365	26430	.....

The lining is made of stone, brick, or other refractory material and is about one foot thick. The bottom is made either of brick or rammed plastic material, the tuyeres being almost invariably of brick, from 20 to 26 inches in length, and with holes from three-eighths to one-half inch in diameter. The total tuyere area varies at different works from 2.0 to 2.5 square inches per ton of charge. The blast pressure may be 30 pounds per square inch during the first period of the blow, but during the last few years there has been a tendency toward greater tuyere area and a reduction in the pressure to about 20 pounds. In the case of a very hot charge, or if the slag is sloppy, the pressure must sometimes be reduced to 10 pounds after the flame "breaks through" (*i. e.*, after the carbon begins to burn), to prevent the expulsion of metal from the nose. The blowing engine and the tuyere openings being proportionate to the work in hand, the heats, whether heavy or light, are usually blown in from 7 to 12 minutes.

SEC. VIb.—*Chemical history of an acid Bessemer charge.*—The chemical history of a typical charge was investigated by F. Julian at the South Chicago Works of the Illinois Steel Company, and his results are given in Table VI-A. which is copied from a most admirable paper by Prof. Howe.*

TABLE VI-B.

Calculations on Weights of Bessemer Slags. (See Table VI-A.)

Method of Calculation.	Weight of Slag in pounds.			
	After blowing 2m. 0s.	After blowing 3m. 20s.	After blowing 6m. 3s.	After blowing 8m. 8s.
From content of CaO	1024	1374	1420	1385
From content of MgO	1389	1471	1471	1385
From content of Al_2O_3; no increase assumed	746	819	1034	1385
From content of Al_2O_3; 15 pounds increase assumed	480	624	911	1385
From content of MnO	1514	1443	1331	1385

The weight of the slag is not recorded, but apparently all the data are given that are necessary to calculate the complete history, for the amount of manganese that burns is known, and, from the percentage which this forms of the total cinder, the deduction may be made that the slag at the end of the fourth period weighs 1385 pounds. This figure seems quite probable, and, with it as a basis, it seems possible to calculate the conditions at earlier stages of the blow. One method of doing this is founded on the content of lime and magnesia. The presence of both of these factors must arise from the introduction of small quantities of cupola or blast-furnace slag into the converter, and, since there is no possible source of supply of either during the process of blowing, they must be in constant quantity throughout the operation. Another method is founded on the content of alumina, but this determination would be less reliable, for there is a certain constant increase in the quantity present, owing to the scorification of the bottom. In the present case the calculation has been made by two different hypotheses;

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* *Notes on the Bessemer Process. Journal I. and S. I.*, Vol. II, 1890, p. 102.

first, that no alumina is added to the slag during the blow; second, that 15 pounds enters the cinder between the beginning and end of the operation. A third method is founded on the quantity of manganese in the slag; this amount is changing continually, but as none can enter the slag save from the iron, and as the composition of the metal is given for each stage of the process, it would seem that reasonably accurate results might be obtained from this source. Table VI-B shows the figures thus determined.

A little consideration will show that there are radical errors in the data, since the results do not agree among themselves; in the second calculation, on the basis of MgO, and in the fifth, on the basis of MnO, the work is palpably wrong, since the figured weight of the first slag is greater than that of the final. Without doubt, some of the trouble arises from the incorporation of slag which was left sticking to the sides of the converter from previous heats, and which melted gradually as the blow progressed. There is also great difficulty in procuring a true sample of slag at any intermediate stage of the operation owing to its viscous nature. These conditions, coupled with a certain error caused by the slopping of slag from the converter, render it impossible to write the chemical history from the data of one charge. The above attempt is recorded to show the limits which bound any such series of analyses.

Similar discrepancies will be found between the amount of oxygen theoretically necessary to burn the metalloids, and the quantity actually supplied. Up to the fifth test the oxygen needed for the combustion of the silicon, manganese and carbon (to CO) should be 1148 pounds. To this must be added about 67 pounds which is absorbed by the iron in the slag, giving a total of 1215 pounds. The volume of air actually supplied was 190,406 cubic feet, containing 2732 pounds of oxygen. Allowing a very generous margin for leakage and inefficiency of blowing cylinders, it is evident that the errors are so great that no instruction can be gained by calculations of the separate periods.

The presence of traces of phosphorus in the slag, given in Table VI-A, has been commented upon by Prof. Howe,* who attributes the phenomenon to a local contamination by shot mechanically held. This is probably not the whole story, for I have found that acid open-hearth slag with 50 per cent. SiO_2 may carry 0.04 per cent.

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* *Notes on the Bessemer Process. Journal I. and S. I.*, Vol. II, 1890, p. 101.

of phosphorus, and this could not all come from shot, but must arise, in part at least, from an absorption of phosphorus by oxide of iron. The failure of the silica to break up the resultant phosphate of iron may easily be explained by the persistence with which traces of elements refuse to be eliminated under conditions which suffice for the removal of all but an inconsiderable proportion. I have elsewhere* dwelt upon this fact at some length.

SEC. VIc.—*Variations in the chemical history due to different contents of silicon.*—With a low initial heat, the elimination of silicon is almost complete before the carbon is seriously affected, but there is a certain critical temperature where the relative affinities of silicon and carbon for oxygen are reversed, and, when this is attained, no matter at what stage of the operation, the silicon immediately ceases to have preference, and the carbon seizes the entire supply of oxygen. This continues until the carbon is reduced to about .03 per cent., but beyond this it is very difficult to go, for these last traces hold on even though the blast be continued with oxidation of iron.

If the metal has contained silicon during the burning of carbon owing to an excessively high temperature, the blowing may be kept up after the drop of the carbon flame and the silicon will be oxidized in preference to iron, but in ordinary practice silicon is eliminated early in the operation, for scrap is added to the charge in sufficient quantity to utilize the excess of heat and prevent the attainment of the critical thermal altitude. The same cooling effect may be attained by the injection of steam into the air supply, but this is less economical than adding scrap, for by the latter method a part of the charge is melted without any extra cost.

It has been the practice at many foreign works, particularly in Germany, to have the pig-iron at a very high temperature in the manufacture of rail steel, and blow "hot" in order to produce a decarburized metal containing silicon. The steel is cooled to a proper casting temperature by the addition of scrap in the ladle, and large quantities of rails and other products have been thus made with from 0.3 to 0.6 per cent. of silicon.

Some pig-iron, notably in Germany and Sweden, contains a considerable proportion of manganese; this burns in some measure at the same time as the silicon, and is usually all eliminated before the carbon begins to oxidize, but at high temperatures, as well as

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* *The Open-Hearth Process. Trans. A. I. M. E.*, Vol. XXII, p. 462.

when the manganese is present in large quantity, the carbon has preference. In Sweden this fact is made use of in the manufacture of tool steels, the operation being stopped when the bath is high in carbon, the metal still containing a sufficient proportion of manganese to insure good working. This renders necessary that the silicon content be kept low in the pig-iron in order that none may be left in the steel.

SEC. VId.—*Swedish Bessemer practice.*—The Swedish practice, which stands on an entirely different footing from American and English work, has been thoroughly discussed by Akerman,* and many of the following statements are founded on his authority. The pig-iron is made with silicon not much over 1.0 per cent. to insure that the product shall be free from this metalloid even if the blow be interrupted when high in carbon. The charge is taken in a molten state from the blast-furnace to the converter, a practice which has been in general use in Sweden since the first trials of the process in 1857, so that our most modern plants in their use of "direct metal" are simply copying a system which for many years was looked upon as too primitive for advanced metallurgy.

TABLE VI-C.

Analyses of Manganiferous Bessemer Pig-Irons and the Resulting Baths and Slags.

Name of Works.	Sample.	Time to beginning of boil.	Time of blowing when samples were taken.	Composition of Metal; per cent.			Composition of Slag; per cent.			
				C	Si	Mn	SiO_2	FeO	MnO	Al_2O_3
Langhyttan.	Pig-Iron.	. . . . .	. . . .	3.94	1.14	.64	. . .	. . .	. . .	. . .
	Bess. bath	2m. 45s.	2m. 15s.	4.20	.04	.12	48.76	34.72	13.95	.78
	" "	. . . . .	4m. 30s.	1.10	.03	.12	59.82	21.08	15.48	.98
	" "	. . . . .	5m. 30s.	.05	.01	.06	48.48	35.82	12.29	.72
Nykroppa.	Pig-Iron.	. . . . .	. . . .	4.35	.88	1.15	. . .	. . .	. . .	. . .
	Bess. bath	1m. 30s.	2m. 30s.	4.10	.10	.15	53.26	13.50	29.76	2.28
	" "	. . . . .	5m. 30s.	1.00	.05	.15	62.34	9.54	23.70	3.90
	" "	. . . . .	6m. 30s.	.08	.04	.08	44.52	30.60	21.39	2.14
Westanfors.	Pig-Iron.	. . . . .	. . . .	4.22	1.06	5.12	. . .	. . .	. . .	. . .
	Bess. bath	2m. 30s.	4m. 15s.	4.20	.43	3.26	45.87	4.20	46.38	3.08
	" "	. . . . .	8m. 35s.	1.30	.12	.85	39.07	6.24	52.26	2.49
	" "	. . . . .	9m. 20s.	.55	.07	.43	37.63	9.45	48.92	2.94

The slow working and small charges which must always characterize the Bessemer practice of Sweden, renders necessary a hot-blowing metal, and since the silicon cannot be high without danger

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* *Bessemer Process as Conducted in Sweden.* *Trans. A. I. M. E.*, Vol. XXII, p. 265.

of leaving some in the product, it is customary to have from 1.5 to 4.0 per cent. of manganese in the pig. Table VI-C gives analyses of metals and slags at different periods of the operation, the data being taken from the paper by Akerman just referred to.

It will be seen that when manganese was present in large proportion, there was quite an amount left in the steel after the boil had begun and even after most of the carbon had been eliminated. This will be further illustrated by Table VI-D, which gives additional results from the Westanfors Works, and which is also taken from the paper by Akerman.

Table VI-D.

Examples of Bessemer Steel Made from High-Manganese Pig-Iron by Interrupting the Blast before Complete Removal of Carbon.*

Pig-Iron with 4 per cent. Mn and 1 per cent. Si.

Element.	Composition, per cent., of various heats.							
C	1.3	1.1	0.9	0.7	0.5	0.3	0.2	0.15
Mn . . .	0.6	0.55	0.5	0.4	0.3	0.2	0.15	0.12
Si	0.06	0.05	0.045	0.045	0.04	0.03	0.02	0.015

Pig-Iron with 5 to 6 per cent. Mn and 1 per cent. Si.

Element.	Composition, per cent., of various heats.				
C	1.3	1.1	0.9	0.7	0.6
Mn . . .	1.25	1.05	0.9	0.7	0.6
Si	0.25	0.2	0.15	0.12	0.1

The presence of oxide of manganese renders the slag more fluid and also reduces the content of iron oxide, as is clearly shown by the analyses of the Westanfors slags. This is in accord with the theory elsewhere advanced concerning the composition of open-hearth slags, that after a certain basicity and fluidity are attained, the demand for more bases is not urgent. (See Section Xc.)

Sec. VIe.—*History of the slag in the converter.*—Akerman discusses, with considerable fullness, the part which the slag plays in the oxidation of the metalloids, but I have ventured to disagree with him on this point.* In the open-hearth process, the history of the slag is the history of the operation, for all the changes

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* *Trans. A. I. M. E.,* Vol. XXII, p. 667.

in the composition of the metal must of necessity be done through the mediation of the slag, but in the Bessemer the blast enters from the bottom and passes upward through the metal before it ever comes in contact with the slag. It is quite true that the charge is in a state of violent ebullition and that the slag is constantly carried down into the metal, but, nevertheless, such a mixing does not seem to be a necessary and inherent part of the operation, for, when the heat is first turned up, the silicon is immediately oxidized, although no slag is present. In short, the question almost resolves itself into a *reductio ad absurdum*, for it is the oxidation of the silicon which first creates the slag, and hence it can hardly be that slag is necessary for the oxidation of silicon. It is quite true that the slag does automatically adjust its own composition, and will do so even after the addition of large quantities of iron oxide, but probably with much less precision than in the open-hearth furnace.

In American practice no attention is paid to the composition of the slag, for at most works the iron contains only a trace of manganese, while at others it hardly ever exceeds 0.50 per cent., this amount rendering the slag somewhat more fluid, while, with a content much above this, there is considerable loss of metal by slopping. Whether the initial metal contains manganese or not, there will always be a certain proportion in the final slag from the reaction with the recarburizer. An average sample was taken of about 100 heats at The Pennsylvania Steel Company's works, and the results are given in Table VI-E in comparison with the analysis of Chicago slag, as given in Table VI-A. No attempt was made to separate the different iron oxides, the metal being all calculated as FeO.

TABLE VI-E.

Composition of American Bessemer Slags.

Composition, Per Cent.				Origin of Sample.
SiO_2	FeO	Fe_2O_3	MnO	
62.20	17.44	2.90	13.72	Chicago (See Table VI-A .)
59.70	19.30	....	12.00	Steelton 100 heats.
69.50	15.34	....	9.37	Steelton 100 heats; pig iron = 2.50 to 3.00 per cent.Si.

The composition of the slag is sometimes greatly changed in one or more charges by the practice of blowing with the vessel partly tipped over while the carbon is burning. This position brings some of the tuyeres above the level of the metal, so that the blast rushes over the surface, oxidizing considerable iron, and also burning part of the CO to CO_2. Under ordinary conditions, the gases escaping from the mouth of the converter during the boil consist mainly of N and CO, but when a part of the air enters just above the metal and the rest from below, as it will do if the vessel is inclined, there will be a greater calorific development, so that this method is taken to raise the temperature of a cold charge at the expense of a greater waste of iron, and a greater wear of the lining.

These cold charges may arise from too low a content of silicon, from a low initial temperature, or from a newly-repaired vessel. It is unusual in our rapid American practice to have much difficulty from insufficient heat, for the fastest plants will make an average of eight heats per hour from a pair of 10-ton vessels, giving an output of 50,000 tons per month. Under these conditions a content of one per cent. of silicon in the pig-iron, without any manganese, is found sufficient for the production of the necessary heat. Little attention need be paid to the initial content of carbon, for, as it burns mostly to CO, and as the nitrogen and carbonic oxide must both be heated to the full temperature of the charge, with the absorption of a large quantity of energy in their free expansion, the combustion of this element supplies very little heat to the bath. In the burning of silicon, on the contrary, the only gas escaping is the nitrogen, and with the exception of the calorific power necessary to heat this gas and the silica to a yellow heat, the entire energy of the action is utilized in the bath.

SEC. VIf.—*Calorific history of the acid Bessemer converter.*—In the previous edition of this book there appeared a calculation on the amount of heat generated during the operation in a Bessemer vessel, but some changes are necessary in the work because there have been quite recently some new determinations on the calorific value of silicon. It has always been assumed that this element when burned produced 7830 calories per kilogramme, but it now appears that this value, which applied to the hydrated oxide, is too high, and a much lower value applies to the dry oxide formed in a calorimetric bomb.

In the former calculation it was considered that the carbon was all burned to carbonic oxide (CO), while it is well known that a certain proportion burns to carbonic acid (CO_2), this proportion varying with the progress of the operation; in the following calculation it will be assumed that one-fifth of the total carbon is burned to carbonic acid, thus increasing considerably the calorific energy.

These matters have been discussed with one of the highest authorities on such matters, Prof. J. W. Richards, of Lehigh University, and I have asked him to give the solution of the problem under his own name. In the former edition the theoretical rise in temperature was found to be 481° C. It is here found to be 329° C. Considering the change made in the value of silicon, which in itself reduces the final temperature by 45° C., it will be seen that the two calculations may be regarded in a very rough way as corroborative of each other.

The assumption that two per cent. of iron is burned to useful purpose, is founded on the fact that the Bessemer department at The Pennsylvania Steel Works produces about 120 tons of vessel-slag for every 1000 tons of pig-iron. This slag, after being cleaned by the magnet, averages 15 per cent. of iron, so that the loss is 1.80 per cent. of metal. The volume of slag is determined in great measure by the amount of silica available for each heat, and this silica comes from the wear of the lining, from erosion of the bottom, and from combustion of silicon. The percentage of the latter element in the pig-iron used in the above practice is about 1.75 per cent., which is somewhat higher than is essential, so that scrap must be used to cool the charge. If the pig-iron were supposed to contain only 1.00 per cent. of silicon, the weight of the slag will be considerably reduced, but as the wear of the bottom and lining will remain nearly constant, the decrease will not be proportional. It will be assumed in the present calculation that 1.5 per cent. will represent the usual loss of combined iron in the cinder.

A part of the metal enters the slag as shot, a separation by the magnet giving an average content of from 6 to 8 per cent., indicating a loss of about three-quarters of 1 per cent. of the total output, and this portion is a complete loss as far as both product and heat are concerned. The large pieces of scrap in the vessel slag may be picked out by hand, and, as these are generally returned to the cupolas without reweighing, they are not reckoned in the percentage of loss. The smaller particles can only be recovered by the rather expensive process of crushing the slag and passing it over a magnetic separator.

There is about 8 per cent. of loss in the converter in ordinary practice, of which the metalloids do not give over 5 per cent., so that about 3 per cent. of metallic iron must be accounted for. The amount combining with the slag has been shown to be about 1.8 per cent., while the shot is 0.75 per cent., so that about one-half of 1 per cent. of metal must be ejected from the nose of the vessel by the force of the blast in the form of fine dust and splashes. Most of this metal is oxidized outside the converter, but a part of it is burned within and gives its heat to the charge. Together, with the 1.5 per cent., which enters the slag, we may assume that something less than 2 per cent. in all is available as fuel.

When the iron is melted in cupolas there is an additional loss of 2 per cent., making a total of 10 per cent. It is shown in Sec. VIh that about half of 1 per cent. of all the iron charged in the cupolas is carried off as oxide in the slag, but in addition to this there is quite an appreciable amount which is lost when the cupola is dumped, and another part that is absorbed by the lining of the hearth. The capacity of linings to absorb oxide of iron can only be appreciated by one who has melted the first heat on a new bottom in an open-hearth furnace.

There is also quite a diminution in the weight of the iron caused by the oxidation of silicon and manganese, and perhaps carbon. It is hardly fair to speak of this as loss, as these elements must be burned one time or another, and if they are not eliminated in the cupolas, they will cause just so much more loss in the converter. The same reasoning, of course, applies with still more force to any sand that may cling to the iron. It is manifestly absurd to regard sand as iron, and yet many account books are kept in that way.

Calculation of Rise of Temperature During the Blow, by Prof. Joseph W. Richards.

The calculation is made on the assumption that, given a bath of pig-iron at 1400° C., and air coming in at 100° C., and the amount of heat required to heat the air to the temperature of the bath being first allowed for, then the heat evolved by the union of the oxygen with the bath must be absorbed by the products of the oxidation. These products are steel, slag, oxides of carbon and nitrogen. The steel and slag will be raised to the final temperature of the bath; the gases will escape continuously, and, therefore, be heated to the average temperature of the bath, in the case of nitrogen, or to an assumed three-quarters of the total rise in the case of oxides of carbon, which come off during the latter half of the blow. The heat absorbed by the lining is indefinite, but a rough approximation to it can be made by assuming that a thickness of lining of one centimetre participates in the increase of temperature. The amount of heat lost by radiation cannot be allowed for, so that no attempt to do so will be made.

TABLE VI-F.

Calorific History of the Acid Bessemer Converter.

Data: 1000 kg. pig-iron; Si=1.00 per cent.; C=3.50 per cent.
Initial temperature=1400 C. Average temperature about 1600° C.
Loss=8 per cent. Metallic iron burned=2 per cent.
Specific heat at 1600° C., per cubic metre CO and N=0.40; CO_2=1.34.
Specific heat at 1600° C., per kilo liquid steel 0.21, liquid slag 0.25, lining 0.25; per kilo CO and N=0.32, CO_2=0.68.
Specific heat of air 100° C. to 1400° C., per cubic metre=0.346; per kg.=0.268.

NET HEAT DEVELOPMENT.

	Calories.	Surplus.
Combustion of Silicon—		
10 kg. Si+11.4 kg. O=21.4 kg. SiO_2	=64,140	
11.4 kg. O=49.6 kg. air, absorbing 49.6×0.268×1300	=17,280	46,860
Combustion of Iron—		
20 kg. Fe+5.7 kg. O=25.7 kg. FeO	=23,460	
5.7 kg. O=24.8 kg. air, absorbing 24.8×0.268×1300	= 8640	14,820
Combustion of Carbon—		
7 kg. C+18.7 kg. O=25.7 kg. CO_2	=56,930	
28 kg. C+37.3 kg. O=65.3 kg. CO	=68,600	
	125,530	
56 kg. O=243.5 kg. air, absorbing 243.5×0.268×1300	=84,830	40,700
Total surplus heat developed........		102,380

CALORIFIC CAPACITY OF THE PRODUCTS.

Weight×Sp. heat at 1600 degrees.		
920 kg. liquid steel	×0.21	=193.2
150 kg. liquid slag	×0.25	= 37.5
50 kg. lining	×0.25	= 12.5
25.7 kg. CO_2	×0.68×3/4	= 13.1
65.3 kg. CO	×0.32×3/4	= 15.7
244.8 kg. N	×0.32×1/2	= 39.2
Total capacity per 1° C.		=311.2

$$\text{Theoretical rise of temperature}=\frac{102{,}380}{311.2}=329^\circ\ \text{C.}$$

The surplus heat developed, after allowing for the heating of the air to the temperature of the bath, will be utilized in heating the steel, slag and gases produced, also the lining, while some is lost by radiation. Omitting the latter, it can therefore be said that the total surplus heat thus available, divided by the calorific capacity of the products at the average temperature of the bath (i. e., the heat required to raise their temperature 1° C.) will give the theoretical rise in temperature. For reasons already given, only half the calorific capacity of the nitrogen is used, and three-quarters that of the oxides of carbon.

The surplus heat charged respectively to the credit of silicon, iron and carbon does not express accurately the relative value of those substances for increasing the temperature of the bath, because the bath is in practice comparatively cold while silicon is being burnt and comparatively hot while carbon is oxidizing. The surplus credited to silicon is therefore smaller, and that to carbon larger, than actually occurs during the blow; but a little reflection will show that the values calculated and used are theoretically accurate for the needs of our calculation of rise of temperature.

This would make the end temperature $1400+329=1729°$ C., leaving out of consideration the loss due to radiation during the blow. It is very probable that the check on the rise of temperature due to this cause will not exceed 50° C., which would leave the corrected end temperature about 1679° C., and the actual rise about 279° C.

SEC. VIg.—*Use of direct metal.*—It has been the custom in Sweden, from the earliest days of the Bessemer process, to use the pig-iron as it comes from the blast-furnace without allowing it to become solid, while in other countries it was almost invariably found, during the early history of the art, that it was more economical to remelt the iron in cupolas. The success of the Swedish metallurgists arose partly from the necessity of saving fuel in a country where coal was not to be found, and partly from the favorable character of the native pig-iron, which, being made from charcoal, never contained high silicon, and which was almost always low in both sulphur and phosphorus, owing to the purity of the ore and fuel.

Moreover, a large proportion of the Swedish Bessemer product has been, and still is, a very hard steel, the blow being interrupted when the metal contains a considerable percentage of carbon, and therefore the operation can be conducted at a lower temperature, and a lower content of silicon is practicable. The manufacture of this hard steel is made feasible by the low phosphorus and low sulphur in Swedish irons, and although the method of interrupting the blow gives very irregular results, it will generally happen that the steel is suited for some purpose, and it can be graded after it is made.

The failure of the direct metal process in other countries arose from the fact that the product of a furnace on one day contained so much silicon that the charges were too hot, on another day the silicon was too low and the blows were too cold, while on the third day the iron was so high in sulphur that the steel was worthless. By allowing all the iron to become cold, and by mixing the different qualities according to fracture, and, at a later period, according to chemical composition, it was possible to get a more regular metal which would represent the average product of the furnace. It was also possible to mix the iron from different furnaces, certain brands being prized on account of their hot-blowing or their cold-blowing qualities, when the reason for their peculiarities was unknown.

The conditions in later years have altered the economic situation, and modern practice has reverted to the more primitive system of using the metal directly from the blast-furnace, this change being made feasible in great measure by improved blast-furnace practice. In some works the percentage of silicon in every cast is determined while the iron is on its way from the blast-furnace to the receiver, so that the blower can be forewarned of any change which is about to take place in the character of the iron. Much information is also gained by a fracture test made upon a small ingot which is cast in an iron mold, every precaution being taken to have all the conditions of pouring as uniform as possible.

It is, of course, generally believed that the introduction of the "Jones mixer" has removed all the difficulties in the use of direct iron, and a recent important decision of the Supreme Court of the United States gives ground for such a belief. It is beyond the province of this book to discuss legal questions with the above court, but it is possible that there were some rather practical points of metallurgy with which this august tribunal was not thoroughly familiar. For many years the use of an intermediate receiving ladle had been common in American works, and with the enormous increase in output and amount of pig-iron handled, the size of this ladle would necessarily be increased, and means be taken to prevent loss of heat. The function of mixing is a comparatively unimportant addendum, and the word "receiver" is a much more accurate word. As such it is coming into general use in both acid and basic Bessemer plants, both here and abroad.

Sec. VIh.—*Use of cupola metal.*—Under the practice of using direct metal it is desirable that the blast furnaces should be within a convenient distance, say two miles, of the Bessemer department, for, otherwise, there will be considerable loss from chilling. For these reasons there are some plants which still remelt all their iron. The cupolas used for this purpose are practically alike in different localities. They measure from 6 to 8 feet in internal diameter, while the height should be at least 20 feet to save fuel.

The consumption of fuel varies according to the height of the cupola, and according to the management, one pound of coke being required for 11 pounds of iron in some works, while in other establishments a ratio of 15 pounds of iron to one pound of coke has been attained. This coke must be as free as possible from sulphur, for it is not unusual to have the content of sulphur in the pig-iron raised .02 or even .04 per cent. during the melting.

Table VI-G.

Loss of Combined Iron in Cupola Slag.

Pig-iron charged, pounds	835,600
Coke "	75,750
Limestone "	15,250
Cupola slag "	40,200
Fe in slag, per cent	8.77
Fe in slag, pounds	3529
Fe in slag, per cent. of pig-iron charged	0.42

About half of 1 per cent. of silicon and some manganese are oxidized during the melting in the cupolas, but these are of little importance when compared with the loss of metallic iron. The total difference in weight between metal charged and metal tapped includes the sand which was attached to the pig, the silicon, manganese and carbon which have been eliminated, and also the scrap and shot which freeze to the lining, or fall through the bottom when the campaign is ended.

The true way to find the amount of iron oxidized is to weigh and analyze the cinder running from the slag-hole. Table VI-G gives the record for 24 hours on 7-foot cupolas.

SEC. VIi.—*Certain factors affecting the calorific history of the converter.*—Aside from the errors involved in the suppositions concerning the burning of iron, the theoretical effects of silicon and carbon upon the operation of the converter are never realized on account of several losses, which may be enumerated as follows:

(1) By radiation and conduction.

(2) By decomposition of the moisture in the blast.

(3) By melting the lining and bottom.

(4) By excess of air passing unaffected through the metal; for even though such excess may burn the CO in the upper part of the vessel to CO_2, a large part of the heat thus produced is carried away in the waste gases rather than absorbed by the bath.

It would be very difficult to make a quantitative estimate of these disturbing factors, and it would be equally unprofitable, for it is easy to obtain sufficient heat without much extra expense by a slight increase in the content of silicon in the pig-iron.

Until within a few years it was thought necessary to have from 2.0 to 2.5 per cent. of silicon in the metal as it entered the converter, but the general practice at the present time is to have from 1.0 to 1.5 per cent., although it is perfectly feasible to operate continuously with a content of from 0.6 to 0.8 per cent.

This reduction of the calorific power has been made practicable by several improvements in practice, none of them of overwhelming importance, but forming a considerable total when added together. Some of these details may be enumerated as follows:

(1) Fast and continuous running, the iron never standing long enough to cool, and the steel ladles and vessels being always hot.

(2) Quick blowing, the radiation from the vessel being proportionately decreased, and the time lessened during which the companion and idle vessel is cooling.

(3) Good bottoms and vessel linings, the heat required to fuse the scorified material being correspondingly reduced, and delays for repairs avoided.

(4) Quick changes of bottoms, less cooling of the vessels occurring while putting on a new section.

(5) The practice of blowing with the vessel partly tipped over when the charge is cool, as described in Section VIc. It was formerly necessary to have an excess of calorific power in the iron in order that there should be a margin of safety when there was a delay or when a bottom was changed, but the expedient of blowing

with the vessel inclined is now in general use, and, to some extent, has rendered this margin unnecessary.

It is the opinion of some metallurgists that this decrease in the initial content of silicon has resulted in a better quality of steel, and Ehrenwerth has endeavored to show why this should follow. His argument may be presented thus:*

When a high content of silicon is used, it is found that there is a greater proportion of free oxygen in the gases which escape from the converter during the first stages of the blow. This change in chemical relations arises from the fact that the percentage of carbon is nearly constant in all irons, and, therefore, with an increase in silicon, there is a corresponding increase in the proportion which the silicon bears to carbon, and a corresponding change in the affinities.

Granting that the presence of free oxygen in the gases escaping from the vessel during the first part of the process is due to the proportionately greater quantity of silicon as compared with carbon, then it would naturally be expected that, if the metal at the end of the operation should, for any reason, contain a high proportion of silicon as compared with its content of carbon, the escaping gases would contain free oxygen.

This proportionately high silicon at the end of the operation is found in heats which contained a high initial percentage of silicon in the iron, and hence such heats would be expected to have free oxygen in the bases which are formed at the close of the operation, and this free oxygen will signify a more highly oxidized and therefore an inferior condition of the metal.

Notwithstanding the argument, which has just been advanced, that the practice of tipping the converter in the case of a cold-blowing charge has rendered unnecessary as large a margin of calorific power as was formerly necessary, it still remains true that it is advantageous, and that it is customary, to have a slight excess of silicon to allow for delays and new bottoms. It is necessary, therefore, to lower the temperature of normal charges by the addition of steel scrap or solid pig-iron, the amount so added being determined from the behavior of the preceding charge, with allowances for any change in the thermal conditions.

The skill attained in estimating the temperature of melted steel

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* *Das Berg- und Hüttenwesen auf der Weltausstellung in Chicago.* **Ehrenwerth, 1895, p. 276.**

seems almost incredible to the lay mind, for when the iron is very regular and all other conditions are uniform, it is possible to detect the difference caused by a variation of 100 pounds in the amount of scrap added to a 7-ton charge in the converter, and I have elsewhere* tried to show that this represents a difference of only 13° C.

This calculation was made many years ago, and I have, therefore, looked over the work to see if it needed revision. Unfortunately, the data are still incomplete regarding the specific heat of steel at different temperatures and its latent heat of fusion, for owing to the existence of certain so-called critical temperatures, at which internal molecular transformations ensue with production of heat, the law of absorption of energy during the heating of iron is an irregular curve. The results of Pionchon† indicate the following equations in which $t = $ the temperature in degrees Cent.:

$$(0^\circ \text{ to } 660^\circ)\quad Sm = 0.11012 + 0.000025\,t + 0.0000000547\,t^2$$

$$(660^\circ \text{ to } 720^\circ)\quad Sm = 0.57803 - 0.001436\,t + 0.000001195\,t^2$$

$$(720^\circ \text{ to } 1000^\circ)\quad Sm = 0.218 - \frac{39}{t}$$

$$(1050^\circ \text{ to } 1160^\circ)\quad Sm = 0.19887 - \frac{23.44}{t}$$

The latent heat of fusion is not known accurately, but theoretical considerations would indicate it to be about 69 calories per kilogramme. If the calculation be reworked by these data, it will be found that the answer is practically the same as before obtained.

It must be acknowledged that all heats are not regulated to such exact measure as just described, but a variation of three or four times this amount is as much as is considered allowable, and more than is expected in current American practice. This accuracy can only be obtained by regular and uninterrupted work, so that we naturally would assume, and, as a matter of fact, do actually find, that the best "scrapping" follows the fastest running.

This fact alone is an all-sufficient answer to the criticism of foreign metallurgists that the large outputs of American Bessemer plants have necessarily been made at the expense of quality. There is absolutely no evidence to show that an ample supply of air, and a consequent shorter blow, will give an inferior product, but on the other hand, the more rapid action renders possible a lower initial content of silicon, and this is thought to be an advantage.

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* *The Open-Hearth Process. Trans. A. I. M. E.,* Vol. XXII, p. 392.

† See Richards; *Journal Franklin Institute,* July, 1893.

Aside from this one item of short blows, there is not a single feature necessarily connected with a heavy output which is open to criticism. A large product means simply that no time is lost; that one blow begins when another ends; that the vessel linings are in good condition; that bottoms are quickly changed; that the vessels are always ready for the iron, and the iron ready for the vessels; that the spiegel cupolas work with regularity, and furnish the recarburizer as soon as it is needed; that the steel is of the right temperature so that the ladles are neither burned through nor sculled, and the pit is free from "messes"; in short, that the machinery is ample, and the men capable. In spite of any statements to the contrary, the fact remains that the fast work of American plants sacrifices nothing but energy and brains.

SEC. VIj.—*Recarburization.*—The method of recarburizing in Bessemer practice varies with the character of the product. In making soft steel, solid ferro containing 80 per cent. of manganese is thrown into the ladle during pouring, the loss of metallic manganese being about 0.2 per cent. of the charge. With rail steel it is customary to add melted spiegel-iron either in the vessel or in the ladle, but sometimes solid ferro is used to supply manganese, melted pig-iron being poured into the ladle at the same time to give carbon. By this latter method the oxidation of manganese in the cupola is avoided, but the additional danger is encountered of incomplete mixing. When carefully carried out, very little trouble arises from this source, but it is more likely to occur with rail steel than with soft metal, for there is less bubbling and boiling in the higher carbon bath and, therefore, less automatic equalization. The loss of manganese depends upon the condition of the bath and upon the amount which is added. In making soft steel it is necessary to blow until the carbon is reduced to about .05 per cent., and, under these conditions, if manganese be added to the extent of .60 per cent. of the weight of the charge, the steel will contain .40 per cent., being a loss of .20 per cent. If, on the contrary, 1.30 per cent. be added, the steel will contain only .90 per cent., being a loss of .40 per cent.

It seldom happens that soft steel is wanted with over .60 per cent. manganese, but larger proportions are not unusual in rail steel. In the latter case it is feasible to economize by stopping the blow when the carbon is about .10 per cent., and, under these circumstances, an addition of 1.10 per cent. will suffice to give 0.90

per cent. in the steel. These figures must not be considered absolute, for they are only approximate and represent about what may be expected in the long run rather than on any one heat. A further discussion on this point will be found in the remarks on recarburization in the open-hearth furnace.

CHAPTER VII.

THE BASIC-BESSEMER PROCESS.

SECTION VIIa.—*General outline of the basic-Bessemer process.*—The basic-Bessemer process consists in blowing air into liquid pig-iron for the purpose of burning most of the silicon, manganese, carbon, phosphorus and sulphur of the metal, the operation being conducted in a basic-lined vessel, and in such a manner that the product is entirely fluid. The method by which the air is introduced has little effect on the character of the product, but, since it is sometimes necessary to cease blowing temporarily in order to take tests of the bath, the use of a rotary vessel with bottom blast is universal.

The distinctive feature of the basic vessel is a lining which resists the action of basic slags; this is usually made of dolomite, but sometimes a limestone is used containing a very small proportion of magnesia. The stone must be burned thoroughly to expel the last traces of volatile matter and then ground and mixed with anhydrous tar. The bottom is generally made by ramming the same material around wooden pins which are withdrawn after firing. At one works magnesite tuyeres are used which are said to last over seventy heats, but the cost is high and the practice has not been generally adopted.

The highest function of the lining is to remain unaffected and allow the basic additions to do their work alone, so that the rapid destruction of a basic, as compared with an acid lining, is not due to any necessary part it plays in the operation, but to the fact that there is no basic material in nature which is plastic, and which by moderate heating will give the firm bond that makes clay so valuable in acid practice. The agent used in its place is a rich tar, and this forms a strong coke under the action of heat and resists for a long while the scouring of metal and slag, and it generally happens that, by the time this coke is burned, the dolomite has become partially fused and "set." There is always, however, a slight shrinkage in the burned stone, no matter how thoroughly it has been roasted, so that there is an ever-present tendency to self-destruction through the formation of innumerable disintegrating cracks.

When air is blown through pig-iron, the first element affected is the silicon. This is true in both the acid and the basic processes, but the completeness of the elimination is less certain in the acid process, for a part of the silicon is sometimes left after the carbon is burned, owing to the production of an excessive temperature at an early stage of the operation. In the basic converter the incomplete combustion of silicon does not occur owing to three reasons, *viz.:*

(1) The silicon is lower in the pig because the oxidation of phosphorus is relied upon for heat.

(2) Burned lime is added before blowing in order to seize the silica as soon as formed and prevent cutting of the lining, and the heating and melting of this lime absorbs so much heat that the critical temperature cannot well be reached, especially since every increase in silicon must be met by a corresponding increase in lime.

(3) The basic slag has a greater affinity for silica than the very silicious slag of an acid converter, and it is probable that under these conditions the critical temperature is raised.

When the silicon is eliminated, the carbon begins to burn and continues until there is only about .05 per cent., while the manganese follows the same course that it does in acid work, part of it being eliminated while the silicon is burning and another part during the combustion of carbon. The proportion of manganese present at any particular time will depend upon the original percentage in the pig, but, comparing similar contents, the amount eliminated will be less than in the acid practice, for there is a less demand for its oxide in a basic slag, and the inducements to oxidation are therefore taken away.

Sec. VIIb.—*Elimination of phosphorus.*—With the exception of the basic lining, which is supposed to remain inert, and the basic slag, which has no chance in the early part of the operation to do anything besides aid slightly in the burning of silicon and retard slightly the oxidation of manganese, the reactions in the metal in a basic converter are almost identical with the reactions in the acid vessel up to the point when the carbon is reduced to .05 per cent. From this point comparison ceases, for there the acid process ends, while the basic begins the characteristic chapter in its history in the elimination of phosphorus and sulphur.

In an acid heat phosphorus is always present to a certain extent, and, if blowing were continued, it may be supposed that at the very surface of an air bubble phosphoric acid would be formed which, rising through the metal, would unite with oxide of iron and form phosphate of iron; but this would immediately come in contact with a silicious slag, or in other words, with a slag possessing more than enough silica to meet the pressing requirements of its bases, and the silica being immediately seized by the oxide of iron, the unprotected phosphoric acid would be robbed of its oxygen by the metallic iron. This may seem a very long explanation of the simple fact that phosphorus does not oxidize, but there are many reasons for supposing that in many chemical actions the atoms are in a state of general translation, so that while many compounds are formed, only those remain which find a suitable environment. It is difficult to explain the formation of phosphoric acid in the basic converter without assuming an action which can just as readily obtain in acid practice, although in the one case the product finds a suitable resting place, while in the other it is instantly destroyed.

During the elimination of carbon, a certain small quantity of phosphorus is burned and held by the slag, but for practical purposes it may be assumed that the percentage at the drop of the carbon flame is equal to the initial content. From that time the phosphorus seizes the oxygen in the same way as the silicon and carbon had done before, and the iron is thus perfectly protected, the phosphoric acid immediately uniting with the lime. It might be supposed that any other base like oxide of iron would serve to hold the phosphorus, but it is found that phosphate of iron is easily reduced by carbon, and that it is in other respects inferior to the oxide of calcium which gives a stable compound.

SEC. VIIc.—*Amount of lime required.*—The amount of lime needed will depend upon three conditions, viz.:

(1) The amount of silicon in the pig.

(2) The amount of phosphorus in the pig.

(3) The quality of the lime.

If the charge is 15,000 pounds, containing 0.50 per cent. silicon, it will produce 160 pounds of silica; and if the final slag must contain 6.0 per cent. silica, then the slag must weigh 2670 pounds; and if it must have 50 per cent. CaO, then 1335 pounds of *unsatisfied* CaO must be added. The qualification is inserted that it must be "unsatisfied," for each pound of silica in the lime detracts from its efficacy. Thus, if the lime contains 2 per cent. SiO_2, there will be 2 pounds of silica in every 100 pounds of addition, and if this is to be made into a slag containing 6 per cent. of SiO_2 and 50.0 per cent. of CaO, then 8 pounds of CaO is useless as far as it can have any effect upon the metal, since it will be appropriated by its own silica. In this way 10 pounds of the lime out of every 100 pounds, or one-tenth of the total amount, is used in satisfying itself.

The amount of silica derived from the lime and from the silicon does not entirely determine the quantity of lime, for there is evidently a limit to the possible content of phosphoric acid in the cinder. Thus, if a bath of 15,000 pounds contains 3.00 per cent. of phosphorus, it will produce 1030 pounds of phosphoric acid, and if the final slag is to contain 50 per cent. CaO and not over 20 per cent. P_2O_5, then this slag must weigh $5 \times 1030 = 5150$ pounds, so that $\frac{1505}{2} = 2575$ pounds of CaO must be added to the charge. It is not specified in this case that the CaO shall be "unsatisfied," for it will be immaterial as far as phosphorus is concerned what the silica may be in the lime as long as the demands of silicon are met.

SEC. VIId.—*Chemical reactions in the basic converter.*—The qualitative chemical history of the basic converter is shown in Table VII-A, which gives the analyses of metal, slags and gases at various stages of the operation, as given by Wedding.

The high percentage of oxygen and carbonic acid in the gases during the first stage of the operation arises from the chilling action of the basic additions, for at low temperatures carbonic acid is not readily reduced by carbon, but as the metal becomes hotter the carbon assumes more complete command and appears almost entirely in the form of carbonic oxide. At the end of the blow, when phosphorus is burning, the oxygen is held in the bath and the only gaseous product is the nitrogen, so that when the combustion of phosphorus is ended there is no such sudden change in the character of the flame as marks the death of the carbon reaction, and in order to be sure of the purity of the metal it is necessary to make fracture tests on small sample ingots before the charge is poured from the converter.

TABLE VII-A.

Analyses of Metal, Slag and Gases from the Basic-Bessemer Converter: No. 1=Heat No. 125 at Ruhrort, Germany.* No. 2=Heat No. 882 at Hörde, Germany.†

Time from Beginning.	Metal.					Slag.						
	Si	C	P	S	Mn	SiO_2	CaO	P_2O_5	FeO	Fe_2O_3	MnO	MgO
Pig Iron No. 1	1.22	3.21	2.183	.080	1.03	. . .	. . .	. . .	. . .	. . . . .	. . .	. . .
2m. 46s.	0.72	3.30	2.148	.047	.71	41.15	41.27	0.84	2.40	. . . . .	9.03	4.13
5m. 21s.	0.15	3.12	2.224	.051	.50	36.30	39.50	3.12	3.97	0.46	11.02	3.39
8m. 5s.	0.007	2.47	2.157	.049	.18	34.41	42.80	2.99	3.60	0.13	10.72	3.35
10m. 45s.	0.012	1.49	2.096	.051	.16	31.94	43.12	4.02	4.23	0.74	9.94	4.01
13m. 28s.	0.005	0.75	2.053	.051	.14	16.64	44.37	7.15	8.42	4.95	8.51	7.34
15m. 13s.	0.008	0.05	1.910	.055	.01	14.65	46.63	11.60	7.15	3.84	7.39	6.34
19m. 14s.	0.005	0.02	0.230	.060	.01	12.94	47.76	18.83	5.84	3.74	4.25	6.00
19m. 31s.	0.005	0.02	0.139	.055	. .	12.20	48.59	18.66	6.79	2.80	4.01	6.26
19m. 49s.	0.004	. . .	0.087	.056	. .	11.71	48.19	18.15	7.19	2.78	4.05	6.38
Rail Steel,	0.01	0.26	0.145	.045	.48	12.77	47.87	16.92	5.94	2.87	4.80	6.75
Pig Iron No. 2	0.58	3.60	2.75	.079	1.57	. . .	. . .	. . .	. . .	. . . . .	. . .	. . .
About 3m.	0.28	2.81	2.57	.079	2.50	9.20	76.10	2.94	0.55	. . . .	8.87	4.86
" 6m.	0.07	2.02	2.08	.073	0.30	9.50	71.40	6.90	0.73	. . . .	9.70	5.33
" 9m.	0.07	1.33	2.25	.074	0.34	9.30	66.17	7.32	2.30	. . . .	8.42	6.47
" 12m.	0.06	0.71	1.55	.079	0.26	10.28	50.71	15.87	7.13	. . . .	9.45	6.90
" 15m.	0.02	0.105	0.061	.054	0.21	6.99	46.84	24.73	11.98	. . . .	5.40	4.09
Steel,	0.02	0.136	0.084	.046	0.55	4.79	42.05	16.33	26.03	. . . .	4.62	6.83

Heat No. 882.	Metal.					Gas.				
	Si	C	P	S	Mn	CO_2	O	CO	CH_4	N
Sample 1	.28	2.81	2.57	.079	2.50	3.5	8.1	2.0	0.9	85.0
" 2	.07	2.02	2.08	.073	.30	3.0	3.0	10.6	1.0	81.4
" 3	.07	1.33	2.25	.074	.34	3.0	0.3	28.3	1.6	66.6
" 4	.06	.71	1.55	.079	.26	1.8	0.2	29.8	1.8	65.0
" 5	.02	.105	.061	.054	.21	1.2	0.8	1.6	0.9	95.6

SEC. VIIe.—*Elimination of sulphur in the basic converter.*—Sulphur is removed for the most part at the same time as the phosphorus, but, if present in very large quantity, it may be necessary to continue the blast after dephosphorization with the sacrifice of a little iron. This however is bad practice and is far from being economical or desirable. In a series of heats made by The Pennsylvania Steel Company, in 1883, a content of 0.25 per cent. was regularly reduced below 0.05 per cent. Manganese was present in this case up to about 2.0 per cent., and this is found to aid in the

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* *Basic Bessemer Process.* pp. 136 and 137.

† *The Progress of German Metallurgy. Trans. A. I. M. E.*, Vol. XIX, p. 366.

work, probably by the formation of sulphide of manganese. Even after the manganese has entered the slag it may be available for this function, for it can be reduced by the phosphorus and incorporated into the metal. Table VII-B is copied from a paper by Stead* to show the increase of manganese in the bath duing a time when there was no addition of this element from outside the vessel.

TABLE VII-B.

Reduction of Manganese from Slag in the Basic Converter.

(See *Journal I. and S. I.*, Vol. I, 1893, p. 63.)

Heat.	Time of taking test of metal.	Composition, per cent., of the metal in the bath.		
		Mn.	P.	S.
No. 184	Disappearance of spectrum line, At second lime addition,	0.19 0.62	2.070 0.463	0.133 0.067
No. 185	Disappearance of spectrum line, At second lime addition,	0.24 0.81	2.180 0.718	0.072 0.042
No. 186	Disappearance of spectrum line, At second lime addition,	0.24 0.79	2.390 0.483	0.081 0.047

The quantitative investigation of the basic converter is unsatisfactory, owing to the fact that some lime is blown out in the form of dust as soon as the charge is turned up, while at a later time a large amount of slag may be expelled by explosive action, this being particularly marked when the temperature is low. Moreover, the lumps of lime do not immediately become incorporated into the slag and no true sample can be taken. It is, perhaps, from these causes that contradictory statements are made by careful observers.

Wedding states† that there is a volatilization of both sulphur and phosphorus, as proven by the fact that the slags from sulphurous metal do not give correspondingly increased percentages of CaS, while in the cinder from hot charges there will sometimes be from 30 to 40 per cent. less weight of phosphorus than was present in the pig-iron, although a cold blow will show the full amount. On the other hand, Stead* gives the figures for a basic charge where all the sulphur that was lost by the metal appeared in the final slag. The analyses and summary are given in Table VII-C.

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* *On the Elimination of Sulphur from Iron.* *Journal I. and S. I.*, Vol I, 1893, p. 61.

† *The Progress of German Metallurgy.* *Trans. A. I. M. E.*, Vol. XIX, p. 367.

TABLE VII-C.

Chemical History of High-Sulphur Iron in the Basic Converter.

(See *Journal I. and S. I.,* Vol. I, 1893, pp. 61 and 62.)

Metal.	Composition, per cent.				
	Initial.	Desiliconized.	Decarburized.	Dephosphorized.	Steel.
Carbon	2.32	2.180	0.07	0.02	......
Manganese	0.66	0.200	0.09	0.06	......
Silicon	1.57	0.300	0.07	trace.	......
Sulphur	0.16	0.148	0.16	0.08	0.07
Phosphorus	1.85	1.920	1.53	0.04	......
Slag.					
CaO	......	44.30	47.00	46.70	......
MgO	......	0.72	0.86	1.80	......
MnO	......	6.60	4.46	2.51	10.79
FeO	......	4.38	8.23	14.02	9.00
Fe_2O_3	......	1.29	1.00	4.29	2.14
SiO_2	......	39.20	29.80	14.90	......
P_2O_5	......	2.61	7.83	14.86	......
S	......	0.16	0.10	0.36	0.36
Probable weight of liquid slag in per cent. of metal	......	7	11	27	......

Quantitative calculation on the Sulphur.

Sulphur in lime used, per cent. = 0.054 per cent.	
Sulphur in Slag:	
27 per cent. of slag @ 0.36 per cent. S (see above columns) = per cent.	0.097
Less sulphur in lime added = 15.2 per cent. of 0.054 per cent. = per cent.	0.008
Total sulphur received from metal, per cent.	0.089
Sulphur removed from metal:	
100 parts of initial iron contained, per cent.	0.160
Less 85 parts of blown metal containing 0.080 per cent. S = per cent.	0.068
Total sulphur removed, per cent.	0.092

It will be noted that the calculation rests on "the probable weight of liquid slag" for *one* heat, and this can hardly be considered a final and conclusive proof that volatilization cannot occur, or that it does not often occur, or even that it does not usually occur. In another chapter (see Sec. XIk) I have tried to show that such loss of sulphur may take place in open-hearth practice, and, if this is true, it seems probable that it will also hold good in the converter.

An account by Hartshorne[†] of the practice at Pottstown, Pa., agrees quite well with the data above given for Hörde. The cupola

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[*] *On the Elimination of Sulphur from Iron. Journal I. and S. I.,* Vol. I, 1893, p. 61.

[†] *The Basic Bessemer Steel Plant of the Pottstown Iron Company. Trans. A. I. M. E.,* Vol. XXI, p. 743.

mixture is of the following composition in per cent.: Si, 0.3 or less; S, .03 or less; Mn, 0.80; P, 2.50 to 3.00. It will be seen that the specification for the cupola mixture is very rigid, and that the limitations must inevitably result in an increased cost for raw material.

Some years ago it was the practice at two different works in Germany to add about two-thirds of the lime at the beginning, so that when the metal was nearly dephosphorized the slag could be decanted, after which the rest of the lime could be put in and the final dephosphorization effected by a purer slag. The first cinder, which was rich in phosphorus and poor in iron, was fit for agricultural purposes, while the second, which was poorer in phosphorus and richer in iron, was used in the blast furnace.

This practice has been discontinued and at all works the total quantity of lime is added at the beginning of the blow. The final slag runs as follows in per cent.: SiO_2, 5 to 6; CaO, 45 to 50; P_2O_5, 16 to 20; FeO, 11 to 13; MnO, 5 to 6; MgO, 5 to 6. In some cases the SiO_2 may be higher, but the P_2O_5 is then in a less soluble state and the slag is not so well suited for agricultural purposes.

SEC. VIIf.—*Calorific equation of the basic converter.*—The calorific equation of the basic converter may be calculated by the same method that was used in the work on the acid process (see Table VI-F), but the great quantity of slag and the absorption of heat in its liquefaction render accurate results rather difficult. The silicon is much lower in the pig-iron and consequently the heat derived from this source is less, but the phosphorus more than makes up for the decrease. It was found in the calculation in Section VIf that the net value of silicon per kg. was 4686 calories; of iron 741 cals.; of carbon 1163 cals., and by the same method we may find that the value of phosphorus is 3821 calories. Assuming an iron with $Si=0.5\%$, $P=1.5\%$, $C=4.0\%$, and assuming also that 4.0 per cent. of iron is burned to useful purpose, the heat produced per 1000 kilos of iron will be as shown in Table VII-D, the total being about 50 per cent. more than the development in the acid converter.

TABLE VII-D.

Production of Heat in the Basic-Bessemer Converter.

5 kg. silicon	23,430 calories
35 kg. carbon	40,700
40 kg. iron	29,640
15 kg. phosphorus	57,315
Total	151,085

It is the general practice to use a pig-iron containing 1 or 2 per cent. of manganese, and about 2 per cent. of phosphorus, and such a pig would produce a still hotter blow than the one above given, but it has been proven in the Westphalian steel works that when a basic plant is worked up to its full capacity, the phosphorus content can be reduced, just as in acid work the percentage of silicon has been cut down far below what was once deemed necessary, but there must always be a greater development of energy in the basic vessel in order to allow for the melting of the lime additions.

SEC. VIIg.—*Recarburization.*—Recarburization is the greatest problem of the basic-Bessemer process, for at the end of the operation the metal contains much more oxygen than an acid bath, while the slag, instead of being viscous and inactive, is very liquid and has a certain amount of loosely held oxide of iron. In making rail steel by the use of melted spiegel, this oxygen in metal and slag may give a reaction with the carbon of the recarburizer, and the carbonic oxide which is formed reduce some phosphorus from the slag. This action is plainly shown in Table VII-A, where the content of phosphorus was raised in the case of "pig-iron No. 1" from .087 before recarburization to .145 in the finished product, the latter figure being much too high for good rail steel.

When making soft steel by the addition of solid ferro-manganese, the rephosphorization is less, but with bad practice it may be a troublesome factor. In "pig-iron No. 2," Table VII-A, the silicon is low in the pig, and the slag is rich in bases, yet the phosphorus in the metal was raised from .061 to .084 per cent., giving a content which is too high for the softest grades. The records given in these tables relate to general practice some years ago, and can hardly be said to represent the best work to-day. Rephosphorization is now controlled in great measure by keeping the temperature of the metal as low as possible, by using a very calcareous cinder, and by preventing the mixing of slag and steel during recarburization. This is done by decanting much of the slag before pouring the steel, and then making a dam to hold back the remainder of the cinder.

In going over carefully the records of one of the best works in Germany and taking averages of large numbers of heats the rephosphorization in rail steel gave a rise of about .025 per cent. in phosphorus. Five averages resulted thus, in each case the first figure being the bath before recarburization and the second the final steel: .044 to .070; .039 to .056; .036 to .062; .032 to .056; .043 to .070. In no case was there any charge where the resultant phosphorus was beyond the usual limit for rails.

In soft steels the rephosphorization is much less owing to the less violent reaction, and the phosphorus content in the steel is lower than those just shown in rail steel. It is however quite certain that the variations in phosphorus and sulphur are much greater than in American open hearth steel. The established American standards call for below .04 phosphorus in all basic steel for bridges and boilers, and every heat is also analyzed for sulphur, something that is seldom done on the Continent. The foreign engineers are in no degree so exacting as the American in regard to chemical composition.

Note: Further remarks on the operation of basic converters will be found in Section XXIVc in Chapter XXIV.

CHAPTER VIII.

THE OPEN-HEARTH FURNACE.

SECTION VIIIa.—*General description of a regenerative furnace.*—The open-hearth process consists in melting pig-iron, mixed with more or less wrought-iron, steel, or similar iron products, by exposure to the direct action of the flame in a regenerative gas furnace, and converting the resultant bath into steel, the operation being so conducted that the final product is entirely fluid.

Regeneration is specified not because it carries any special virtue, but because it is impracticable to obtain the necessary temperature in any other way. The construction of melting furnaces varies in every place, and no one form can be declared perfect, but in all of them the general principles are the same, as well as the methods of producing and controlling the temperature. Where natural gas is used, and in some instances with petroleum, the fuel is not regenerated, but the air is always preheated. The following description will assume that both gas and air undergo the same treatment. In Fig. VIII-A is given a drawing of a very common type of furnace; its grievous faults will be discussed later, but it may be used to illustrate the method of operation. The gas enters the chamber *F,* which is surrounded by thick walls and filled with brickwork so laid that a large amount of heating surface is exposed, while at the same time free passage for the gas is assured. The air enters a similar chamber, *E.* In starting a furnace the bricks in these chambers are heated before any gases are admitted. With rich fuels, like natural gas, this may not be essential, but ordinary producer gas, when cold, can hardly be burned with air at the ordinary temperature, and an attempt to do so may result in serious explosions, so that it is advisable to heat the furnace by a wood fire until the regenerators show signs of redness. When finally the gas and air are admitted, precautions are taken to avoid explosions by filling the passages with the waste gases from the wood fire.

The first effect of their entrance is to cool the chambers on the incoming end, for no heat is produced until they meet in the port at O. From this point the flame warms the furnace and also the chambers E_2 and F_2, through which the products of combustion pass to the stack. After the brickwork in the first set of chambers has been partially cooled by the incoming gases, the currents are reversed by means of suitable valves, and the gas and air enter the furnace by way of the chambers E_2 and F_2, which, as just stated, have been heated by the products of combustion. It will be evident that on every reversal the temperature of the furnace will be higher, for not only will there be the normal increment due to the continued action of the flame which would obtain in any system, but there is another action peculiar to a regenerative construction, for the gases passing through the chambers are hotter on every change in the currents and, therefore, they will produce a more intense temperature in combustion. Thus in all ways the action is cumulative, and there is a constant increment of heat throughout the whole construction.

In the case of a furnace which has an insufficient supply of fuel and which contains a full charge of metal, the increased radiation at high temperatures, together with the absorption of energy by the bath, may automatically prevent the attainment of too high a heat; but in a good furnace, and more especially in an empty one, the action is so rapid that the supply of gas and air must be carefully regulated in order that radiation can maintain an equilibrium. This necessary control of temperature also places a limit on the heat of the regenerators, so that they are usually of a temperature of about 1800° F. (say 1000° C.). Dissociation plays no part in the practical operation of a furnace, for, with common producer gas and air, both admitted to the valves at a temperature of about 60° F. (16° C.), the melting chamber may easily be made hot enough to fuse a very pure sand into viscous porcelain. One such specimen of fused material, made under rather unusual conditions, showed the following composition in per cent.: SiO_2, 98.82; Al_2O_3, 0.9; Fe_2O_3, 0.2.

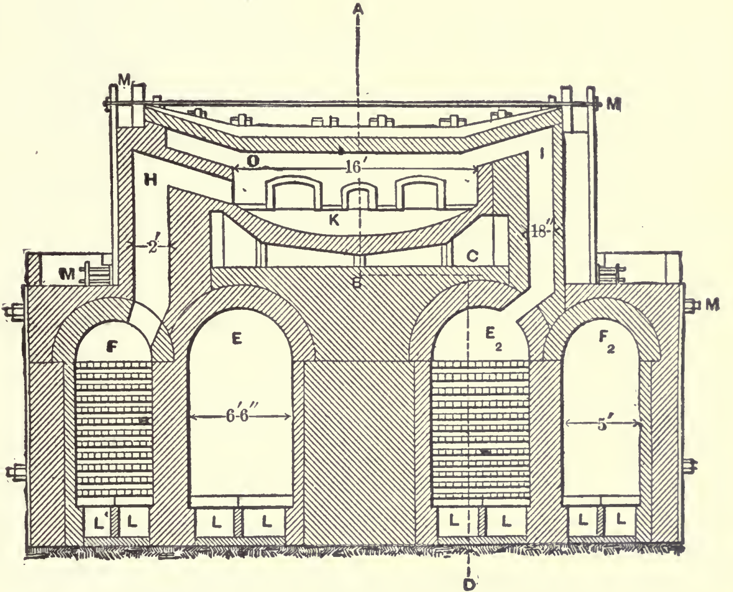
SEC. VIIIb.—*Quality of the gas required in open-hearth furnaces.*—The system of regeneration, which supplies the furnace with a fuel already raised to a yellow heat, renders unnecessary any stringent specifications regarding the quality of the gas. Ordinary producer gas contains over 60 per cent. of non-combustible material, and yet is all that can be desired as far as thermal power is concerned. Certain substances, such as sulphurous acid and steam, are objectionable, but this arises rather from their chemical action upon the metal than from any interference with calorific development. With coal of ordinary quality sulphur causes no trouble, but when it is present in large amounts it is absorbed by the steel.

The presence of steam causes increased oxidation of the metalloids and a greater waste of iron. This oxidation is not always objectionable, since it is sometimes impracticable to obtain sufficient steel scrap, and, if the charge contains an excess of pig-iron, some agent must be used to burn the silicon and carbon. A gas containing hydrogen, like natural gas or petroleum, will be more efficient in this work than a dry carbonic oxide flame, while an excess of steam will make the action still more rapid.

Hence it would be possible to use steam in place of ore as an oxidizing agent, but the practice is not to be recommended. If the steam is used during the melting, a considerable proportion of the oxide of iron which is formed will unite with the silica of the hearth and thus become lost beyond recovery. It is advantageous, therefore, to have no free steam present during the melting of the charge, while after the melting is done the oxygen may be supplied in the form of ore with much more satisfactory results.

The metal at the time of tapping should be as nearly as possible in the condition of steel in a crucible during the "dead melt," and this can only be attained by a neutral flame. In spite of the opinions of many metallurgists, such a flame cannot be obtained for any length of time, since it has no active calorific power, and even when black smoke is pouring from the stack, the silicon, manganese, carbon and iron are absorbing oxygen from the gases. A carbonic oxide flame can be made more nearly neutral than any other, and hence is more desirable at the end of the operation.

SEC. VIIIc.—*Construction of an open-hearth furnace.*—In the furnace which is exhibited in Fig. VIII-A it will be noted that the hearth sits partly upon the arches of the chambers. These arches, during the entire run of the furnace, are at a bright yellow heat and are continually subjected to strains and deformation by the alternating shrinking and expansion of the walls that support them. It is needless to say that a poorer foundation for a furnace would be difficult to conceive, and it is a positive certainty that some day there must be a long stop to make what are called "general repairs," this term being often used to cover the alterations consequent upon defective installation. Yet this drawing is copied from one of our leading trade papers as the design of a firm of metallurgical engineers, and, unfortunately, it is the common type erected by many such firms, both in this country and abroad, who are guided partly by ignorance and partly by the necessity of submitting plans for the cheapest construction that will work satisfactorily until their responsibility ceases.



Longitudinal Section through Center of Furnace.
E, E_2, air chambers; F, F_2, gas chambers; H, gas port; I, air port; K, furnace hearth; L, flues to valves; M, M, binding rods; O, meeting place of gas and air.

FIG. VIII-A.—COMMON, BUT BAD TYPE OF AN OPEN-HEARTH FURNACE.

It is not easy, however, to say just what the best construction is to avoid these difficulties. H. W. Lash, of Pittsburgh, devised horizontal chambers and thereby the charging floor of the furnace was brought down to the general level, and it was not necessary to elevate the stock, as it could be brought in on trucks without any hoist. There are objections, however, to horizontal chambers, for the tendency of the hot gases is to seek the upper passages and thus the benefit of the full area is not secured. In vertical chambers, on the contrary, there is an automatic regulation of the current; for, if there is a hot place, the in-going cool gases naturally seek it, and if there is a cool place, the out-going hot gases find it, and thus there is a constant tendency to equalization and to the highest efficiency of a given regenerator content. The worst feature of horizontal chambers is the lack of any propelling action of the gases. With vertical regenerators the hot gas and air rise naturally and force themselves into the furnace, but with horizontal passages there is only a very slight positive pressure due to the slight up-take near the furnace. The fuel will and should always leave the producer under a slight pressure, so that it will need no further assistance on its way to the furnace, but it is advisable to force the air with a fan blower.

The amount of room necessary in a regenerator is something on which there is much difference of opinion, but there is no doubt that a very much larger amount is economical than is generally given, the only question being where the limit is, for it is not worth while to spend money for additional chamber area when the saving does not give a fair return on the investment. If the chambers are made large enough, every particle of heat can be intercepted, and the gases will go to the stack at the temperature of the incoming gas and the incoming air, but this would be carrying things to an extreme, and financially would not be true economy. It can be stated that the gases should not by any means be at a red heat, although a very large number of furnaces are running with fair fuel economy where the gases during most of the melting operation escape to the stack showing a dull red or a full red temperature.

The space occupied by the air and gas checkers combined should be at least 50 cubic feet per ton of steel in the furnace, while to get the best results this figure should be at least doubled. In other words, in a 50-ton furnace the checker bricks in each chamber should occupy at least 2500 cubic feet, which is equivalent to a space 16′x16′x10′, while if they occupy a space 20′x20′x12′ there will be a further saving in fuel. These dimensions do not include the space below the bricks to give draft area for the gases, nor the space above the bricks to allow the flame to spread over the whole surface of the chamber.

In the 40-ton Steelton furnace, shown in Fig. VIII-B, the volume

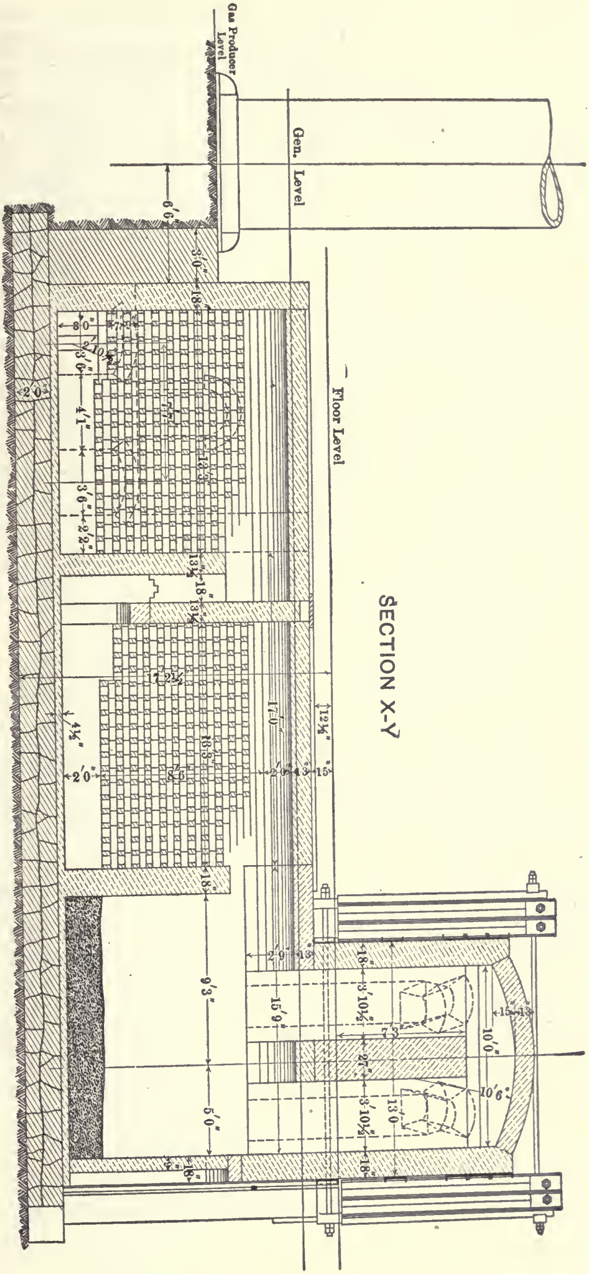


FIG. VIII-B.—40-TON ACID FURNACE, STEELTON, PA.

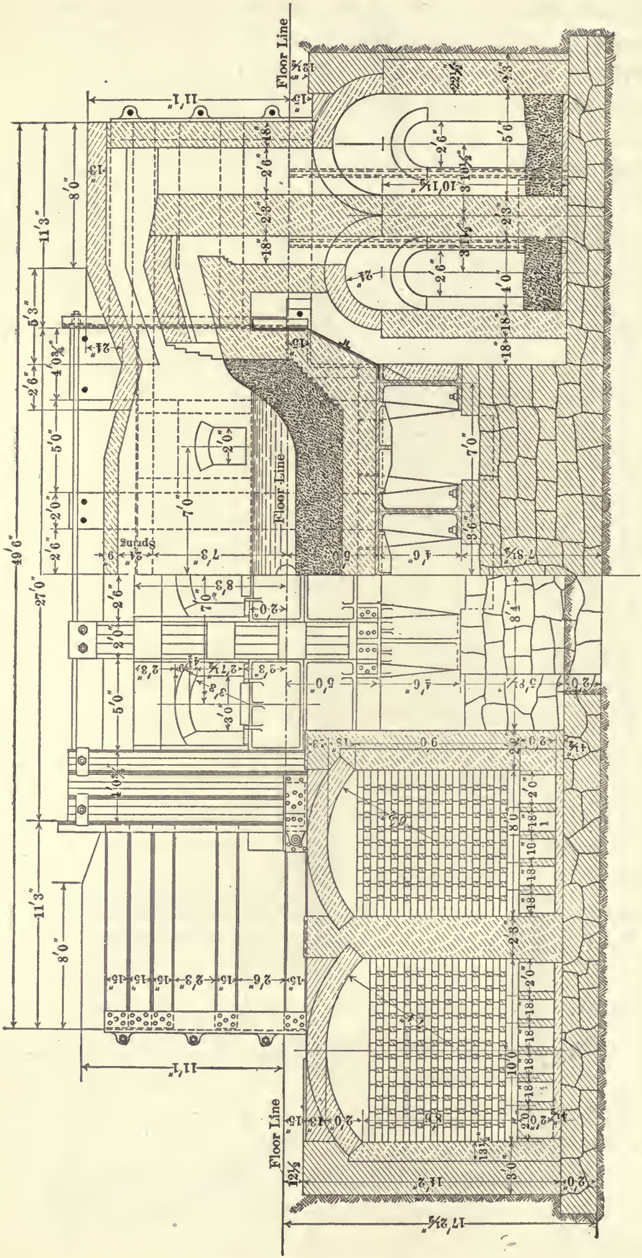


FIG. VIII-B.—40-TON ACID FURNACE, STEELTON, PA.

occupied by the air checkers, as shown in the drawing, is about 45 feet per ton; the gas chamber is of less volume, so that the total is from 65 to 70 feet for both chambers. The double passage, however, allows a better absorption than would be given by the same volume in one mass. In the 50-ton Steelton furnace in Fig. VIII-C the total checker volume on one end is about 100 feet; in the 30-ton Donawitz furnace in Fig. VIII-D about 110 feet; in the 50-ton Duquesne furnace in VIII-E about 55 feet, and in the 50-ton Sharon furnace in Fig. VIII-F about 90 feet.

In one open hearth plant I was told that the content was 100 cubic feet, but found that this was on both ends, the gas checkers on each end occupying 17 cubic feet per ton of steel and the air checkers 32 cubic feet. The products of combustion passing to the chimney from this furnace were red hot during a portion of the operation.

The information just given is by no means sufficient in stating merely the space occupied by the bricks, for it is fully as important to know the amount of space left between them for the passage of the gases. The area of these channels must be far in excess of the area of the ports or of the flue leading to the chimney, since the friction caused by the small passages will retard the flow of gases, and this retardation will increase continually during the running of the furnace owing to the deposits of dust in these passages, decreasing the size of the orifices and forming a rough surface for the current to pass over. For this reason the sum of the area of all the passages between the bricks must be several times as great as the size of the flues and ports. It is the area between the bricks which will in great measure determine the life of the checker bricks, for these bricks must be changed when the passages are clogged with dust. On the other hand, the loss of heat will also depend on these areas, for with larger orifices the gases will go down through the checkers and to the stack without giving up their heat to the bricks, so that open-hearth furnacemen must continually arrive at a compromise between large openings to allow long life to the checkers, and small openings to allow the proper absorption of heat.

There is also a third consideration, which is to arrange the bricks in such a way that they present the maximum area of heat absorption with the least interference with the passage of the gases, and with the least opportunity for the deposition of dust on horizontal surfaces. It would be idle to describe any arrangement of checkers, as the special conditions made necessary by the shape and size of the chambers in different furnaces determine the way in which the bricks shall be laid.

The air chamber should be larger than the gas chamber, because a cubic foot of gas requires somewhat more than a cubic foot of air in order to attain complete combustion and to have a slight excess of oxygen; moreover, the air enters cold, while the gas is generally rather warm; but in practice the relative values of the gas and air chambers will usually be determined much more by the difficulties of getting room than by any nice calculations on the volumes of gases. It is well, however, to keep the principle in mind that if the gas is very hot there is less work for the gas

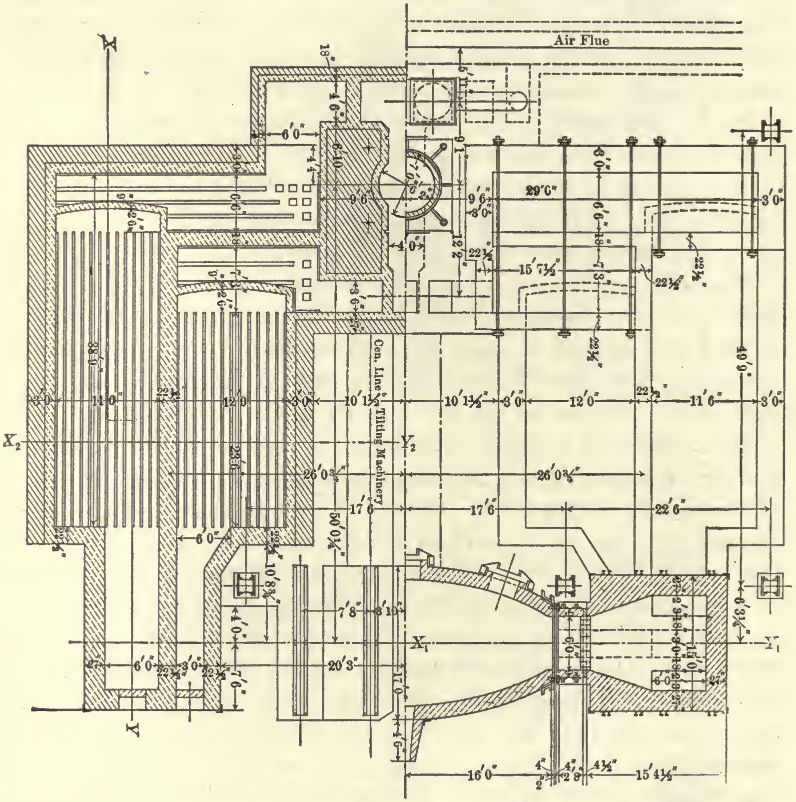
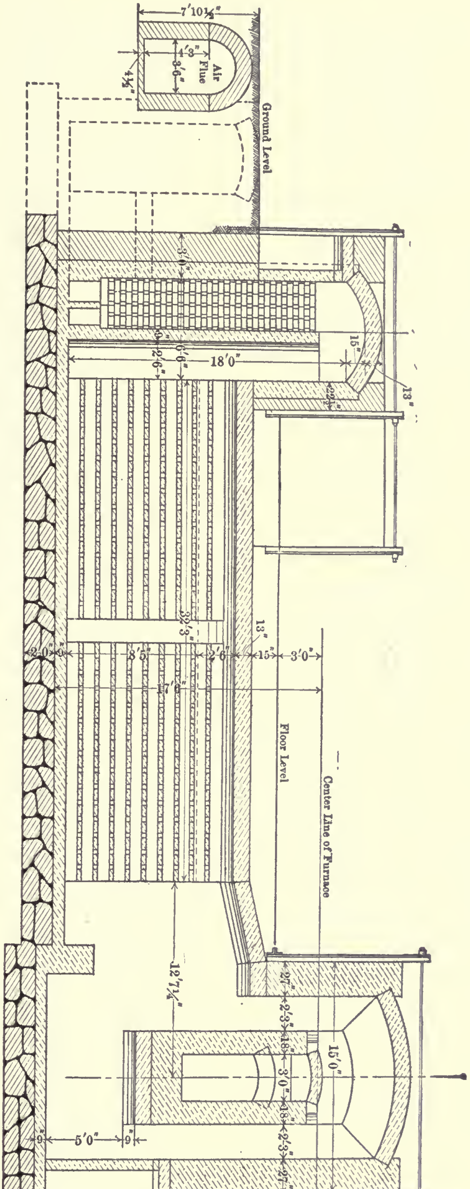


FIG. VIII-C.—50-TON CAMPBELL BASIC FURNACE, STEELTON, PA.



SECTION X-Y

FIG. VIII-C.—50-TON CAMPBELL BASIC FURNACE, STEELTON, PA.

chamber to do, and the fact that under these conditions the gases escaping to the chimney through the gas valve are at a high temperature has nothing to do with the case, for if the entering gases are hot the escaping gases must be hotter. Thus, with a given sized chamber, the escaping gases will always be just a certain number of degrees hotter than the gases that go into it. If in a certain furnace this difference is 300°, then if the entering gas is 400°, the escaping gases will be 700°, and if the entering gases are 700°, the outgoing gases will be 1000°, so that it would be useless to increase the size of the chamber just because the outgoing gases are hot, for these conditions are caused by hot entering gases, and the escaping products would be hot no matter how large the chamber might be. Different melters have different ideas as to how a furnace should be run, and it is sometimes better to let them have their own way than it is to change the practice radically to accomplish a very small saving. One melter may oftentimes do better work if the air is extremely hot, while another may prefer that the air be much colder than the gas. These differences also arise from the particular construction of ports so that if an attempt is made to change the relative temperature of the chambers, it might necessitate a complete change in the construction of the ports and very likely in the roof of the furnace. Under such circumstances the most practicable thing to do is to run the temperatures of the chambers in accordance with the construction of the ports and the roof. These conditions will oftentimes make considerable difference in the relative amounts of heat delivered to the gas chamber and the air chamber, and, therefore, will determine the relative size of the two chambers, and this may account for the difference of opinion of different melters and different furnacemen concerning the proper area for the regenerators.

In the Schönwalder construction, introduced abroad, the main point is to have very large flues underneath the checkers, so as to insure free draught in all parts of the chamber, so that the hot gases will go down and the cold gases come up, equally over the entire horizontal cross section. To make more certain, the chamber is divided into two compartments by a vertical wall, and separate flues run from the valve to each. The results seem to indicate that a saving of fuel follows this construction. It very often happens that it is impossible to build a furnace exactly as desired. This was the case in the constructions shown in Figs. VIII-B and

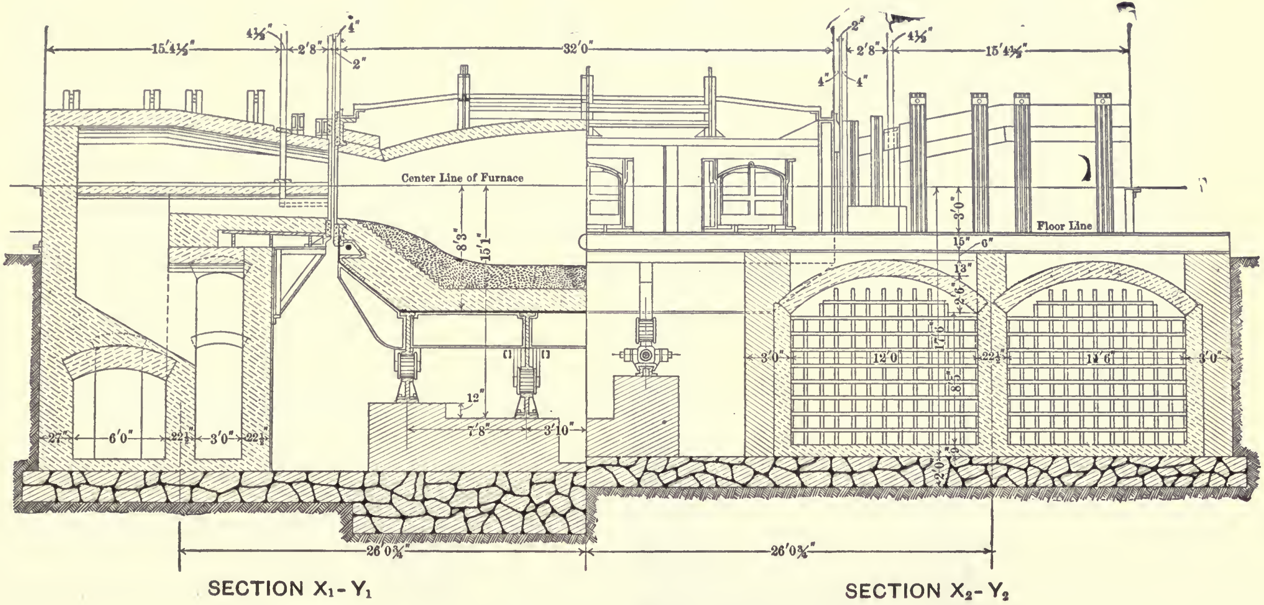


FIG. VIII-C.—50-TON CAMPBELL BASIC FURNACE, STEELTON, PA.

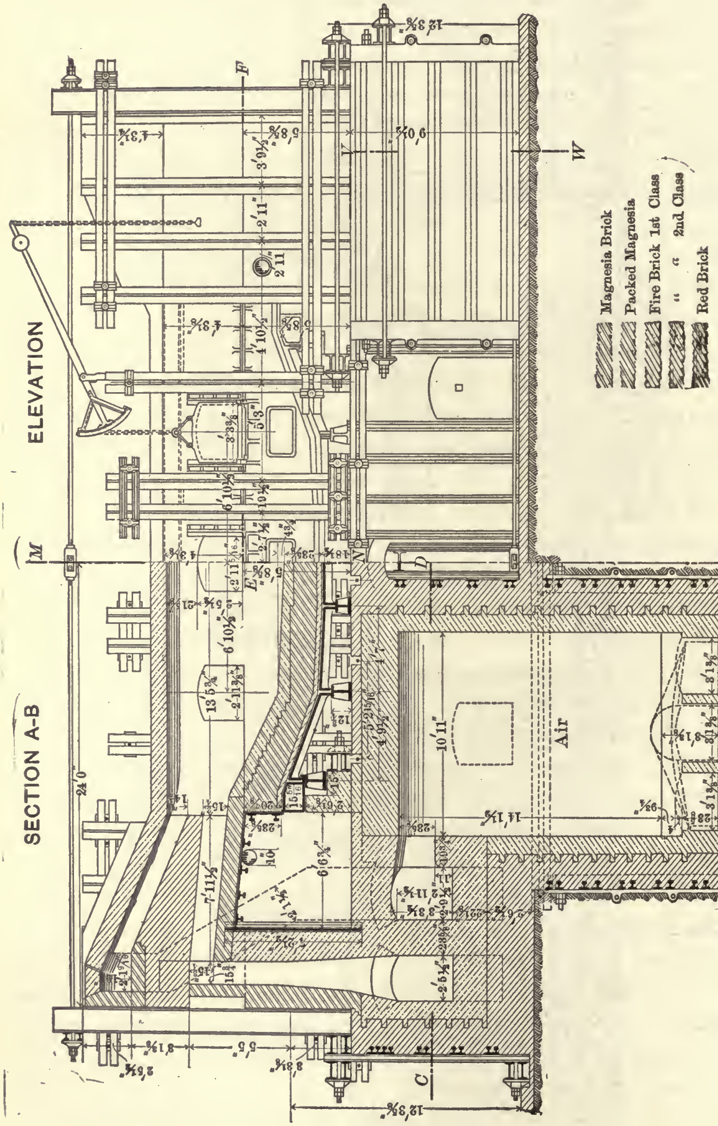


FIG. VIII-D.—30-TON BASIC FURNACE. DONAWITZ. AUSTRIA.

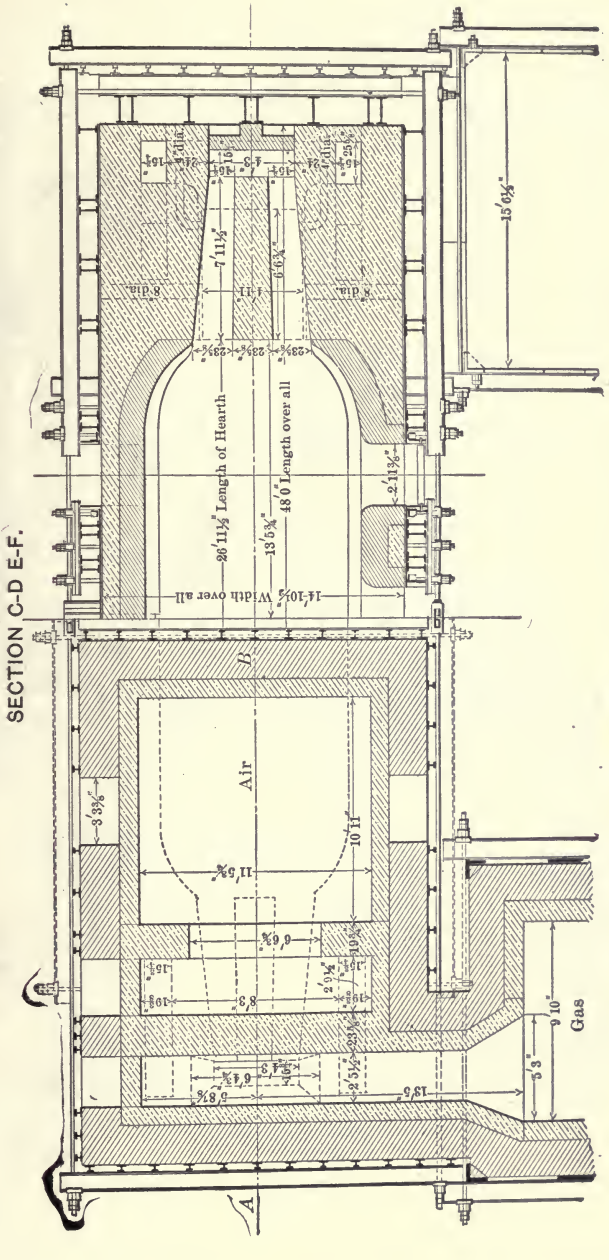


FIG. VIII-D.—30-TON BASIC FURNACE, DONAWITZ, AUSTRIA.

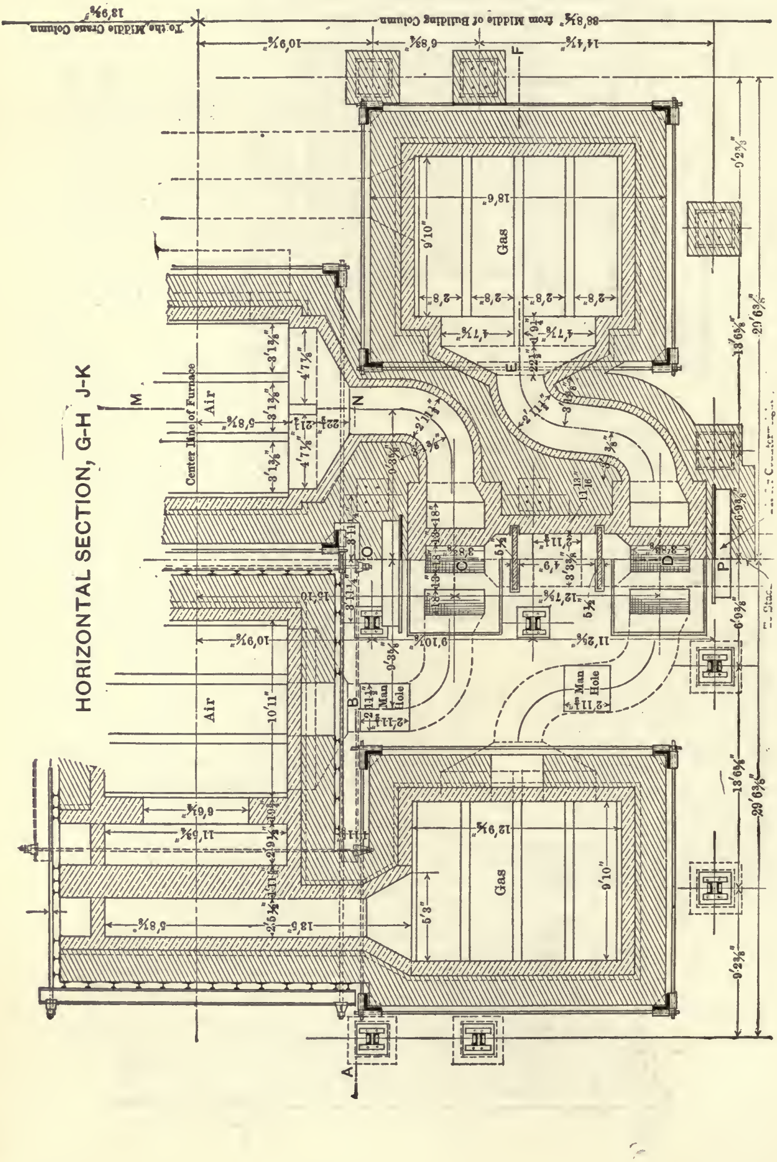


FIG. VIII-D.—30-TON BASIC FURNACE, DONAWITZ, AUSTRIA.

SECTIONS M-N O-P

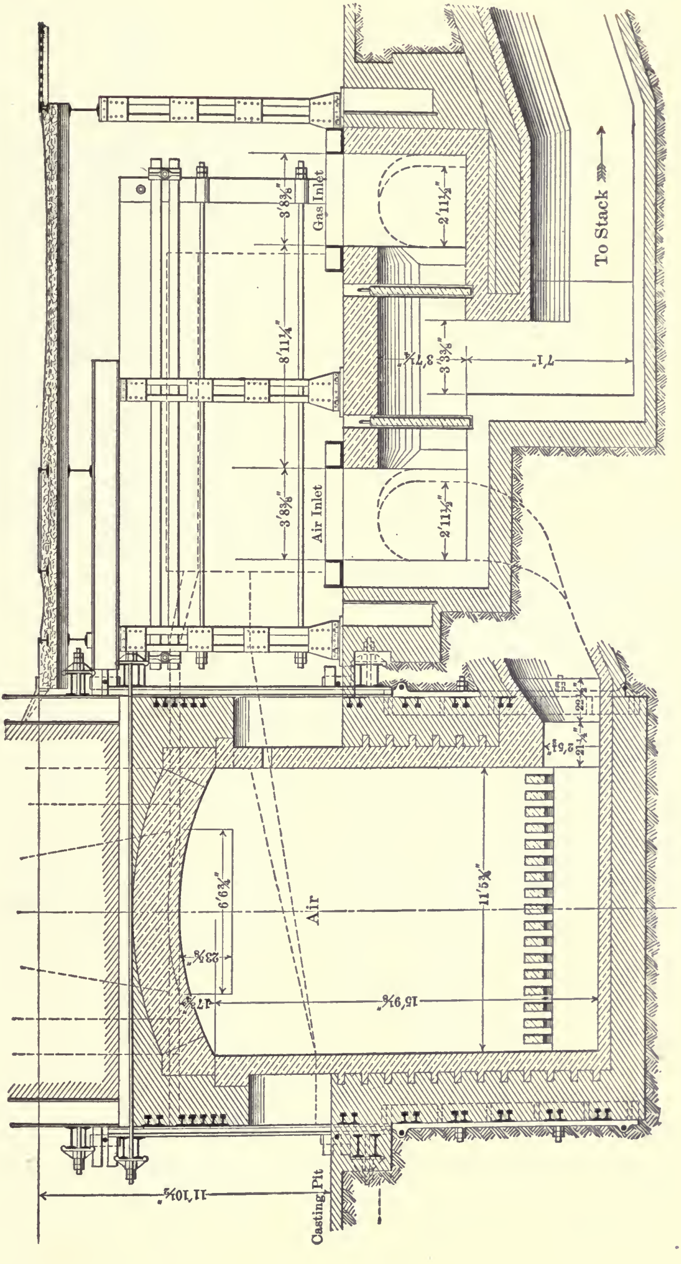


FIG. VIII-D.—30-TON BASIC FURNACE, DONAWITZ, AUSTRIA.

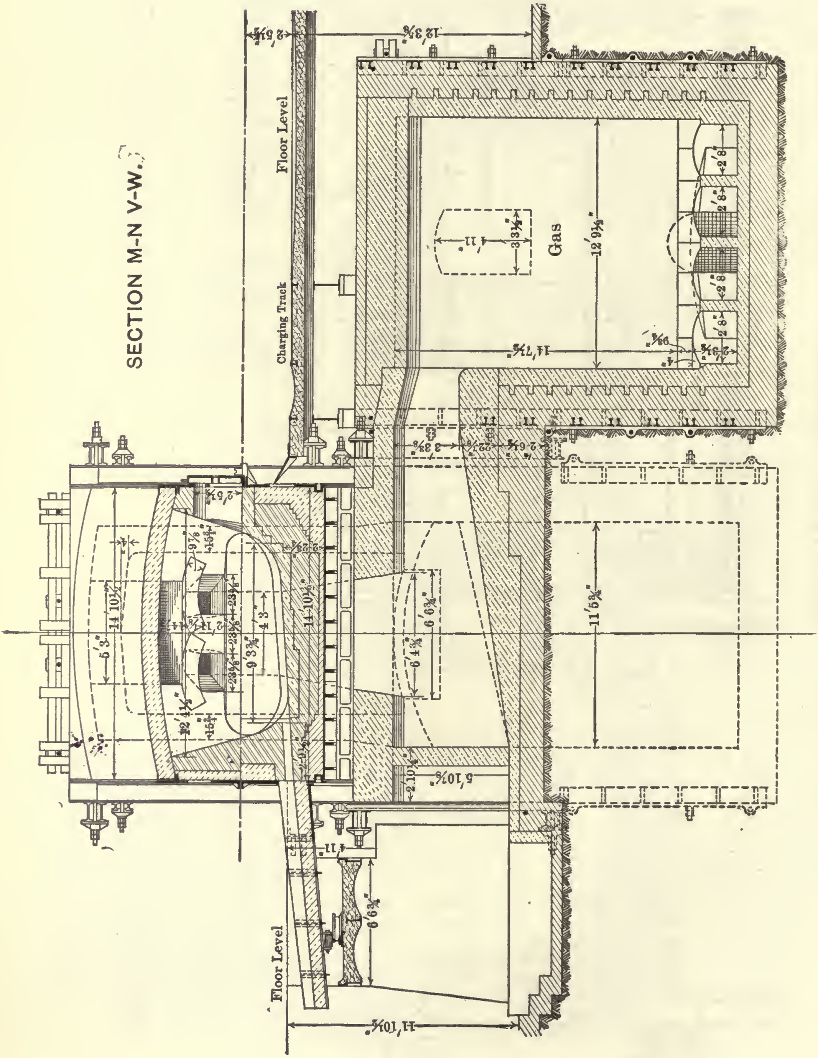


Fig. VIII-D.—30-Ton Basic Furnace, Donawitz, Austria.

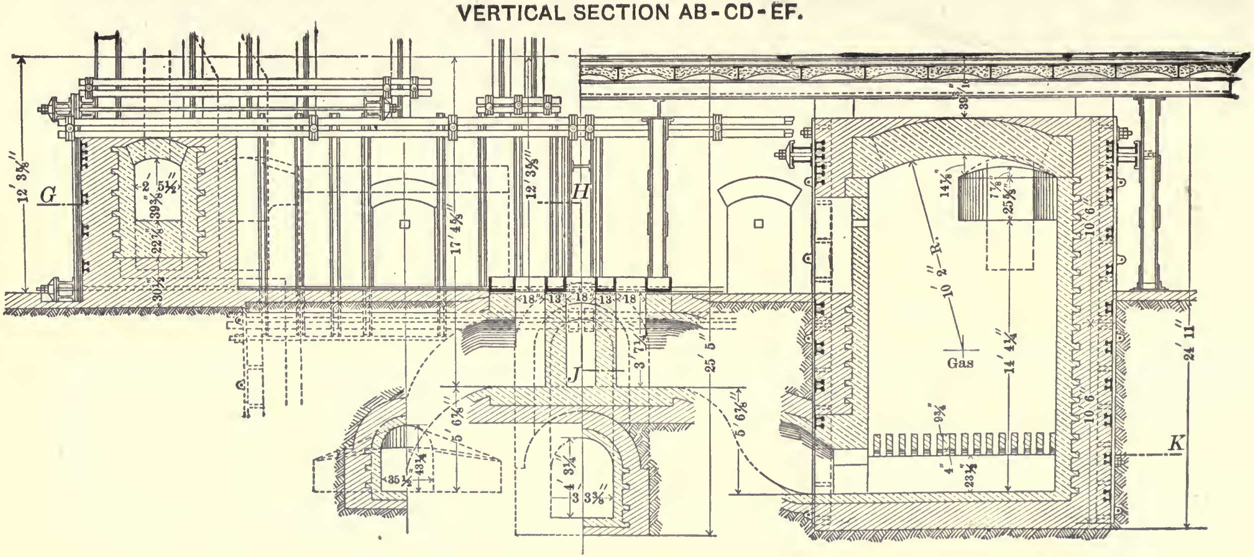


FIG. VIII-D.—30-TON BASIC FURNACE, DONAWITZ, AUSTRIA.

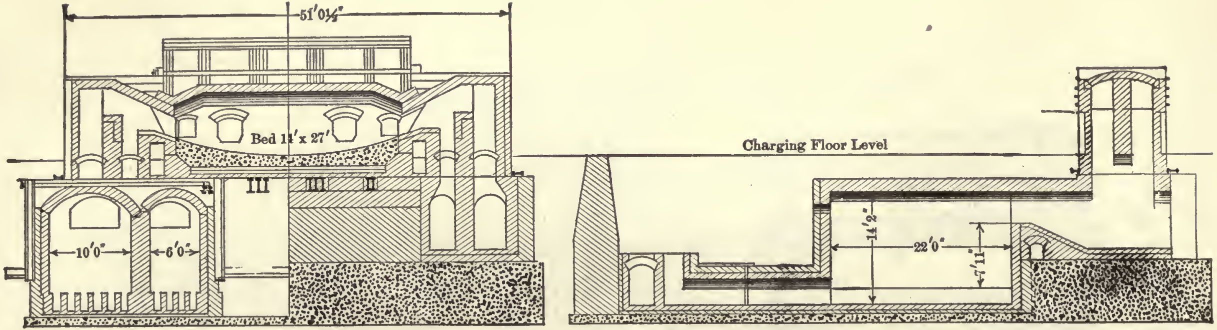


FIG. VIII-E.—50-TON BASIC FURNACE AT DUQUESNE, PA.

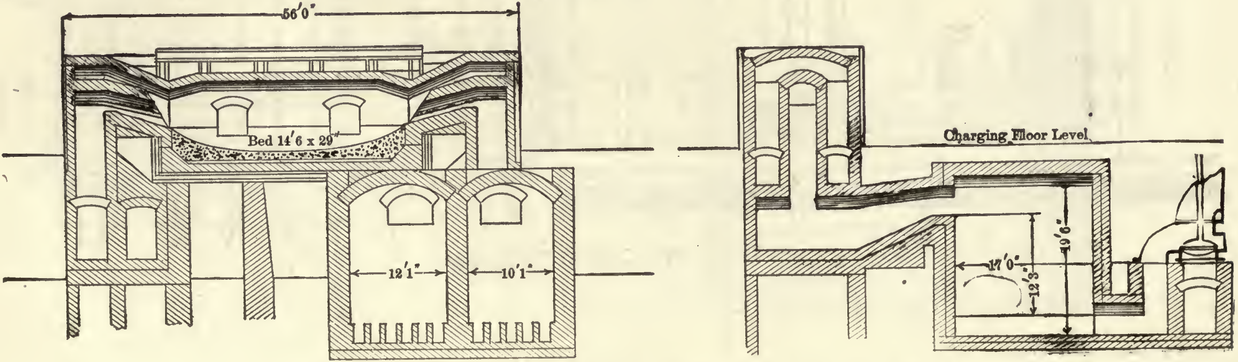


FIG. VIII-F.—50-TON BASIC FURNACE AT SHARON. PA.

VIII-C, for the nature of the ground was such that permanent water existed only fifteen feet below the general level, and it was necessary to go to some trouble to get sufficient room for checkers. It may be supposed that there would be difficulty in getting the gas and air to go through these passages and reverse their direction up and down, but no trouble has been experienced from this cause. It should be noted, however, that the air is blown by a centrifugal fan, the pressure being very low.

Fig. VIII-D shows the method of construction for basic furnaces at Donawitz, Austria, where the practice is excellent both in life of furnace and amount of product. I am indebted to my friend, Carl Sjögren, engineer of the works, for permission to use these drawings.

Fig. VIII-E shows the 50-ton basic furnaces at Duquesne, Pa., and Fig. VIII-F those at Sharon, Pa., both of these being taken from an article on open-hearth furnaces, by Mr. Monell, in the *Iron Trade Review* of November 14, 1901. The drawing of the Duquesne furnace shows how the capacity of the chambers may be decreased when natural gas is used, as both the regenerators are available for heating the air.

SECTION VIIId.—*Tilting open-hearth furnace.*—Many years ago I put in operation the first tilting open-hearth furnace, while a few years afterwards Mr. Wellman built a similar furnace, but used a different system of tilting. In the original type the furnace sits on live rollers running on circular paths; the center of these circular arcs, which is, of course, the center of rotation of the furnace, is coincident with the center of the port through which the gas and air enter the furnace, so that it is utterly impossible for the longitudinal axis of the furnace to move as long as the foundations of the structure remain in place. Hence, as the opening in the end of the furnace is on this axis, it always coincides with the port opening, no matter what position the furnace may occupy. It is exactly like a shaft or grindstone resting on friction rollers, the center of the shaft remaining stationary, and for this reason there is no occasion to cut off the supply of gas and air when the furnace is rotated. In the Wellman type the furnace rolls forward upon a horizontal track and it is therefore necessary to shut off the gas and air as soon as the furnace is tipped in the least from its normal position.

I have very often been asked to compare the relative advantages of these two types, but in the former edition I omitted such argument as by the nature of the case it must be impossible for me to render a judicial and unbiased judgment on the subject. In view, however, of many such requests it would appear proper to express my opinions, whether they be judicial or not.

(1) Both types of tilting furnaces do away with most of the work and delay connected with the tap-hole, and when the bottom is good the next charge can be put in as soon as the metal is tapped.

(2) If the bottom is bad, especially when there is a hole in the flat, a stationary furnace is often delayed by the tap-hole in ways which cannot be easily explained to the layman, but need not be recited to the practical furnaceman. In a tilting furnace of either type no difficulty is experienced, as in some cases a hole can be drained dry by tilting the furnace and even repaired in that position.

(3) It is possible to make the back wall, in either type, by tilting the furnace to its extreme position and throwing bottom material on the back side, for this wall, which is nearly vertical during the regular operation, becomes more nearly horizontal when tipped over. Thus with the furnace in its normal position the slope of this wall may be 20° from the vertical, while if the furnace be tipped 30° it will be only 40° from the horizontal, and it will then be possible to make loose material stay at that angle until it is set by the heat.

In the foregoing advantages over the stationary furnace, both tilting types share, but I believe the original furnace has certain very important recommendations.

(4) The method of making the back wall just described can be done much more readily in the Campbell type, for in the Wellman construction no gas can be kept on the furnace when it is tipped. In the first construction the center of the port is the center of rotation, and it is possible to keep a flame constantly going through when the furnace is tipped. It is not only possible, but no manipulation is required to accomplish it, as in practice the furnace is constantly moved without any attention being paid to the supply of gas and air. It is well known that the setting of a sand bottom requires an extremely high temperature, and it would evidently be impossible to set sand on the back wall without raising the furnace to its full temperature. It would, therefore, be impossible to do

this in a Wellman furnace, while it has been done regularly whenever occasion required for many years at Steelton, the back wall being always maintained at its full thickness up to the skewback of the roof.

In a basic furnace when the dolomite is mixed with just the right amount of tar, the Wellman furnace is able to coke and harden this mixture in place by the heat of the walls and bottom, but the work must take longer and be less satisfactory than in a furnace where the flame can immediately be put upon the dolomite and the coking be done quickly and thoroughly, and the furnace be heated for the next charge, instead of being cooled by exposure.

(5) Owing to the ability to build the back wall in this manner a very steep slope can be maintained, much steeper than can be kept in a stationary furnace. This condition prevents or tends to prevent the cutting of the slag line, for it is my experience that this cutting arises in great measure in both acid and basic furnaces from the oxidizing action of the flame and the pieces of ore upon shallow pools around the slag line. If a small shelf is formed, the metal lying on this shelf is like the water on a mud flat along the banks of a river; there may be a swift current in the channel, but the friction of the bottom on the shallow water prevents a free circulation. Consequently the metal in such a place is oxidized much more and heated much hotter than in the center of the bath, both of which conditions tend to cut the surrounding hearth. If a vertical wall could be maintained at the slag line, the action would be reduced to a minimum, both for the reason given above and because it would be impossible for pieces of ore or scrap to lodge anywhere, and because the area of the surface exposed to slag would be less. For this reason the wear of the hearth on the tap-hole side of a tilting furnace is less than in a stationary furnace. In the case of a Wellman furnace this is true of a basic bottom; in the case of a Campbell furnace it is true of both acid and basic hearths.

(6) The wear on the front or charging side is the same as on any other furnace, and there is the same liability to form holes along the slag line, but in the Campbell type such a hole is seldom a serious matter, for while the charge is in the furnace, and without interrupting the operation for a moment the hearth may be tilted, the hole drained dry, filled with bottom material and set in the usual manner, after which the furnace may be returned to its

proper position with practically a new bottom. This has been done in practice and a hole which had made the iron sheets red hot has been patched so thoroughly that it needed no subsequent attention. Such repairs would be impossible in the Wellman type.

(7) The most important advantages arising from the ability to tip the furnace without altering the flame, comes in the use of large quantities of pig iron. The Carbon Steel Company, at Pittsburgh, made a great number of heats many years ago, using all pig-iron on an acid hearth, but this was done at a great sacrifice of product, the output being one heat per day for each furnace. At Steelton we have antedated all others in America in the regular use both of melted and cold pig-iron as the full charge in a basic furnace, for we began using melted pig-iron directly from the blast furnace in 1891, it being recognized at the time that we were merely repeating what had been done nearly a generation ago across the water. About three years later we ran two or more 50-ton furnaces on cold pig-iron without any scrap, and from time to time, as the limited supply of iron for distribution to the Bessemer and open hearth would allow, we used the iron in a melted state. It was from about 1896 that melted iron was regularly and continuously taken from the blast furnaces to the open hearth plant, from two to four 50-ton furnaces having been run regularly in that manner from then until now.

It is recognized that this has been done before, and is done elsewhere, but it is believed that nowhere else has iron been worked directly from the blast furnace without the use of a receiver, with silicon varying from 0.50 up to 3.00 per cent. and with no prohibitory trouble from frothing or from loss of time. This trouble is avoided by the ability to tip the furnace and thus prevent the metal and slag from flowing out of the doors on the front side, there being no doors on the tap-hole side, the excess of slag being provided for by holes left in the bottom of the port opening. Any hole or runner in a door or in the side of the furnace gives trouble from the chilling of the slag if the stream is small, and if the stream is large there is pretty certain to be some metal lost through the opening, but by having the opening located in the port, at the joint between the fixed end and the rotating portion, the opening is exposed continually to the flame passing over it in either direction and the slag has no chance to cool. If it should happen to solidify, the crust can easily be broken by moving the furnace in either direction, thereby tearing apart the slag and starting the stream again. It is in this manner that the practice has been carried on at Steelton, and the melters soon learned without instructions to keep the furnaces partly tipped over throughout the whole period of the violent frothing, thereby rendering possible the rapid addition of ore.

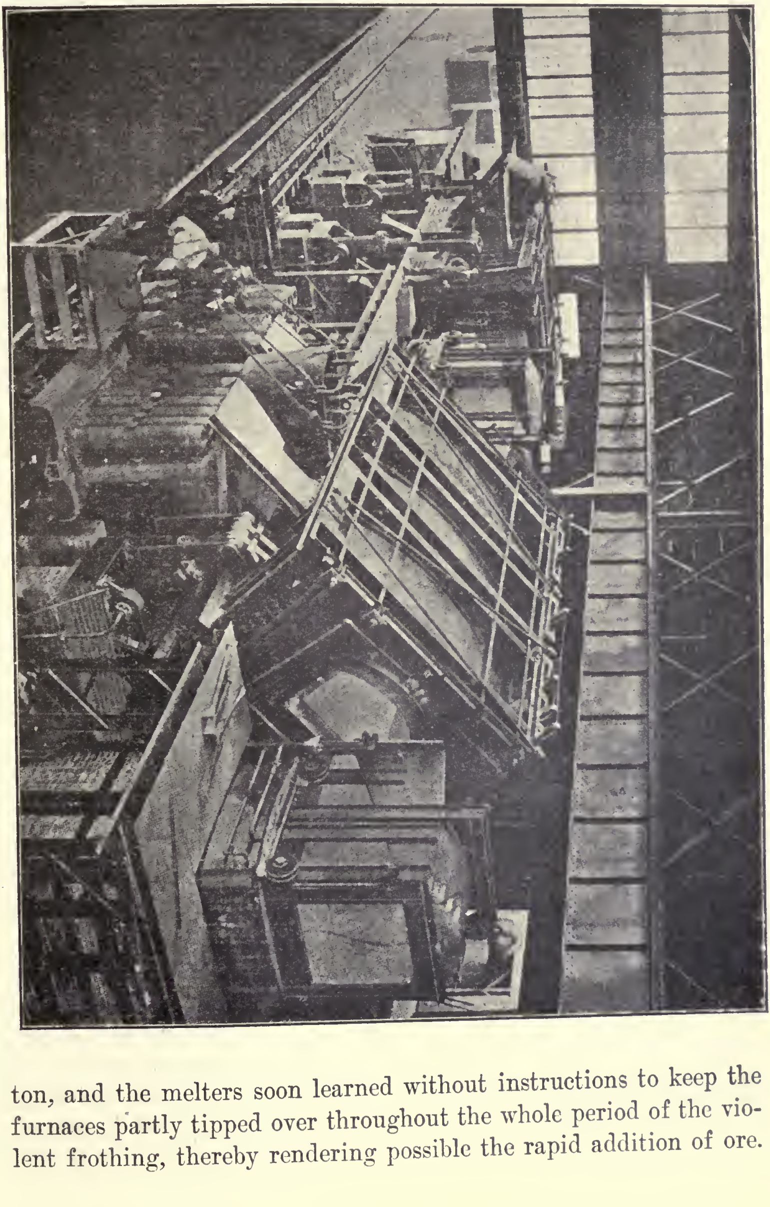


FIG. VIII-G.—50-TON WELLMAN TILTING FURNACE AT ENSLEY, ALA., SHOWING FOREHEARTH.

(8) In an article on tilting furnaces by A. P. Head* he states that one of the objections to tilting furnaces is this:

"The inlet of cold air during pouring tends to oxidize the manganese, which must be made up for by further additions in the molds."

The objection is his own, made after a study of the Ensley plant, and I would say that it does not in any way apply to the original type, as there is no chance for cold air to enter a furnace where the connection with the port is maintained undisturbed at all positions.

In Fig. VIII-C has been shown the 50-ton furnaces which have been used for many years at Steelton, while Fig. VIII-G gives a view of those erected by the Wellman-Seaver Company at the new plant at Ensley, Ala. This latter view is interesting as showing the fore-hearth which was here tried for the first time. It is a modification of the old converter ladle, used long ago in Sweden. In my opinion there are many serious objections to its use on an open-hearth furnace.

A tilting furnace costs more than a stationary construction, but it does away with much hard and hot work, for the only labor connected with the hole is an occasional trimming or shaping, which can be done at any convenient time. It is customary to keep the opening closed on the outside with a little loose material to exclude air, this being raked out about half an hour before the operation is finished so that the charge can be poured into the ladle when desired. The advantage of this ability to tap instantly will be appreciated in the case of special steels, and particularly in making steel castings where great accuracy in composition is required.

The absence of a taphole is of value for other reasons, for it becomes possible to pour the entire charge into a ladle and then tap the metal back into the furnace, leaving the slag in the ladle. This practice may be employed in acid or basic practice to get rid of the voluminous slag produced in the pig-and-ore process, or it may be used in basic work to remove a very sulphurous, a very phosphoric, or a very silicious slag, and by thus giving an opportunity for the construction of a new clean cinder, allow a more impure raw material than can be used under any other system. It may also be of great advantage in the transfer of metal from an acid to a basic furnace, or *vice versa*. This idea, which has been

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* *Journal I. and S.*, Vol. 1899.

proposed numberless times, has always been considered impracticable, but at the plant of The Pennsylvania Steel Company it has been carried out without difficulty, and acid steel can be regularly made with from .010 to .015 per cent. of phosphorus, no appreciable chilling of the charge occurring in the transfer.

SEC. VIIIe.—*Method of charging.*—The labor of charging an open hearth furnace under the old system by means of peels operated by hand labor was of the most exhausting character. This method is still used at a large number of works in Europe, but it has about gone out of use in America. Fig. VIII-H shows a method of charging a tilting furnace by dumping the stock in the door when the furnace is thrown over. This method of charging was used at Steelton for several years and is still employed on isolated furnaces where the output does not warrant expensive machinery, but for all plants of any size the use of charging machinery has become almost universal. The best known apparatus for this purpose is the Wellman Charging Machine, shown in Fig. VIII-I. It is possible to remove the entire top of a furnace, and we have two furnaces at Steelton of this type and more are

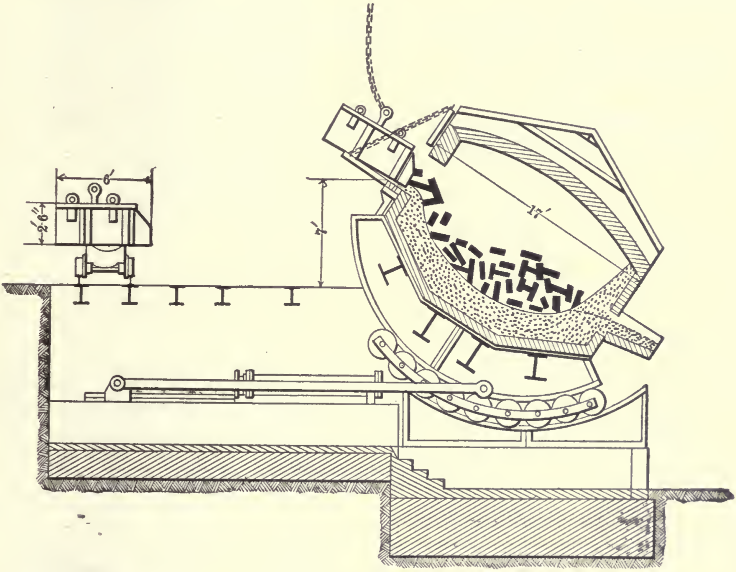


FIG. VIII-H.—METHOD OF CHARGING A TILTING FURNACE.

in use in other works in America, where the whole roof is removed by an overhead crane, thus giving an opportunity to put in very large pieces of scrap. This is very convenient in disposing

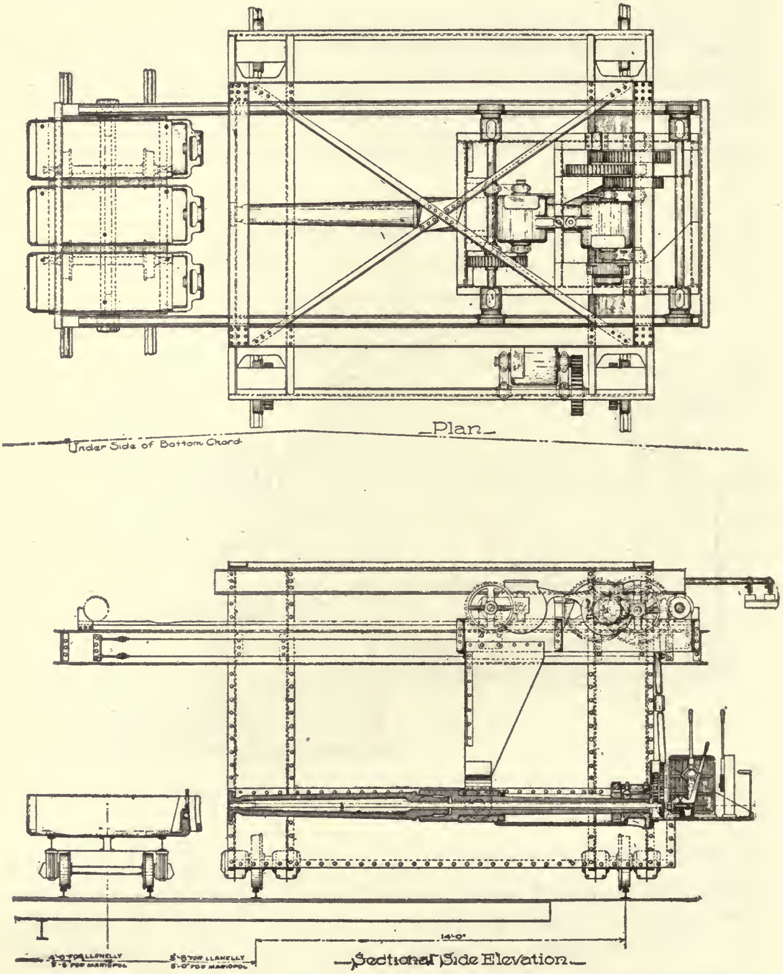


FIG. VIII-I.—WELLMAN CHARGING MACHINE.

of heavy sculls and pieces that cannot easily be broken, but the furnace cools so much during this process of taking off the roof that considerably more fuel is used than in the ordinary types, and the roof does not last as long owing to the severe strains in cooling and heating. This construction is therefore not recommended as a general type.

SEC. VIIIf.—*Ports.*—The working of the furnace depends very much upon the arrangement of the ports through which the gases come and go. The gas should enter below the air, because, being lighter, mixture is facilitated, and also because this arrangement does not expose the metal on the hearth to a stratum of hot air and cause excessive oxidation. The point where the two gases meet should be about five feet from the metal; if much less than this, combustion can hardly begin before it is checked by contact with the cold stock; if much more, and if the burning mixture is conducted between confining walls, the brickwork will be rapidly melted.

Both gas and air should enter the combustion chamber under a positive pressure, forcing them into contact with each other and throwing the resultant flame across the furnace in such a way that the draught of the stack on the outgoing end can pull it down through the ports without its impinging upon the roof. A prevalent idea among furnacemen is that the draught of the stack pulls the gases into the furnace, but this is entirely wrong. They are not pulled; they are pushed in by the upward force of the white-hot vertical port on the incoming end, and it has been explained that where this force is not sufficient, as in horizontal chambers, a blower should be used as an auxiliary.

Much has been written about building the roof of the furnace very high and keeping the flame away from the stock, it being supposed that combustion is thereby aided and the heating done more economically by radiation. The suggestion of a high roof is a very good one, as it prevents the cutting of that portion of the furnace; but, contrary to what seems a common impression, such a construction is not necessarily synonymous with heating by radiation. When the ports are properly built and the gases well controlled, the melting is hastened by having the flame strike down upon the stock, although, probably, the oxidizing influence is more powerful.

A reference to the figures in Sec. VIIIc will show the different ways in which the port question has been answered. In Fig. VIII-C the portion of the construction next to the furnace is a removable cage containing the arch that divides the gas and air. When this arch is worn back this section can be removed by a crane and replaced by a new one, the whole operation not taking over one hour, and not interrupting the operation of the furnace. This system is the device of C. E. Stafford, now president of the Tidewater Steel Company, Chester, Pa. The drawing of the furnace at Duquesne shows how simple the problem becomes when natural gas is used.

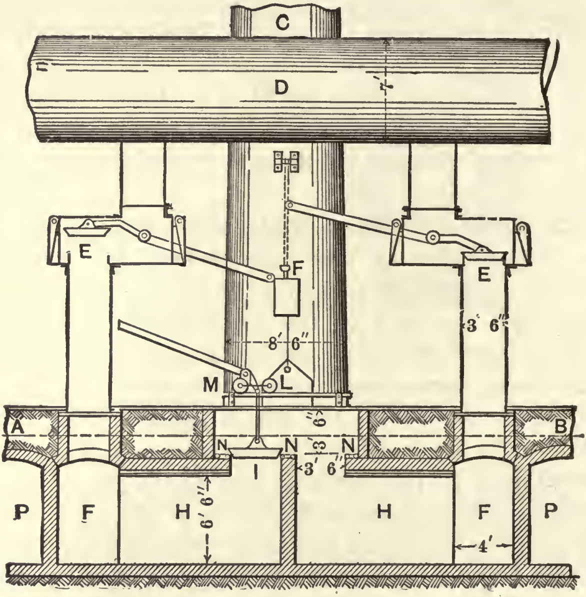


FIG. VIII-K.—REVERSING VALVES AT STEELTON.

Vertical Section Through Gas Reversing Valve.

C, stack; *D*, main gas tube; *E, E*, branch gas tube, showing valve; *F, F*, gas chambers; *H, H*, gas chamber flues to reversing valve; *I*, stack reversing valve for gas; *L*, stack damper for gas; *M*, valve reversing track and buggy; *N, N*, water-cooled valve seats; *P, P*, air chambers.

SEC. VIIIg.—*Valves.*—The amount of gas and air admitted to the chambers is regulated by some simple form of throttle valve. Reversing apparatus is also necessary, since the course of the currents must be changed at least twice every hour. For this purpose the ordinary butterfly valve is in common use. Its simplicity, the ease with which it is manipulated, the small space it occupies, and its small first cost, have led to its general adoption and to an equally general unwillingness to recognize its radical and irremediable defects. From the nature of the case it is exposed on one side to the incoming gases, and on the other to the products of combustion. It will sometimes happen that these waste gases are red hot, and the inevitable result is a warping of the valve or box, and a leak from the gas main into the chimney. There is no adjustment possible, and the only remedy is to replace the whole outfit. It is far preferable to spend more money on the installation and put in valves which will last longer and which can be changed in case any warping occurs.

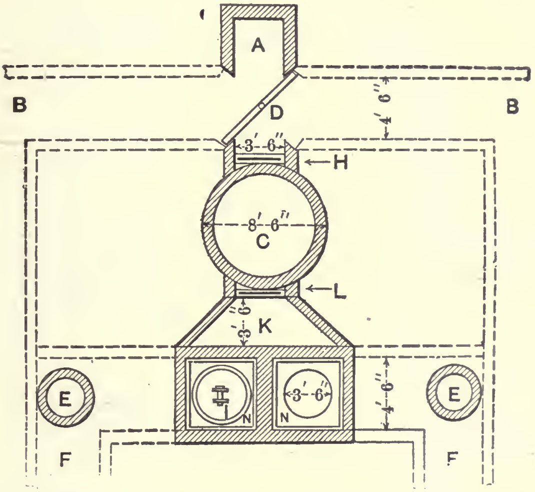
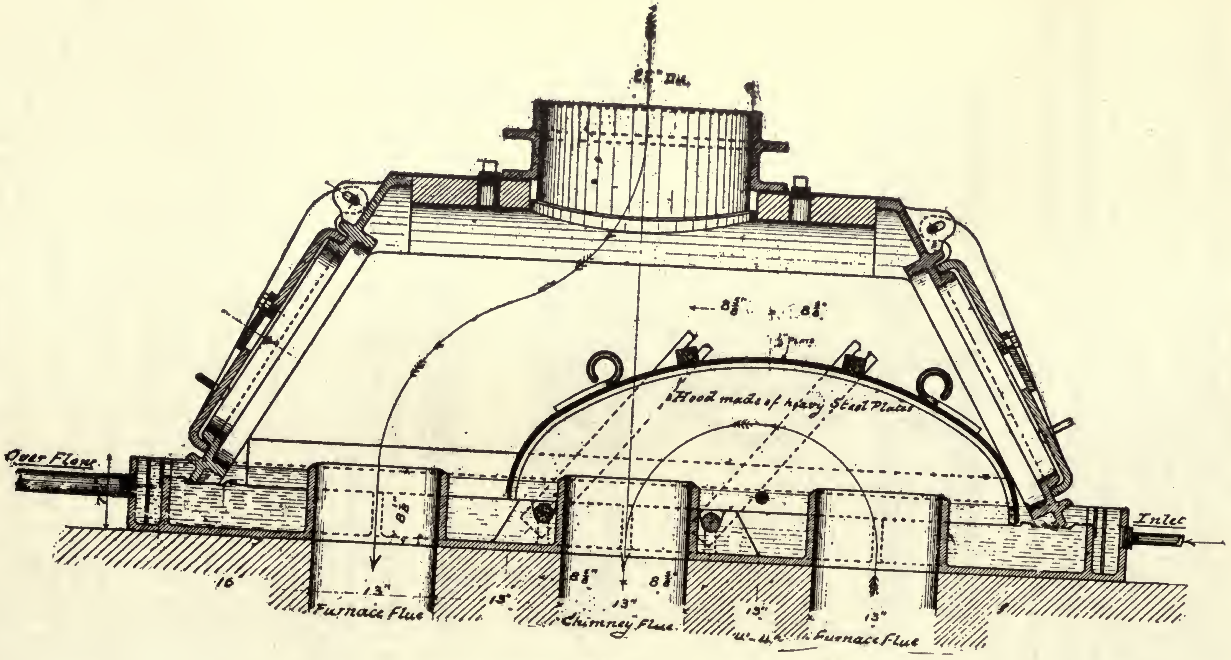


Fig. VIII-K.—Reversing Valves at Steelton.

Horizontal Section.

A, air inlet; *B*, *B*, air chambers; *C*, stack; *D*, air reversing valve; *E*, *E*, gas inlets; *F*, *F*, gas chambers; *H*, stack damper for air; *I*, stack reversing valve for gas; *K*, flue from reversing valve to stack; *L*, stack damper for gas; *N*, *N*, water-cooled valve seats.

Fig. VIII-K shows a system of valves which has been used at Steelton with good results for a number of years, whereby the gas inlet valve and the reversing valve are entirely separate and the inlet valve is removed from all exposure to heat. This system was devised more especially for oil gas or where crude oil was the fuel, since under these conditions it is necessary that the chambers at the outer end should be at a high temperature in order to maintain the oil in a state of vapor. This necessitates a very high temperature throughout the whole length of the chamber and an ordinary valve will not stand this high temperature without excessive leak-



8'-1"

Half Top View with Casing removed

FIG. VIII-L.—FORTER VALVE.

age and warping. Such a complicated arrangement, however, is not necessary when coal gas is used if the chambers are of sufficient capacity to give a low temperature at the reversing valve. A perfect valve has not yet been devised, for such a valve should not be capable of warping if it happens to get hot, and it should not leak if it gets coated with tar or soot, and it should not be easily shut up by an accumulation of soot and tar. No valve has yet been made which fills all these conditions, but Fig. VIII-L shows a Forter valve, which is, perhaps, as good as any in being easily manipulated and simple in construction. It is open to the same objection that a great many valves are, in that the gas is exposed to water and carries a great deal of steam into the furnace.

SEC. VIIIh.—*Regulation of the temperature of an open hearth furnace.*—The temperature of the interior of the furnace and of the metal is estimated by the eye, deep-blue glasses being used as a protection from the intense glare. It is essential that the melter possess considerable skill in this line, for if the metal is too cold it cannot be cast, and if too hot it will give bad results. I have elsewhere* shown that the practiced eye can detect a difference of 13° C. in the temperature of Bessemer charges, and this may also be taken as the measure of skill to which many open-hearth melters attain.

It has been explained that the intense heat of a regenerative furnace is made possible by the preheating of the gas and air in chambers which have been warmed by the products of combustion, these chambers being alternately heated by currents traveling from the furnace to the valves, and cooled by currents going from the valves to the furnace. If the currents were not reversed, the chambers on the outgoing end would be heated uniformly throughout their length to about the temperature of the furnace, while, at the same time, the chambers on the incoming end would be uniformly cooled to the temperature of the incoming gases. By the reversal of the currents there is a continual conflict between these extremes, so that in a furnace in good working order the ends next the melting chamber are at a bright yellow heat, and the ends next the valves are about 200° F. (say 100° C.) above the temperature of the incoming gases.

Air always enters cold, but it is believed by some furnacemen

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* *The Open-Hearth Process. Trans. A. I. M. E.*, Vol. XXII, p. 392. See also certain remarks in Sec. VIi.

that it is economical to have the gas delivered to the valves as hot as possible. To some extent this is an error, for it is certain that the checkers in the outer end of the gas chamber cannot possibly be cooled below the temperature of the entering gas, and it is just as certain that the products of combustion escaping to the stack cannot possibly be cooled below the temperature of these checkers. Hence, it follows that if, during a given time, there is an equal quantity of gaseous matter passing through the chamber in either direction, the heat carried in by hotter fuel is carried out by hotter waste gases, and therefore no economy is obtained.

With hot gas, however, it is not necessary to pass such a large proportion of the products of combustion through the gas chambers, and an extra amount may be diverted to the air chambers, where the heat may be used to advantage, so that a certain gain accrues. This gain may be quite important when the coal contains only a small proportion of the denser hydrocarbons, for under these conditions the gas leaves the producer at a high temperature; but when the coal is very rich in volatile components, the gas is at a very low temperature when it comes from the fire, and the gain from its immediate use may be inappreciable. It is true that all the tar is utilized when hot gas is used, but it will be shown, in Sec. IXb, that this represents only a small part of the total calorific development.

SEC. VIIIi.—*Calorific equation of an open-hearth furnace.*—More than ten years ago I published an investigation into the calorific balance of an open-hearth furnace.* Quite recently other experiments have been conducted by von Jüptner,† who gives three sets of data. As might reasonably be expected the answers obtained by von Jüptner do not perfectly agree with my results, and it will be profitable to analyze the causes of disagreement. Selecting from the three experiments the one where the coal consumption was the lowest so as to give a better ground for comparison, the factors may be thus summarized:

(1) The quantity of coal burned per ton of steel was 638 pounds at Steelton and 854 pounds in Germany.

(2) In Germany the loss of unburned carbon in the producer

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* *The Physical and Chemical Equations of the Open-Hearth Process. Trans. A. I. M. E.*, Vol. XIX.

† *Chemisch-Calorische Untersuchungen über Generatoren und Martinöfen von Hanns v. Jüptner und Friederich Toldt.*

ashes represented 22 per cent. of the heat value of the coal, while at Steelton this loss was only 5.6 per cent.

(3) In spite of the higher coal consumption in Germany this heavy loss in the producer ash left a smaller quantity of heat going to the open-hearth furnace, so that the German producer was the more wasteful and the German open-hearth the less wasteful.

(4) The products of combustion from the German furnace escaped to the stack at a temperature 100° C. higher than at Steelton, thereby causing a greater loss in these gases.

(5) In the Steelton furnace there was only a small amount of excess air, but there was a loss of unburned carbonic oxide in the waste gases representing 3.5 per cent. of all the heat value of the coal. In the German furnace there was no unburned gas escaping, but the amount of air used was 50 per cent. in excess of the amount theoretically necessary, so that considerable heat was carried off by this excess.

The foregoing differences are matters of practice and are not open to criticism, but there are some other points where the results are in error, for in my former calculation I erred in the specific heats of the gases and also in the estimate of steam in the products of combustion from the open-hearth furnace. Allowance was made for the steam produced by the combustion of the hydrogen in the gas and of the water vapor contained in the air, but I did not take account of the moisture present in the producer gas, which will absorb heat in the producer and also carry away energy in the waste products of the furnace. In other calculations on producer practice I had calculated this factor, but neglected it in working out the problem of the melting furnace.

This correction, however, proves to be of little importance, as the amount of steam contained in the Steelton gas is only half as much as in the German product. The heat absorbed by this small amount does not amount to much according to my method of calculation, although it does play an important part in the method followed by von Jüptner. He assumes that all the steam in the producer gas carries away a quantity of heat equal to that necessary to convert it from water into the gaseous state. This assumption is undoubtedly correct in regard to the moisture contained in the coal, but it is difficult to see how it applies to the water arising from the combustion of the hydrogen in the coal. Von Jüptner calculates the amount of heat produced by the combustion of hydrogen and uses the full calorific value of this element on the assumption that the resulting water is condensed. He then counts this heat of vaporization as being lost in the steam of the gas. This same heat must then be counted as part of the available heat entering the open-hearth furnace, and must again be reckoned as escaping in the waste gases from the furnace. All this seems entirely unnecessary, and it makes a radical difference in the percentage of heat lost in the waste gases. It seems much more logical to neglect this heat of vaporization; to consider that hydrogen develops only 29,000 calories per kilogramme, and to take into account in all the subsequent operations only the real specific heat of the steam. In any metallurgical operation whatever, the heat generated by condensation takes place in the upper realms of the atmosphere, a hundred feet above the top of the chimney, and never enters into the problem at all.

Taking the figures as given by von Jüptner to represent the loss of heat in the steam contained in the waste gases of the furnace, calculation shows that 70 per cent. is due to this latent heat of vaporization and 30 per cent. to the real sensible heat. If the figures were corrected for this the loss from steam would be about 2.8 per cent. of the total, which would agree quite well with Steelton practice. This change would at the same time increase the value of the other items and show a somewhat greater loss in radiation and conduction.

I believe that von Jüptner is also in error in his method of calculating everything from 0° C. as a basis. He figures the amount of heat carried in by the gas, the air, and the metal, taking 0° C. as the datum plane. A little consideration will show that this arbitrary temperature has no relation whatever to the problem in hand. It would be quite as logical to take as a datum plane a temperature of -100° C. or -10,000° C. In either case the calculation would be quite correct from one point of view, but it would be quite incorrect from another point. If we assume a low enough datum plane, then the amount of heat brought into the furnace by the gas and air and stock would be far in excess of the amount of heat produced by combustion, and the distribution of heat as expressed in calories and in percentages would be absurd. The only datum plane which will give logical results will be the average temperature of the materials put into the furnace. The volume of gas and the volume of air supplied to the furnace are nearly equal, and therefore the proper datum plane is the average of the temperatures of the incoming gas and air. This neglects the temperature of the metal charged into the furnace, but this may easily be allowed for.

In further elucidation of the general problem I have again worked out the equation of a furnace. The experiments, as before, were made at the works of The Pennsylvania Steel Company and under my own supervision. There are at Steelton two acid-lined 50-ton furnaces, which run on a coal consumption of 500 pounds per ton of steel, this figure being based on the weights of the cars of coal delivered to a separate group of producers. In order to find the amount used while the furnace is charged with stock, it will be safe to deduct one-eighth of this amount to allow for idle time, and this gives 440 pounds (200 kg.) of coal, which is used while the furnace is doing actual work in heating and melting.

The coal is not the only source of energy, as a certain amount of heat is created by the combustion of the metalloids, this amount depending on the composition of the charge and the amount of iron oxidized. Following is a comparison of the amount of metalloids and the amount of iron oxidized in the experiments by Jüptner and in the old experiments at Steelton:

Element Oxidized.	Per Cent. of Total Charge.	
	Jüptner.	Steelton.
Si............	0.48	0.41
Mn	1.23	0.88
C	1.03	0.95
Fe...........	2.24	0.98

The practice was nearly the same in both cases, except that the loss of iron was more than one per cent. greater in the German furnace, and the production of heat was therefore somewhat greater. The heat value of the internal combustion was found by Jüptner to be 169,560 calories per ton of steel, while at Steelton it was 143,000 calories. The difference can be shown to be accurately accounted for by the greater loss of iron, and as a slight variation in this factor does not materially affect the calculation, inasmuch as the heat so produced is a small part of the total, and inasmuch as it will necessarily vary with each change in the percentage of pig-iron, it has been arbitrarily assumed in the new determinations that the heat produced by internal combustion in the furnace will be 155,000 calories per ton.

The heat produced by this coal is used or lost in many ways, the principal of which may be thus enumerated:

(1) Lost in unburned carbon in the producer ash.

(2) Absorbed in the internal reactions of the producer.

(3) Carried away as sensible heat of steam and gas in the producer gases, this sensible heat being of no use in the open-hearth furnace.

(4) Absorbed by the metal in heating and melting.

(5) Carried to the stack in the products of combustion as sensible heat of steam and gas.

(6) Carried to the stack in the excess air supplied to the furnace.

(7) Carried to the stack in unburned hydrogen and carbonic oxide.

(8) Lost by radiation and conduction.

Of these several different ways in which the energy is dissipated some are losses pure and simple, as, for instance, the carbon in the producer ash and the loss by radiation; some are losses which are in part inevitable, as, for instance, the absorption of energy in the internal reactions of the producer, while some are utilizations, as, for instance, the absorption of heat in melting.

The object of the investigation is to find how much of the calorific value of the coal is applied usefully and how much is wasted, and to answer this question it is necessary to know how much is theoretically necessary to perform the required work, in order to compare this figure with the calorific energy actually supplied to the producer and the furnace.

The amount of energy needed to heat and melt the stock is given by von Jüptner as 328,250 calories per ton, while in the older investigation I had found it to be 290,000 calories. This is a very close agreement when it is considered that there is some uncertainty about the specific heats at high temperatures of different kinds of pig-iron and steel. It is to be noted that I did not take into account the melting of the slag, because I considered that all the component parts of the slag were either in the metal or in the sand bottom, and consequently did not need to be considered save in regard to the latent heat of fusion, which would be negligible. It will be safe therefore to assume in the new calculation that the energy utilized in heating and melting amounts to 310,000 calories per ton, which is a mean between the two results.

In the new determinations the loss on account of carbon in the producer ash is much lower than in the earlier experiment. This arises from an improvement in general producer practice and the average loss at present in Steelton from this cause is about two per cent. of the total heat value of the fuel.

After making the calculations by the methods pursued before, I submitted the whole manuscript to Prof. J. W. Richards, of Lehigh University, Bethlehem, Pa. He found errors in my calculations, some of importance, and some relating to rather fine points of thermal chemistry which would not affect the nature of the result, but which should not exist in a published investigation. The most important error was in the calculation of the heat equation of the steam in the producer, while another was in the amount of energy absorbed in the gasification of the volatile components of the coal. This latter figure was taken from Bell and he in turn used the generally accepted estimate, but it has been recently proven that a comparatively small amount of heat is required for this gasification.

I therefore asked Prof. Richards to follow the line of calculation I had pursued and substitute his figures whenever a change was necessary, and I have deemed it only right that the work should appear under his name. The method of calculating the amount of gas from a given weight of coal, and the losses and distribution of heat is the same as that used in my paper before referred to in Vol. XIX of the "Transactions of the Mining Engineers." It may therefore be unnecessary to say that the calculations in that paper are incorrect as far as they relate to the decomposition of steam in the producer, but at that time very little steam was used, and this error is unimportant.

The results of the investigation appear in Tables VIII-A, VIII-B and VIII-C, and there are also given for comparison the determinations made at Steelton some years ago and those of von Jüptner, both of which have been already referred to. Taking as a whole the results shown in the tables we may draw the following conclusions:

(1) A producer properly run demands about one-quarter to one-fifth of all the heat value of the coal, and delivers the remainder as available combustible in the gas.

(2) If the loss of coal in the ash is very high the gas may contain less than half the heat value of the coal.

Note; see Sec. IXb for a further discussion of producer practice.

(3) In making calculations on the heat distribution in the open hearth furnace, it is necessary to consider the heat produced by the combustion of the silicon, carbon and iron of the bath, for this amounts to about one-seventh as much as is supplied by the combustion of the gas.

(4) The heat supplied by the combustion of the metalloids and of the iron is one-half of the quantity necessary to heat and melt the charge.

(5) The distribution of heat in the open-hearth furnace must be calculated in percentages of the sum total of the heat supplied by the gas and the heat supplied by internal combustion.

(6) Roughly speaking, about one-half of all the heat supplied to an open-hearth furnace is lost by radiation and conduction.

(7) About one-quarter of the heat is lost in the waste gases going to the chimney.

(8) About one-quarter of the heat is utilized in heating and melting the stock.

It must be borne in mind that the foregoing conclusions are founded on experiments where the coal consumption throughout the month was 500 pounds per gross ton of steel ingots. In furnaces where the coal consumption is higher, the percentage of heat utilized will be less, and the amount lost by radiation and in waste gases will be greater.

The total loss in waste gases in the Steelton experiment was 23.4 per cent. of the total value of the coal, and the gases escaped to the stack at an average temperature of 680°, this average being based on an estimate of the proportional amount escaping from the two chambers, the temperature of each having been determined.

It has been explained that the average temperature of the gas and air was 280° C., so that there was a loss of 23 per cent. for 400° C., or 6 per cent. for each 100° C. If this is true, then an increase in the cubical content of the regenerative chambers, sufficient to reduce the temperature of the waste gases 100° C., will effect a saving of 6 per cent. in furnace economy, and after allowing for the gain in heat from the metalloids and the loss of heat in the producer, this will represent a saving of about 5 per cent. in the fuel consumption. There would thus be a saving of from 25 to 45 pounds of coal per ton, depending on the fuel economy of the furnace. It is easy from this to calculate for each locality the saving in money from larger chambers, and compare it with the quite considerable outlay necessary to obtain the economy.

The loss from radiation and conduction appears to be twice the loss in the escaping gases, but it is necessary to consider that this item embraces all the errors of determination and calculation. The practical melter knows very well the immense waste from these causes, and he may very likely have been sufficiently unfortunate to see a furnace where the heat radiated plus the heat going to the chimney equaled the heat produced, for when a furnace is worn out, and the chambers are clogged with dirt, and the ports are melted back so that a good flame is impossible, and when the roof and walls are thin and cracked, then it may happen that after the steel is melted it is almost impossible to get it hot. It is evident that no more gas is burned per minute than when the furnace was new, and therefore the loss in waste gases should not be much greater. These waste gases may be hotter owing to the dirty condition of the checker brick, but the difference is not sufficient to account for all the conditions. The trouble is that a little less gas comes in to the furnace and a little less heat is produced per minute, while the loss of heat is greater owing to the thin walls and roof and thus, instead of a surplus to give to the bath there may even be a deficit at times, and unfortunately the radiation increases with each increase of temperature. It is from this latter cause that the furnace may easily be capable of melting down the charge, but incapable of reaching the exalted temperature necessary for handling the melted steel.

The evident teaching of this lesson is to prevent the loss of heat by thick walls, but the practical man knows that a thick roof gives so much trouble that it seems better to sacrifice heat and use the ordinary thin covering. Perhaps the most feasible way to save fuel is to have ample ports and get a fast working furnace, for the charge is then quickly melted and it will be clear that the loss by radiation will be about in proportion to the time of operation. By making heats in one-third less time, the radiation would be decreased one-third, and if the loss from this cause is 50 per cent. in the slower furnace, then the faster work will save about one-sixth of the coal.

The remainder of this section gives the mathematical investigation by Prof. Richards as above explained.

Mathematical Investigation by Prof. J. W. Richards.—Calculation of Tables VIII-A, VIII-B and VIII-C.

Table VIII-A on the distribution of heat in the producer is calculated by use of the following physical constants and principles of calculation:

The carbon of the fuel minus the carbon in the ash, gives the total carbon in the gas. Total carbon in the gas divided by the carbon in one cubic metre, gives the volume of gas produced. Carbon in one cubic metre is found most easily from the principle that one cubic metre of either CO, CO_2, or CH_4 contains 0.54 kg. of carbon; C_2H_4 contains twice that weight. The calorific value of the gas is found by multiplying the volume of each combustible ingredient by the calorific power of one cubic metre of the combustible gas, and adding the products. The products of the dry distillation of the coal are taken from results on a similar coal at the beginning of distillation, coked in Semet-Solvay coke ovens, as reported by Prof. H. O. Hofman. The volume of CH_4 and C_2H_4 in the gases may be assumed as coming all from this distillation; the volume of H gas distilled off is a little less than the CH_4. The volume of CO and CO_2 in the total gases, minus that coming from the distillation, gives the CO and CO_2 formed by combustion in the producer. The total volume of free hydrogen produced minus that coming from the distillation, gives the free hydrogen liberated in the producer by the decomposition of steam. The total weight of hydrogen in the gas, in every form (CH_4, C_2H_4, H and H_2O) minus the weight of hydrogen in the coal in any form (assumed as 4 per cent. in the dried coal and 0.5 per cent. present as hygroscopic water) gives the hydrogen which must have come in with the blast. Assuming average humidity of the air, the weight of hydrogen present in it as moisture is calculated; the difference between this and the total hydrogen of the blast is the hydrogen coming in from the steam jet, whence the weight of steam blown in.

The heat created in the producer is from formation of CO and CO_2. Some of this is rendered latent by being absorbed in the decomposition of H_2O in the blast; this heat re-appears in the open hearth when the gases are burnt; it is part of their calorific power. The rest of the heat created in the producer is lost as sensible heat in the hot gases or by radiation and conduction. These losses are definite losses. The total calorific power of the coal is the calorific power of the gases produced, plus the definite losses of heat from the producer as just defined. The proportion these losses bear to the total calorific power of the coal is the percentage of producer loss.

Von Jüptner and Toldt used no steam jet, and therefore had very little decomposition of steam in their producers. They, however, calculate the total calorific value of the coal by adding together the calorific power of the gases and the total heat created in the producer, including, moreover, in the latter item the heat of combustion of the hydrogen of the coal which goes into the gases as water. Aside from the fact that these writers use the calorific power of hydrogen to liquid water (which has already been objected to by Mr. Campbell as including the irrecoverable and therefore negligible heat of vaporization of the steam formed), it seems that the above calculation of the total calorific power of the coal contains two erroneous items, viz: (1) any heat rendered latent in the producer by decomposition of steam is counted in twice, once in the heat developed in the producer, and the second time it is included in the calorific power of the gas. This item is, however, small in their particular case, while it is a considerable item in the Steelton producers. (2) The including of the heat of formation of the water in the gas coming from the combination of hydrogen of the coal with oxygen in the coal is practically assuming that all the H of the coal is free to burn, and neglects the principle of "available hydrogen" or "hydrogen free to burn." The total calorific power of the coal is thus increased by this quantity more than the actual calorific power of the coal can really be, and the surplus thus found over and above the experimentally ascertained calorific power of the coal is called by von Jüptner and Toldt the "heat of gasification" (Vergasungswärme) of the coal. It will be seen that this is entirely a hypothetical quantity which has no place in the calculations in theory and no existence in practice.

Physical constants used in the calculations:

Weight of 1 c. m. H gas (at 0° and 760 m. m.) 0.09 kg.
Weight of 1 c. m. any other gas=0.09 kg.x1/2 its molecular weight.
Weight of C in 1 c. m. of CO, CO_2,CH_4=0.54 kg.
Mean specific heat of 1 c. m. from 0° to t° C.

CO, H, N or O	0.306+0.000027 t
CO_2	0.374+0.00027 t
H_2O	0.342+0.00015 t
CH_4	0.418+0.00024 t
C_2H_4	0.424+0.00052 t

HEAT OF COMBUSTION OF FUELS.

	Per molecular weight.	Per kilo.	Per c. m.
C to CO	29,400	2,450	
C to CO_2	97,600	8,133	
CO to CO_2	68,200	2,436	3,069
H to vapor H_2O	58,080	29,040	2,614
CH_4 to CO_2 and H_2O gas	191,560	11,970	8,620
C_2H_4 to CO_2 and H_2O gas	319,260	11,400	14,367
Si to SiO_2	180,000	6,430	
Fe to FeO	65,700	1,173	
Fe to Fe_2O_3	195,600	1,746	

TABLE VIII-A.

Distribution of Heat in the Producer.

Coal per ton of steel produced, pounds	440
Coal per ton of steel produced, kilogrammes	200
Carbon in coal, per cent	75.68
Carbon in 200 kg. coal, kg	151.36
Ash in coal, per cent	7.12
Carbon in producer ash, per cent. of ash	21.07
Carbon in producer ash, per cent. of coal	1.90
Heat value of carbon in ash per 200 kg. coal, calories	30,700
Producer gas: composition by volume, per cent. (dry gas) CO_2, 5.7; CO, 22.0; CH_4, 2.6; C_2H_4, 0.6; H, 10.5; O, 0.4; N, 58.2.	
Steam accompanying 1 c. m. gas (determined) c. m	0.0375
Calorific value per cubic metre, calories	1260
Carbon in one cubic metre dry gas, kg	0.1689
Carbon in gas per kg. of coal (0.7568—0.0190) kg	0.7374
Volume of gas per kg. of coal (0.7378÷0.1689) c. m. (dry)	4.37
Volume of dry gas per 200 kg. coal, c. m	874
Calorific value of gas per 200 kg. of coal, calories	1,101,240

Products of dry distillation of 1 kg. coal (assumed).

CO_2 0.026 kg.=0.013 c. m.
CO 0.027 kg.=0.022 c. m.
CH_4 0.082 kg.=0.114 c. m.
C_2H_4 0.033 kg.=0.026 c. m.
H 0.0098 kg.=0.109 c. m.

Volume of CO_2 in gas per kg. of coal (0.057×4.37) c. m.	0.249
Volume of CO_2 from distillation of 1 kg. coal, c. m	0.013
Volume of CO_2 produced by combustion, per kg. coal, c. m.	0.236
Volume of CO_2 produced by combustion per 200 kg. coal, c. m.	47.2
Heat of formation of 47.2 c. m. CO_2 calories	207,300
Volume of CO in gas per kg. of coal (0.22×4.37) c. m.	0.961
Volume of CO from distillation of 1 kg. coal, c. m	0.022
Volume of CO produced by combustion, per kg. coal c. m.	0.939
Volume of CO produced by combustion per 200 kg. coal c. m.	187.8
Heat of formation of 187.8 c. m. CO, calories	248,460
Total heat created in producer per 200 kg. coal, calories.	455,760
Temperature of gas leaving the producer, degrees Cent.	655
Mean specific heat of dry gas (20° to 655°) (calculated)	0.3468
Sensible heat in dry gases per 200 kg. coal (874×.3468×635)=192,470	

Mean specific heat of steam (20° to 655°)	0.443
Sensible heat in steam per 200 kg. coal (0.0375×874×0.443×635)=9280	
Total sensible heat in gas and steam per 200 kg. coal calories	201,750
Volume of free H in gas per kg. of coal (0.105×4.37) c. m.	0.459
Volume of free H from distillation of 1 kg. coal, c. m.	0.109
Volume of free H from decomposition of H_2O in producer, c. m.	0.35
Volume of free H from decomposition of H_2O per 200 kg. coal, c. m.	70
Weight of H liberated from H_2O per 200 kg. coal, kg.	6.3
Heat thus absorbed in decomposing steam, calories	182,700
Total weight H in 1 c. m. gas, including steam, kg.	0.0186
Weight H in gas per 200 kg. coal, kg. (0.0186×874)	16
Weight H in 200 kg. coal (200×0.045), kg.	9
Weight H coming from air and steam, per 200 kg. coal, kg.	7
Weight H_2O coming from air and steam, per 200 kg. coal, kg.	63
Weight H_2O coming from air used, at average conditions, kg.	9.6
Weight steam blown in, per 200 kg. coal, kg.	53.4
Weight of steam decomposed in producer (6.3×9) kg.	56.7
Deduct moisture of air, assumed all decomposed, kg.	9.6
Steam of steam jet decomposed, per 200 kg. coal, kg.	47.1
Percentage of steam in steam jet decomposed $\left(\frac{47.1}{53.4}\right)$	88

Heat generated in producer, calories	455,760
Heat taken out of producer in gas and steam	201,750
Surplus left in producer, calories	254,010
Absorbed in decomposing steam (rendered latent)	182,700
Loss by radiation and conduction, calories	71,310

Summary of above results on Producer Practice, per 200 kg. coal.

	Calories.
Lost as carbon in ash	30,700
Lost by radiation and conduction	71,310
Sensible heat of hot gas and steam	201,750
Total heat loss of producer	303,760
Calorific power of producer gas	1,101,240
Total heat value of coal	1,405,000
Per cent. lost in producer	21.6

Losses in the Producer in Percentage of the Heat Value of the Coal.

	Calories.	Per cent. of value of coal.		Per cent. of total producer loss.	
Lost as C in ash	30,700	2.1		10.1	
Radiation and conduction	71,310	5.1		23.5	
Sensible heat of steam	9,280	0.7	14.4	3.1	66.4
Sensible heat of dry gas	192,470	13.7		63.3	
	303,760	21.6		100.0	

TABLE VIII-B.

Distribution of Heat in the Open-Hearth Furnace.

C in gas per kg. of coal, kg.	0.7378
C in gas per 200 kg. coal, kg.	147.56
C in 1 c. m. (dry) chimney gas, kg. (0.127×0.54)	0.06858
Volume (dry) chimney gas per 200 kg. coal, c. m.	2152
Free oxygen present in this gas (2152×0.067), c. m.	144
Excess air corresponding to free oxygen, c. m.	699
CO_2 in chimney gas (2152×0.127), c. m.	273
N in chimney gas (2152×0.806), c. m.	1735
N in excess air used, c. m.	536
N in theoretical products of combustion, c. m.	1199
N in producer gas per 200 kg. coal (874×0.582), c. m.	509
N in air necessary for theoretical combustion, c. m.	690
Air necessary for theoretical combustion, c. m.	872
Excess of air used, percentage 680÷872	78
H_2O in chimney gas (2152×0.078), c. m.	168

Heat in air used, at 280°, Sm (0° to 280°)=0.314—	
Theoretical air needed (872×0.314×280) calories	76,650
Excess air used (680×0.314×280) calories	59,770
Total, calories	136,420
Heat in producer gases used, at 655°—	
Dry gas 874 c. m. (874×0.347×655) calories	92,650
Steam 33 c. m. (33×0.440×655)	9,510
Total, calories	102,160
Total heat brought to furnace, not available, calories	238,580
Heat taken out in chimney gases, at 680°—	
Dry, theoretical combustion (1472×0.367×680), calories	367,750
Steam formed (168×0.444×680), calories	50,190
Total in theoretical products of combustion, calories	417,940
In excess air used (680×0.324×680), calories	149,820
Total in the chimney gases, calories	567,760
Heat brought to furnace and not available, calories	238,580
Heat loss in chimney chargeable against furnace, calories	329,180
Proportion of chimney loss chargeable against furnace, per cent	58

Items of Chimney Loss Chargeable Against Furnace:

	Calories.	Per cent.
Dry gases from theoretical combustion	213,220	64.8
Steam from theoretical combustion	29,100	8.8
Excess air used	86,860	26.4
	329,180	100.0

Summary of Above Results on Furnace Practice per 200 kg. Coal =One Ton Steel.

	Calories.
Potential value of gas	1,101,240
Combustion of metalloids	155,000
Total heat available	1,256,240

Sensible Heat in Waste Gases Chargeable Against the Furnace.

	Calories.	Per cent. of available energy.
(a) Dry, theoretical products of combustion	213,220	17.0
(b) Steam of theoretical products of combustion	29,100	2.3
Total in the theoretical products of combustion	242,320	19.3
(c) Excess air used	86,860	6.9
Total in entire products of combustion	329,180	26.2
Heating and melting stock	310,000	24.7
Radiation and conduction (by difference)	617,060	49.1
Total as above	1,256,240	100.0

Comparison of von Jüptner's Results with Steelton Practice.

Table VIII-C gives von Jüptner's results (Exp. III) as given by him, and as recalculated and corrected. It also gives Campbell's data, both old and new. The two Campbell sets are not strictly comparable, nor are the first of von Jüptner's and the first of Campbell's, but the corrected von Jüptner results are comparable with the later Steelton figures. Von Jüptner loses 25.9 per cent. in producer ash, against 2.1 per cent. at Steelton. Of the 74.1 per cent. actually utilized, von Jüptner gets 50.7 per cent. potential in the gas, or only 68 per cent. of the potential of the coal actually consumed. On the other hand, of the 97.8 per cent. utilized at Steelton 78.4 per cent. is potential in the gas, or 80 per cent. of the potential of the coal actually consumed. The Steelton practice is therefore 26.7 per cent. better as far as burning the coal is concerned and 10 per cent. better in utilizing the combustion for the production of gas. The former advantage is due to a better form of grate and more careful working; the latter advantage to the steam jet, which transfers 10 per cent. of the power of the coal from the producer to the furnace. The net result is that the Steelton practice is 50 per cent. better than that of von Jüptner.

TABLE VIII-C.

Distribution of Heat in Producer and Furnace Combined.

Per Ton of Steel.	Von Jüptner.				Campbell.			
	Original.		Corrected (Richards).		Old Determination.		New Determination (Richards).	
	Amount (calories).	Per cent. of total.	Amount (calories).	Per cent. of total.	Amount (calories).	Per cent. of total.	Amount (calories).	Per cent. of total.
Coal in producer, pounds	....	....	854	....	638	....	440	....
Heat value of coal, kilogramme calories	....	....	2,337,450	....	2,377,420	....	1,405,000	....
Producer practice—								
Lost as carbon in ash	....	....	606,470	25.9	140,650	5.6	30,700	2.1
Heat generated in producer which is lost, i. e., not used in furnace	....	....	547,730	23.4	694,840	27.6	273,060	19.5
Potential of gas used in furnace	....	....	1,183,250	50.7	1,541,930	66.8	1,101,240	78.4
Total=value of coal as above	....	....	2,337,450	100.0	2,377.420	100.0	1,405,000	100.0
Furnace practice—								
Potential in gas as above	1,252,080	....	1,183,250	83.2	1,541,930	....	1,101,240	87.6
Combustion of metalloids	169,560	....	169,560	11.9	143,000	....	155,000	12.4
In gas, air and stock	225,430	....	69,930	4.9				
Total available heat for furnace	1,647,070	....	1,422,740	100.0	1,684,930	....	1,256,240	100.0
Sensible heat of dry gases of theoretical combustion (chargeable)	392,500	23.8	258,530	18.0	210,530	12.5	213,220	17.0
Sensible heat of steam of theoretical combustion (chargeable)	169,170	10.3	38,080	2.7	24,670	1.5	29,100	2.3
Sensible heat of excess air (chargeable)	124,320	7.6	116,830	7.7	10,790	0.6	86,860	6.9
Unburnt combustible in waste gases	....	....	....	....	58,590	3.5	....	....
Total in waste gases chargeable against the furnace	685,990	41.7	413,440	28.4	304,580	18.1	329.180	26.2
Absorbed in heating and melting	328,250	19.9	328,250	23.1	290,000	17.2	310,000	24.7
Radiation and conduction (by difference)	632,830	38.4	681,150	48.5	1,090,350	64.7	617,060	49.1
Total in furnace as above	1,647,070	100.0	1,422,840	100.0	1,684,930	100.0	1,256,240	100.0
Percentage of the total heating power of the coal and metalloids utilized in heating and melting stock	....	....	....	13.5	....	11.5	....	20.0

CHAPTER IX.

FUEL.

SEC. IXa.—*The combustion of fuel.*—A full definition of the word "fuel," and the correlated term "combustion," would necessitate a journey into the domain of chemical physics. Such a dissertation would not be entirely unprofitable, for in the modifications of the Bessemer process the calorific value of silicon, manganese, phosphorus and iron are of vital importance, but in the affairs of everyday life the term "fuel" embraces only the various forms of carbon known as charcoal and anthracite coal, and combinations of carbon and hydrogen, such as natural gas, petroleum and bituminous coal, while the meaning of "combustion" is also narrowed down to the union of such substances with oxygen. In the case of complex hydrocarbons, like wood, soft coal, or oil, the full history of combustion would be a record of manifold dissociations and syntheses; but for practical purposes it may be considered that in all compounds of hydrogen and carbon there is an isolation of each element just previous to union with oxygen, and the molecular history may, therefore, be represented by the following simple equations:

$$C+2O=CO_2,$$

1 kilo $C+2\ 2/3$ kilos $O=3\ 2/3$ kilos CO_2,

producing 8133 calories.

$$CO+O=CO_2,$$

1 kilo $CO+4/7$ kilo $O=1\ 4/7$ kilos CO_2,

producing 2438 calories.

1 cubic metre $CO+1/2$ cubic metre $O=1$ cubic metre CO_2,

producing 3072 calories.

$$2\ H+O=H_2O,$$

1 kilo $H+8$ kilos $O=9$ kilos H_2O,

producing 34,500 calories, including latent heat in steam.

29,040 calories, not including latent heat in steam.

1 cubic metre $H+1/2$ cubic metre $O=1$ cubic metre H_2O,

producing 2614 calories, not including latent heat in steam.

$$C+O=CO,$$

$$1 \text{ kilo } C+1\ 1/3 \text{ kilos } O=2\ 1/3 \text{ kilos } CO,$$

producing 2450 calories.

It has been questioned whether this latter action ever takes place, the theory being that carbon always burns first to CO_2 and is then reduced to CO by absorption of incandescent carbon. Whether this is true or not is of little moment, for nothing is gained or lost in calorific energy by the transmutation, and it is, therefore, simpler to assume a direct action.

The above equations represent the combustion of carbon and hydrogen with oxygen. Needless to say this never occurs in practice, for it is burned with air, and air is a mixture of oxygen and nitrogen, the proportion by weight being 23.2 oxygen and 76.8 nitrogen, and by volume 20.9 oxygen and 79.1 nitrogen; and it follows, therefore, that the products of combustion from burning coal are composed in great part of nitrogen. The products from burning hard coal and soft coal will vary somewhat, owing to the fact that soft coal contains about 5 per cent. of hydrogen, and oxidation of the hydrogen produces water, and in taking a sample of the gases from the stack, this water is condensed as it passes through the tubes of the apparatus and does not appear in the analysis as usually performed, but in order to burn this hydrogen it is necessary to supply a certain quantity of air and this air

TABLE IX-A.

Products of Combustion of Hard and Soft Coal.

Excess Air.	Hard Coal.		Soft Coal.	
	CO_2 Per Cent.	O Per Cent.	CO_2 Per Cent.	O Per Cent.
No excess.	21.0	0.0	19.1	0.0
10	19.1	1.9	17.3	2.0
20	17.5	3.5	15.8	3.6
30	16.1	4.8	14.5	4.9
40	15.0	6.0	13.5	6.1
50	14.0	6.9	12.6	7.1
60	13.0	7.8	11.7	8.0
70	12.3	8.6	11.0	8.8
80	11.7	9.3	10.4	9.5
90	11.1	9.9	9.9	10.1
100	10.5	10.5	9.4	10.6

carries with it a certain amount of nitrogen, and this nitrogen does appear in the products of combustion, so that in burning soft coal the products of combustion contain a slightly higher percentage of nitrogen and a slightly lower percentage of carbonic acid than will be obtained in the burning of hard coal.

Table IX-A shows the composition of the products of combustion of hard and soft coal when burned with varying amounts of air.

The first line gives the results of theoretical combustion when just sufficient air is added to completely burn the carbon and hydrogen and each succeeding line shows an additional 10 per cent. of air in excess of what is theoretically needed. It is found in practice that such an excess is necessary to insure complete combustion. The amount of excess necessary varies with the conditions under which the coal is burned, but it is seldom possible to have complete combustion with less than 30 per cent. excess air. The percentage of nitrogen is not given, but it is easily found by difference, as whatever is not carbonic acid or oxygen is nitrogen. It will be seen that there is scarcely any difference between the products formed from soft coal and from hard coal, and that the amount of free oxygen present indicates the excess air that is present. The coal always contains a certain amount of ash, but this may be entirely neglected in such calculations, for the ash does not escape from the stack and the products of combustion are just the same whether the coal is pure carbon or whether it contains a large quantity of earthy matter.

Combustion of carbon (coal) with no excess of air:

$$1 \text{ kg. carbon} + 8.87 \text{ cu. metres air} = 1.86 \text{ cu. m. } CO_2 + 7.01 \text{ cu. m. N}$$

Combustion with 100 per cent. excess:

$$1 \text{ kg. carbon} + 17.74 \text{ cu. m. air} = 1.86 \text{ cu. m. } CO_2 + 14.02 \text{ cu. m. N} + 1.87 \text{ cu. m. O.}$$

The equations given herewith represent the volume of air required by each kg. of carbon and the volume of the products caused by the combustion. In one case the formula represents theoretical combustion and in the other case with 100 per cent. excess air; for any intermediate amount of air the carbonic acid will be the same, and the nitrogen and the oxygen will be proportional. This excess air means a considerable loss of heat.

There must necessarily be a loss even if there be no excess of air, for the products of combustion are so voluminous, owing to the amount of nitrogen present, that they carry off a great deal of sensible heat. The amount so carried away will depend upon the temperature of the waste products, but it will not be exactly proportional to the temperature, as has already been shown in Table II-F, in Chapter II. Using the figures there given and interpolating for intermediate points, a calculation may be made on the specific heat of the gaseous mixtures shown in Table IX-A and the loss of heat determined. The results are shown in Table IX-B, from which may be learned that if the gases from a coal fired boiler escape at 200° C., a temperature which is attainable, the loss in sensible heat is 7.5 per cent. when no excess air is present, but if 100 per cent. of excess air is used the loss will be 14.4 per cent. When the temperature is 300° C. the loss with 100 per cent. excess air is 21.6 per cent. and with 400° C. it is 29.5 per cent. The figures in the table for 300° C. and 600° C. were calculated in full, and it will be noted that they are not exactly proportionate owing to the variations in the specific heats of the gases, but they also show that for moderate temperatures the error will be small if exact proportionality be assumed. In this calculation no account has been taken of the water produced by the combustion of the hydrogen or the moisture present in the air. These two items will

TABLE IX-B.

Loss of Heat in Products of Combustion of Hard Coal in Per Cent. of Total Heat Produced.

	Temperature of Gases; Degrees Cent.				
	100	200	300	400	600
Specific heat of waste gases—					
No excess air	.328	.336	.344	.352	.367
20 per cent. excess	.327	.334	.341	.348	.363
40	.324	.331	.338	.345	.358
60	.322	.328	.335	.341	.354
80	.320	.326	.332	.338	.349
100	.318	.324	.329	.334	.345
Per cent. of heat lost—					
No excess air	3.8	7.5	11.3	15.5	24.0
20 per cent. excess	4.5	8.9	13.4	18.4	28.3
40	5.1	10.3	15.4	21.1	32.5
60	5.8	11.7	17.5	23.9	36.8
80	6.5	13.0	19.5	26.7	41.0
100	7.2	14.4	21.6	29.5	45.3

increase slightly the loss of heat, but both the moisture in the air and the hydrogen in the coal vary so greatly under different conditions that it is hardly worth while to make any average concerning them.

Sec. IXb.—*Producers.* In almost all metallurgical operations where gas is used for heating, the fuel employed in the producer is a rich bituminous coal; but in some special cases, as for instance in drying ladles and the like, anthracite coal is sometimes used. For driving gas engines hard coal is much to be preferred, as the gas contains very little tarry vapor, and hence needs much less scrubbing. It is necessary therefore to consider both fuels.

(a) *Bituminous coal in a gas producer:*

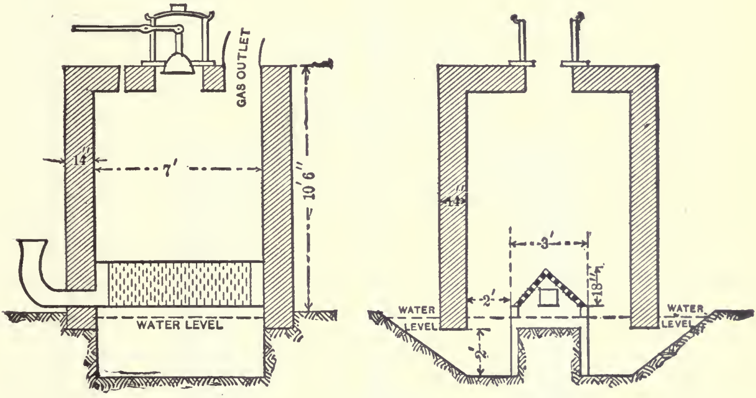

Fig. IX-A.—Water Seal Producer.

The conversion of soft coal into gas is performed by burning it in a thick fire and collecting the gases evolved. Air is blown in beneath the grate to force combustion, and a jet of steam is also admitted to keep down the temperature and prevent the formation of clinkers. Within the last few years the water seal producer has been very generally adopted. Many different forms have been used, but the main principles of the construction are illustrated in Fig. IX-A, while Fig. IX-B shows a special form. The space below the water level is supposed to be full of ashes, which can be removed without any interference with the operation of the producer. The ashes will also fill the room for one or two feet above the water line. Above this will be glowing carbon, and the

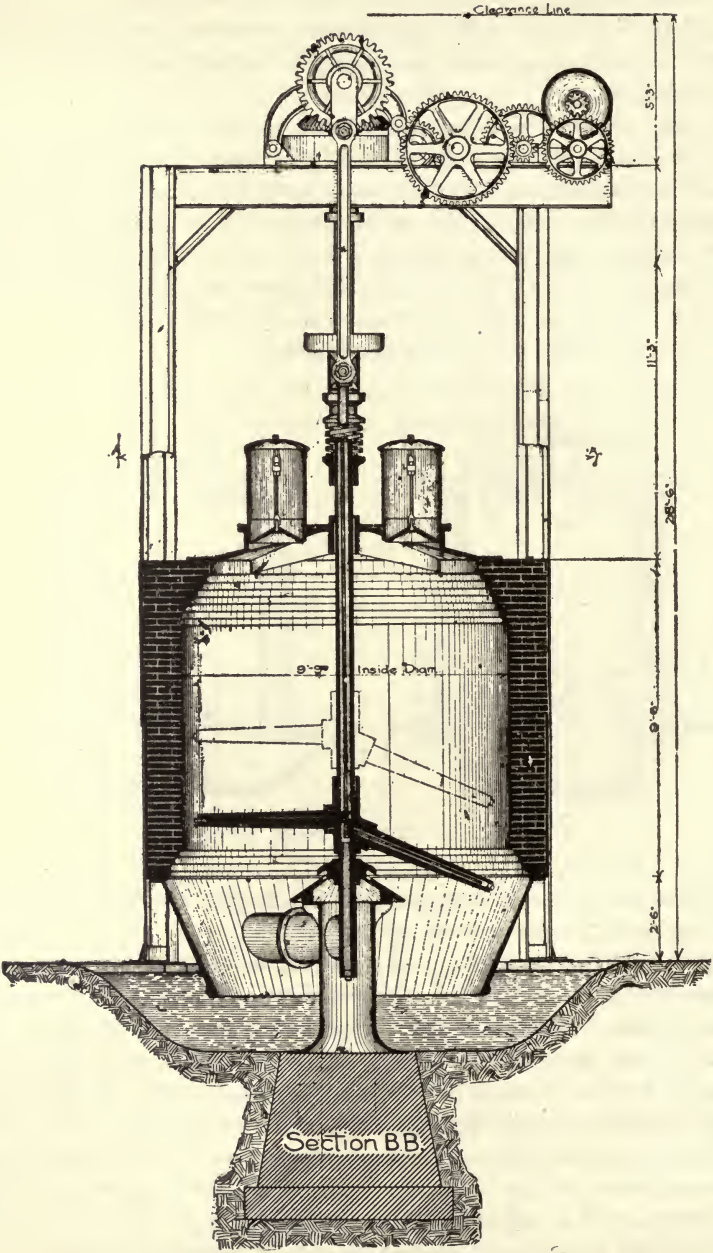

Fig. IX-B.—Frazer Talbot Producer.

air as it goes up forms carbonic acid (CO_2), and this rising through the bed of coal absorbs more carbon and becomes carbonic oxide (CO), but this action is never complete, and some carbonic acid passes through the fire unchanged. With a hot deep fire free from cavities the gas may contain as low as 2.5 per cent. by volume of CO_2, but if the fire be thin or if it is riddled with holes, there may be as much as 10 per cent.

It is also in the "zone of combustion" that the steam is broken up by the carbon with formation of hydrogen and carbonic oxide, but, as in the similar reduction of carbonic acid, this reaction is never perfect and some steam always goes through unaltered. The best decomposition is attained in a hot fire, but this is just the condition that is not desirable on account of the formation of clinkers. On the other hand, if the supply of steam be increased indefinitely the fire will get colder and colder, producing no gas and letting steam and air pass through unconsumed. There is a mean between these extremes which is almost forced upon the operator, wherein the fire is kept at a constant temperature, and in this condition there is not much increase in hydrogen from the steam, while, on the contrary, there is quite a little steam passing away with the gases.

In the upper zone of the fire, the volatile hydrocarbons of the fuel are distilled by the heat of the combustion beneath, and in this way the gaseous products contain a certain proportion of tarry vapors, some of which are condensed in the conducting tubes. The zones of combustion and distillation are not separated by any arbitrary line, but a goodly share of the rich components of the coal are carried down into the body of the fire and exposed to a high temperature. This causes the separation of carbon, some of which, staying in the fire, is burned with the coal, while the rest is carried forward into the conducting tube. When the fire is very hot, large volumes of soot are formed in this way and soon give trouble in the pipes, but when cool there is little soot, but much tar. The worst condition is when holes form in the bed of coal. This allows air to come through and burn the hydrocarbons above the fire with a smoky soot-producing flame, cakes the coal into an unworkable mass, and increases the percentage of carbonic acid in the gas.

In Sec. VIIIi were discussed certain producer experiments, and the gas there given may be taken as fairly representative of ordinary practice, the composition being as follows:

Siemens Gas.	Per cent. by volume.
CO_2	5.7
C_2H_4	0.6
O	0.4
CO	22.0
H	10.5
CH_4	2.6
N, by difference	58.2
	100.0

It has been shown that some of these percentages, notably of CO_2, H, and CH_4, will vary through wide ranges according to the condition of the fire, but the content of nitrogen will always be about 60 per cent. This component remains passive throughout all the future history of combustion, but it so reduces the calorific intensity that the gas is applicable only to regenerative furnaces.

The ordinary methods of gas analysis fail to take definite account of any save true gaseous components, but in the products of a soft-coal fire there are certain amounts of soot and tar. Some of this material is deposited in the conduits, but this does not constitute a very great part of the total energy. I have elsewhere* recorded that in the case of an exposed 7-foot iron pipe, 250 feet long, the condensation of tar amounted to only three-tenths of 1 per cent. of the total heat value, while the gas itself, after passing through the tube, contained a proportion that represented from one-tenth to one-eighth of the total heating power.

In spite of the low calorific power of this tar it is found that when the suspended matters are removed by scrubbing, the value of the gas is reduced very seriously, for it is the tar which gives luminosity to the flame and thereby renders it able to heat not only by direct impact, but by the no less potent action of radiation. It is by virtue of this quality that the luminous flames from the dense hydrocarbons so far surpass the clear products of an anthracite fire.

The investigation given in Sec. VIIIi showed that the losses of energy in a producer as operated at Steelton were as follows:

Lost as carbon in ash	2.1
Sensible heat of dry gas	13.7
Sensible heat of steam in gas	0.7
Radiation and conduction (by difference)	5.1
Total	21.6

---

* *The Open-Hearth Process. Trans. A. I. M. E.,* Vol. XXII, p. 376.

The total shows that over one-fifth of all the heat value of the coal is lost in one way or another. The figure for radiation and conduction is determined by difference, and hence bears all the errors in the determinations. The other items offer some ground for discussion.

(1) The carbon in the ash.

In Sec. VIIIi reference was made to certain experiments in Germany by von Jüptner in which the loss of carbon in the producer ash represented 20 per cent. of the total value of the coal, for he states that the ash coming from the producer contained 74 per cent. of carbon and only 26 per cent. of true ash, this refuse being what would be considered a very fair fuel in some localities. It is hardly right to take such a practice as representative of good methods, as such a waste is entirely unnecessary, for at Steelton it is found quite possible to run soft coal gas producers where the ash contains less than 20 per cent. of carbon, and, in fact, may average from 12 to 18 per cent. It is possible to estimate very closely how much of the total value is lost if we know the percentage of carbon in the ash and the percentage of ash in the original coal. The latter point must be taken into consideration. For instance, if the coal contains 13 per cent. of ash, and if when working this coal the waste material coming from the producer contains 87 per cent. of carbon, it would show that absolutely no work had been done in the producer and that, therefore, there was 100 per cent. waste, but if the coal contained only 4 per cent. ash and the ashes coming from the producer contained 87 per cent. carbon it would show that only

Table IX-C.

Percentage of the Total Heat Value Represented by the Presence of Varying Proportions of Carbon in the Ash.

	Per Cent. of Total Heat Value Lost.			
Per Cent. Ash in Coal.	4	7	10	13
20 per cent. C in ashes.....	1.5	2.5	3.2	4.0
40 " " "	3.0	5.5	7.0	8.5
50 " " "	4.0	7.0	10.0	13.0
60 " " "	5.5	10.0	14.5	20.0
70 " " "	8.0	15.0	21.0	....
80 " " "	15.0	25.0	....	....
85 " " "	20.0	....	....	....

about 30 per cent. of the coal had been wasted. It is therefore of great importance to take the purity of the coal into consideration, and the relative losses with different proportions of ash are not exactly proportional, for they follow different curves when plotted. By calculating different coals I have found the heat value represented by certain percentages of carbon in the ashes and they are given in Table IX-C.

It will be seen that with a coal of 7 per cent. ash and with the producer ashes containing less than 20 per cent. of carbon the loss of heat value is less than 2½ per cent. of the original value of the coal, which is a very radical difference from the loss mentioned by von Jüptner, wherein 20 per cent. of the total value was thrown away from this cause.

(2) Sensible heat in gas and steam.

The sensible heat of producer gas is wholly wasted, for in a regenerative furnace it makes no difference what the temperature of the entering gas may be, as the temperature of the outgoing products of combustion on the opposite end will be just that much higher, so that the loss on one end balances the gain on the other. In the experiment before mentioned by von Jüptner, the average temperature of the producer gas in four experiments is 267° C. I am much inclined to doubt the correctness of these temperatures, for I find that von Jüptner's loss from radiation and conduction alone was as much as all the factors in the Steelton practice combined, while the loss from sensible heat of gas and steam was low on account of the low temperature of the escaping gases. It is well known that the loss by radiation is determined by difference, and it is clear that a cold fire should not give as much loss by radiation as a hot one, so that the matter may be straightened out by assuming that von Jüptner took the temperature of the gases at some distance from the producer and that the item of radiation included a part of the sensible heat of the gas. Under this assumption the true radiation from the body of the producer becomes more nearly what would be expected, although a detailed comparison of the producer calculation is useless owing to the confusing way in which von Jüptner calculates the heat history of the hydrogen on the basis of its full calorific value, including the latent heat of condensation. This has already been referred to at length in Sec. VIIIi.

It is quite possible that the fires were at a low temperature for a short time, but I hardly believe that they could be run continuously under such conditions. I have made experiments on that line and operated a fire for several hours at a black heat, but at the end of that time the whole top of the fire had become a bed of tar, so that it was impossible to do any poking, and it was necessary to stop charging fresh coal and to decrease the amount of steam and to allow the fire to burn up and distill and break up the tarry matters so that the fire could be worked properly. In the experiments at Steelton the gases were at 655° C. and it is quite certain that most producers are run at this temperature.

It may appear at first sight that the presence of carbonic acid (CO_2) in the gas must be taken as the first and most important loss, but a little reflection will show that this item is taken care of under the head of sensible heat and under radiation; for the production of an excess of carbonic acid must give rise to heat and this heat must show itself somewhere. If it is used to dissociate steam then it is not lost, for the gas will be enriched by the hydrogen. Consequently it is not entirely right to assume that a slight increase in carbonic acid necessarily means poorer practice. The gas above quoted as made at Steelton ran as follows:

$$CO_2=5.7 \qquad\qquad H=10.5$$

It is clear that if less steam had been used the fire would have been hotter and if properly poked would have shown a lower percentage of CO_2; but it would probably also have shown a lower percentage of H, so that nothing would have been gained in the calorific value of the gas, and the heat value of the coal would not have been better conserved.

TABLE IX-D.

Percentage of the Total Heat Value of the Coal Represented by Varying Amounts of CO_2 in Gas.

2 per cent. CO_2= 5.3 per cent. loss
3 " " " 8.0 " " "
4 " " " 10.8 " " "
5 " " " 13.7 " " "
6 " " " 16.6 " " "
7 " " " 19.6 " " "
8 " " " 23.0 " " "
9 " " " 26.5 " " "
10 " " " 30.0 " " "

Notwithstanding this theoretical fact that a higher content of carbonic acid is by no means a proof of bad practice, it remains true that under usual conditions the percentage of carbonic acid is an index of the fuel economy, and it is possible to calculate by a rather long process the percentage of heat represented by certain proportions of this gas. Table IX-D shows the percentage of the total heat value of the coal which is represented by certain proportions of CO_2 in the gas, provided that the heat produced by its formation is not utilized in the decomposition of steam.

In the producer gas previously considered there was 5.7 per cent. of carbonic acid, which, according to this table would represent 15.7 per cent. of the total value of the coal. The calculation of Prof. Richards in Table VIII-A shows that the formation of CO_2 in the case there under consideration produced 207,300 calories, when the total heat value of the coal was 1,405,000 calories. The carbonic acid in this case represented 14.8 per cent., while Table IX-D would indicate 15.7 per cent. for the same gas. The agreement is sufficiently close, since the table does not pretend to be absolute, but is constructed for purposes of comparison only. In ordinary producer practice the carbonic acid runs from 4 to 6 per cent., indicating a loss from this cause of 11 to 16 per cent. of the total heat value of the coal, but under exceptionally good practice the gas will carry between 3 and 4 per cent. of carbonic acid, indicating a loss of from 8 to 11 per cent., thus causing a saving of say 5 per cent. in the amount of coal used. With bad practice the gas may contain 10 per cent. of carbonic acid, indicating a loss of 30 per cent. of the total heat value, which is about 17 per cent. more than is necessary, so that under this practice the amount of coal consumed is one-sixth greater than would be used in good practice. A high percentage of carbonic acid may usually be detected without the aid of a chemist, for it is bound to show itself in a hot fire, and the sensible heat of the gases in the tube is not only the result, but the exponent and measure of the waste.

(b) *Hard coal:*

Hard coal is about equal to soft coal when used for firing boilers, both in facility of working and in the quantity required, and the smaller sizes are extensively used for this purpose in the eastern portion of the United States. The smallest sizes are used, as they are not marketable for household purposes and can be had at a less cost. They are, however, more troublesome and require special grates and usually forced draft. This material has also been used successfully in producers, the gas consisting almost wholly of carbonic oxide (CO) and nitrogen.

In operating such a fire it is necessary to inject steam at the grate or the producer becomes unmanageably hot. The steam rots the clinkers and cools the fire, and hydrogen is produced as in the manufacture of water gas. The gas produced is of about the following composition:

	Per cent. by volume.
CO	27.0
H	12.0
$CH_4+C_2H_4$	1.2
CO_2	2.5
N	57.3

This is nearly the same result that will be obtained in a soft coal producer, but, when the attempt is made to substitute the one for the other, it is found that while gas from anthracite is nearly equal in producing low temperatures, such as firing boilers or drying ladles, it is far inferior, if not entirely valueless, in creating an intense heat, even when properly regenerated; it is supposed with much reason that this inferiority lies in the absence of the suspended volatilized tarry matters, which are characteristic of soft coal gas. These components have quite an appreciable heating value, but their main function is to give luminosity to the flame, and, by increasing its power of radiation, augment enormously its practical value. The absence of these components, however, makes anthracite producer gas particularly well adapted for use in gas engines, as for this work it is necessary to avoid any soot producing components on account of the dangers of premature ignition.

SEC. IXc.—*Miscellaneous fuels.* There are some fuels which are essentially local in their character like natural gas and oil; a few remarks will, therefore, suffice for them, and for water gas also, which is used somewhat in metallurgical operations.

(a) *Natural gas:*

In the favored district lying just west of the Alleghenies in Pennsylvania, West Virginia, Ohio and Indiana, natural gas has been almost universally used for all kinds of heating from about 1884 until the present time. The composition varies in different wells, but in all cases the gas is made up of members of the paraffine series, with not over one-half of 1 per cent. of carbonic acid

(CO_2) and from 2 to 12 per cent. of nitrogen. By ultimate analysis it gives about 70 per cent. of carbon and 23 per cent. of hydrogen, while, by ordinary methods, it shows from 67 to 93 per cent. of marsh gas, the remainder, when the marsh gas is low, being principally hydrogen. At first this gas was passed through regenerative chambers, but this was discontinued owing to the deposition of soot and to the discovery that sufficient heat was obtained by leading the gas directly to the ports and burning it with air which had been regenerated in the usual manner.

Of late years the supply of gas has been decreasing and the demand has been met by the constant drilling of new wells in new territory. There is a limit to this method, and it would seem that before many years this fuel would cease to be a factor in the larger operations of a steel works.

(b) *Petroleum:*

Crude oil may be transformed into a vapor by atomizing with steam and then superheating the mixture, but unless exposed for sometime to a yellow heat it remains a vapor, and hence will condense if carried through long, uncovered pipes or introduced into the cold valves of a regenerative furnace. It may be put into the chambers at some point where the temperature is high, and in this way condensation will be prevented as well as the waste heat be utilized. There is also a partial molecular rearrangement with the steam, but the action is far from perfect, for, after passing through 20 feet of small brick flues at a yellow heat, the product may contain 20 per cent. of free aqueous vapor. The mixture of oil vapor and steam may be burned in a muffle, for, after the walls are red hot, there is a reciprocal sustention of heat; but the use in reverberatory furnaces is very wasteful since the action is very sluggish. Even in regenerative practice a charge of cold stock retards combustion much more with oil than with coal gas, and even at maximum temperatures, the flame is longer on account of there being double work to do before the combustion is complete. Each molecule of oil, as it comes into a hot furnace, undergoes a process of dissociation, the rich hydrocarbons breaking up under the tension of internal molecular activity. This absorbs heat and thus for an instant the action of disruption lowers the temperature below the point of ignition. Moreover, as each point of oil explodes, it makes a small balloon of gas, and it takes a moment for this to become mixed with the air necessary for its combustion. If steam is present its reduction by carbon entails a certain delay.

These matters may seem trifling, but they are probably the explanation of the very important fact that, under the usual conditions of furnace operation, a flame from oil vapor is longer than a flame from coal gas. In the burning of clear carbonic oxide, or a mixture of it with nitrogen, there is no preliminary decomposition to be performed, the air being free to immediately touch and burn the molecules of the fuel.

It is impossible to state the comparative economy in the use of coal and oil, since their relative values vary so widely in different localities. It often happens that the freight on fuel is three, four, five or perhaps ten times its value at the source of supply, and it will be evident, since oil contains so much more calorific power, that the freight per unit of heat value becomes less and less, compared with coal, as the absolute transportation charge increases; so that if both were to be carried fifty miles, coal might be much the cheaper, while if the distance were a thousand miles, the status would be just the reverse; moreover, the price of oil is constantly varying through very wide limits owing to the discovery of new methods of utilizing what have before been subsidiary or waste products. A rough comparison may always be made by assuming that 50 gallons of oil are equivalent to about 1000 pounds of soft coal when used in regenerative furnaces or under boilers. In the latter case, the success of the practice depends upon the arrangements made to prevent chilling of the flame before vigorous combustion is in progress.

(c) *Water gas:*

NOTE: This discussion on the manufacture and use of water gas is condensed from a much longer article by George Lunge, in *The Mineral Industry* for 1901.

When steam is passed over incandescent carbon (preferably in the shape of coke or anthracite) the subjoined reaction takes place:

$$C+H_2O=CO+H_2$$

That is to say, equal volumes of carbon monoxide and hydrogen are formed, the mixture possessing the caloric value of 2800 metric heat units per cu. m., an amount one-half the heat value of gas made by distilling bituminous coal in retorts. The heat produced by gram-molecules is for $CO+H_2+O_2=CO_2+H_2O=68.4+57.6$

$=126$ heat units, whereas the direct combustion of carbon, $C+O_2=CO_2$, produces only 97 heat units. It stands to reason that the introduction of an incombustible substance like water cannot be the source of fresh energy, and the apparent gain of energy represented by the figure: $126-97=29$ heat units must be explained by its introduction from an extraneous source. This is found in the heat that accumulates in the incandescent fuel. The reaction: $C+H_2O=CO+H_2$ is endothermic; i. e., it takes place with expenditure of heat. The splitting up of H_2O requires an expenditure of 57.6 heat units, of which only 28.6 are supplied by the reaction $C+O=CO$, so that a difference of 29 heat units has to be made good.

In the long run these 29 heat units must be supplied apart from the incandescent fuel, the temperature of which constantly sinks and soon falls below the point where the reaction $C+H_2O=CO+H_2$ is prevailing (assumed to be above 1000° C.). Below this temperature another reaction comes into play, viz., $C+2H_2O=CO_2+2H_2$, which produces a gas composed of one-third inert carbon dioxide and two-thirds combustible hydrogen. This second reaction is also of endothermic character, and if real water gas is to be made, the operation must be divided into two distinct phases or stages. Beginning with a stock of incandescent coal in a generator 2 or 3 m. in height and at a temperature of about 1200° C., steam, preferably in the superheated state, is introduced and water gas is formed according to the reaction,

$$C+H_2O=CO+H_2.$$

Soon, however, the temperature sinks and carbon dioxide CO_2 is produced in the gas by the secondary reaction,

$$C+2H_2O=CO_2+2H_2.$$

Before the carbon dioxide begins to prevail, the steam must be shut off, the temperature being then below 1000° C. This whole period of "steaming" lasts 4 or 5 minutes, and the gas produced during this period is called "blue gas," containing by volume 48 to 50% H, 40 to 45% CO, 4 to 5% CO_2, 4 or 5% N, and having a calorific value of about 2600 heat units per cu. m.

Immediately after the steam is shut off, the "blowing up" or second stage begins; air is blown into the generator, whereby carbon is burnt and the temperature at once rises. When it has reached the required degree, the air blast is shut off, and the generator is ready for another "steaming." Until quite recently the blowing-up was carried on exactly as in the manufacture of ordinary producer gas (Siemens gas), so that the carbon was burnt to monoxide only, thereby generating 29 heat units instead of 97 heat units, which were set free for each atom of carbon; but this was considered unavoidable, as the great bulk of fuel contained in the generator must necessarily reduce any carbon dioxide formed to carbon monoxide, and probably at such high temperatures that from the first carbon monoxide only is formed. This drawback has been overcome by the Dellwik-Fleischer process*, whereby such conditions are established in the generator that during the blows a practically complete combustion to carbon dioxide is obtained within the bed of fuel to be heated, while at the same time conditions are maintained favorable to the making of water gas. The radical difference between the "old" processes and the method originated by Dellwik is that in the former the gas, while leaving the generator during the "blow," contains principally carbon monoxide, together with the inevitable nitrogen, while in the latter it consists principally of carbon dioxide and nitrogen.

	Per 1 pound carbon.	
	Old way.	Dellwik method.
Water gas, cu. ft.	21.7	44.7
Heat units	3627	7465
Per cent. utilized	48	92.5

The difference in results is outlined herewith. In the old water gas processes the quantity of gas formed during the blows is amply sufficient to raise the steam needed for the process; in the new process the escaping heat is only sufficient to preheat the feed water for the boiler. We must, therefore, add 12 to 15% of fuel for the steam, which reduces the theoretical quantity of gas obtained from 12 lb. of carbon to 656 cu. ft., and limits the possible utilization of the heating value of the fuel to about 80%.

Sec. IXd.—*Heating furnaces.*

(a) *Soaking pits:*

Nothing is more interesting to an American who visits the steel plants of Europe than to find that no coal furnaces are used to heat the ingots between the Bessemer and the rolling mill, but that

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* *Journal I. and S. I.*, May, 1900.

they are allowed to heat themselves from internal heat in a Gjers soaking pit, a very small amount of coal being often used to maintain a reducing atmosphere. This old device appears to be perfectly satisfactory, and it is difficult to understand why it cannot be used in America, but although it has been thoroughly tried in this country, it has been put aside, probably forever. It is one of many things which are declared to be perfectly successful in Europe, but which would not be so called in this country if the results were the same. There is always trouble on Monday morning, and the first round of ingots must be allowed to heat the pits and then withdrawn to be heated elsewhere. The ingots must be put in without delay and must be rolled when ready, or the pit will cool. These things do not fit into American practice, where no one factor must be allowed to retard the mill a moment. It is better to burn a little coal and have ingots always ready to roll without regard to when they were made.

It is probable also that failures in this country arose in great measure from the kind of steel. The pits work much better on very soft steel, and as the carbon is raised it is necessary to lengthen the time that the ingot remains in the furnace. No foreign works makes rail steel as high in carbon as we do in America, and more than one foreign engineer will shake his head over the problem of regularly heating steel in this manner when it must often carry from .50 to .65 per cent. of carbon, with higher manganese and phosphorus than is used abroad. Whether these conditions were or were not the cause of the failure and abandonment of these pits in at least four American works many years ago, the fact remains that they were thus abandoned.

(b) *Regenerative furnaces:*

It is the universal practice in America and the general practice abroad to use regenerative furnaces for heating ingots or blooms whenever these ingots or blooms are red hot to start with. Under these conditions it requires less fuel in a regenerative furnace than in any other type, and there is no interruption in the output of a furnace. In heating ingots the amount of fuel needed is very small. The furnaces in America are invariably of the vertical type and resemble a Gjers soaking pit, and are operated in much the same manner save that small quantities of gas and air are admitted. At the works of the Maryland Steel Company at Sparrow's Point, Md., only 40 pounds of coal are used per ton of ingots, taking the average from week to week. Counting the producer labor this does not cost over 5 cents per ton, which is much better than to have interruptions of work with unfired pits and a lot of cold ingots every Monday morning.

In the same way it is customary in America to use regenerative furnaces to reheat blooms coming from the blooming mill before finishing into small shapes. This costs something, but it saves also, as such furnaces serve as a sort of reservoir to receive blooms when the ingots are rolled faster than the finishing mill or to deliver them when the blooming mill is behind. In other words reheating tends toward the uninterrupted operation of the mill, which is the first requisite of economy. It also saves the wear of the rolls and the consumption of steam fuel in the finishing mill. As above stated, for giving a wash heat to hot blooms in this method of work, the regenerative furnace is most convenient and economical.

(c) *Soft coal in reverberatory furnaces:*

A reverberatory furnace is one in which the fire is at one end, the stack at the other, and the stock is placed on the hearth between, the flame passing over the top of whatever is placed upon the hearth to be heated. Such a furnace is suitable for heating cold blooms or billets. A regenerative furnace is not suitable because each charge of cold material lowers the temperature of the regenerators and after about four or five successive charges, it takes longer to heat the blooms than would be required in a coal fired furnace. The operation of a reverberatory furnace is far from satisfactory. When the furnace is filled with cold blooms, the absorption of heat is so great that combustion is retarded and a clear hot flame cannot be obtained. At a later period of the operation, when the blooms are hot, a clear hot flame cannot be carried, as the metal would be oxidized. During the advanced stages, it is necessary to run more or less of a smoky flame and as the blooms on the hearth are of very nearly the same temperature as the flame, it follows that very little heat is utilized in the furnace, but that most of the energy passes out the flue. After the blooms have reached their proper state and during the time that the blooms are being drawn and rolled one at a time, it is evident that all the heat entering the furnace goes out the stack, except what is lost by radiation and conduction. In the ordinary reverberatory furnace the amount of fuel actually used to heat a ton of steel is twenty times as much as theory would call for.

One common way of getting more perfect combustion is to introduce air at the bridge wall or just over the fire, but oftentimes this results in more loss than gain, for the average heater will not regulate the amount of air each minute to correspond to the exact amount of smoke that comes from the fire, and if it is not so regulated, the flame will often be too sharp and the metal on the hearth will be oxidized. The cost of an increase in the loss of metal of only 1 or 2 per cent. will more than balance the gain in coal, and may even equal the entire cost of the fuel. In more than one European works I have been given very good figures for coal consumption, but have been told that the waste by oxidation was from 5 to 7 per cent.

In many localities where fuel is cheap it has been the practice to let the flame from the heating furnace escape directly into a stack, but no argument is needed to show that the hot products of combustion should be passed through a boiler. The amount of heat available cannot very well be calculated, but is known by experience. It varies with the condition of the charge, being less after the furnace is filled with cold blooms, and greatest when they are at the full heat. It is quite evident that it is not a good investment to put up a boiler big enough to absorb every particle of waste heat during the short period when the furnace is at its highest temperature, and it is also evident that the boiler should be more than enough to handle the minimum. The exact point of economy will depend necessarily upon the price of coal, because if fuel is high, a larger boiler will be warranted than when coal is cheap. It is doubtful if any works has erred in spending too much for boilers over the furnace. Nearly all have done the opposite. Steam must be made, and if it is not made by this waste heat, which calls for no expenditure of labor in handling coal or ashes, then it must be supplied by boilers in the fire room.

After considerable investigation of this subject, I would give as my opinion the following:

(1) For each ton of coal used in twelve hours, the waste heat from the furnace averages from 25 to 30 horse power.

(2) When the furnace is at its highest heat, it represents a continuous development of 35 horse power per ton of coal burned in twelve hours.

(3) When a furnace is supplied with a boiler capable of absorbing one-half of all the heat created at the highest temperature of

the furnace, the average loss throughout the day will be about one-third of the total made, or about one-half of what is utilized, this being due to the fact that this limited capacity is enough at certain periods, and that the boiler makes beyond its rated and economical capacity, as shown by the great loss of heat in the escaping gases.

(4) When a furnace is equipped with ample boiler capacity, the horse power developed by each ton of coal put into the fire box will be about one-half as much as would be developed by the same coal if burned under an ordinary stationary boiler.

In Table IX-E are given analyses of the waste gases from soft coal reverberatory furnaces after passing through boilers. In the first column is given the interval from the time when the furnace was charged to the time when the test was taken, and in the second column is given the number of tests that were averaged to give the composition stated.

TABLE IX-E.

Waste Gases from Reverberatory Furnaces.

Interval from charging furnace to taking tests.	No. of Tests.	CO_2	CO	O
Less than 20 minutes........	17	10.8	4.9	4.2
20 minutes to 1 hour..........	18	11.9	3.9	2.9
1 hour to 2 hours..............	6	11.8	7.5	0.5
2 hours to 3 hours............	7	10.6	7.2	1.1
3 hours to 4 hours..	6	9.8	4.2	5.4
True average.....	54	11.0	5.0	3.0

Observations were made as to the time when fresh coal was added, but the analyses did not seem to show any relation thereto. Thus there were 14 tests showing over 6 per cent. CO and the average time since coaling for these was 13 minutes. There were 20 tests showing less than 3 per cent. CO, and the average time since coaling was 16 minutes. There were 8 tests with over 6 per cent. oxygen, and the average time since coaling was 16 minutes.

The results are so nearly uniform for the different periods of the operation that we may take the average as representing the general history, and find the loss of heating power due to the escape of unburned CO and also the loss of heat by the excess of air or oxygen that is present. In the same way the gases taken at the later periods of the work may be compared. The seven tests taken about two hours and a half after charging show a high percentage of CO and a moderately low percentage of oxygen, while those taken an hour later show a smaller waste of CO, but a large excess of air.

It is not necessary to take into account the actual consumption of coal. As a matter of fact this was not taken at the particular time that the tests were made, except in one case, when it ran 490 pounds of coal per ton of blooms heated. Having the composition of the gas it is easy to find the amount of each component in a given volume or weight of gas and to find what proportion of carbon is burned to CO_2, what proportion to CO, what oxygen is required and what percentage of excess is present and the loss of heat from each cause. The results are given in Table IX-F, the loss from excess of oxygen being calculated on the assumption that the gases leave the boiler at a temperature of 250° C.=480° F., which is higher than should obtain in good boiler practice, but which is much lower than the average of fairly well-equipped furnace boilers.

TABLE IX-F.

Calculations on Waste Gases from Reverberatory Furnaces.

		Kind of Gas.		
		Average.	2 h. 30 m.	3 h. 30 m.
Composition.	CO_2 per cent	11.0	10.6	9.8
	CO per cent	3.0	7.2	4.2
	O per cent	5.0	1.1	5.4
Loss from CO per cent		21.5	27.8	20.8
Loss from oxygen per cent		3.6	0.5	3.3
Total loss per cent		25.1	28.3	24.1

It will be seen that even with gases varying through pretty wide limits the loss due to unburned combustible and to an excess of air is fairly constant. As already explained, the operation cannot be conducted for the benefit of the boiler. The proper heating of the steel is the first consideration and the boiler must take care of itself. Moreover, we cannot expect good combustion to take place after the gases have gone into the boiler, since unburned gases will go through side by side with oxygen, but it does not follow that everything has been done that can be done. There is room for improvement when over one-fifth of all the power is wasted by non-combustion, but even under ordinarily good arrangements, it is possible to run a rolling mill with the power obtained from boilers over the heating furnaces, without any assistance from the fire room.

(d) *Continuous furnaces:*

A continuous furnace is a reverberatory furnace, but it is not charged with a whole heat of cold blooms at one time. The blooms or billets are fed in at the flue end, pushed toward the firebox and drawn when they reach the hottest part. The pieces are always hot when they reach the vicinity of the fire, and, therefore, the combustion of the fuel is facilitated, as the flame coming over the bridge wall is never cooled by a lot of freshly charged blooms, as in the intermittent furnace. As the flame goes onward to the flue end, it constantly finds colder and colder blooms and gives up its heat, so that if we conceive a furnace of indefinite length, the escaping gases will be entirely cold and every particle of specific heat utilized, except what is lost by radiation.

Notwithstanding these theoretical advantages, there are certain obstacles in the road. The same rules hold good that have been before enunciated, regarding a certain necessary loss of combustible to insure against oxidation of steel, while the loss from unburned carbonic oxide and from excess of air will probably be much the same as shown in the discussion of reverberatory furnaces.

One of the difficulties about a continuous furnace is to move the pieces from one end to the other. It is, of course, the natural and almost universal way to put the hearth on an angle, but some power must be applied. In Europe, where such furnaces are very common, it is not unusual to roll the blooms or ingots forward by hand labor only, the pieces being tipped over by means of bars through doors at the side, but the cost of such labor would be prohibitive in America, while this practice gives rise to heavy loss, as the coating of scale falls off at every turn and exposes a fresh surface to oxidation. It is impossible to say how much of the heavy oxidation is due to this cause and how much to a sharper flame than is customary in America, but both causes doubtless contribute to the result. In one foreign works rails are buried in the hearth of the furnace, which are replaced when they burn away, and when the furnace is repaired, the ingots being pushed forward by power; in other cases, no rails are used, but the ingots are simply pushed along the sand bottom, which is, of course, much torn by the operation.

In America the invariable practice is to have the billets rest on water-cooled pipes. These pipes absorb considerable heat and cool the under side of the bloom somewhat, but the gain in time and labor completely overshadows this small loss. Such furnaces in this country, with few exceptions, are used for billets not over six inches square, since it seems difficult to heat larger blooms sufficiently uniformly on the top and bottom, and there is not time when they reach the end of the furnace to turn them over and let the under side get hot. In the exceptions before noted, the blooms are of nearly uniform size and the conditions are favorable, a furnace of this type being successfully operated on pieces 8 inches square and 10 feet long. Much time, money and ingenuity are being spent on this problem, and the end is not yet.

It is with much hesitation and a consciousness of rank heresy that I wish to register my doubts as to whether there is any economy to be gained in thus handling heavy blooms and miscellaneous material. The labor of charging a continuous furnace is less than for any other type, but with modern machinery the ordinary furnace can be charged and drawn very nearly as cheaply. The control of the temperature, in cases where this is important can be regulated much better in the old way, and the consumption of fuel is not very different, when all factors are considered. The argument has already been made that steam must be produced in some way, and the question is whether the total coal consumed in the furnace and at the fire room is greater in the one case than in the other. I have asked that simple question of two score men in America and Europe, and have not found one who knew from actual investigation. In most cases the old furnaces had never been fitted with proper boilers. In the few cases where the data were at hand, the only conclusion possible was that no fuel was saved by the continuous furnace.

SEC. IXe.—*Coke ovens.*—Almost all the coke of America and about three-fourths of that produced in England is made in the old bee-hive ovens, whereby a pile of coal is burned slowly until the volatile matters are expelled, these volatile matters passing away in clouds of smoke. This smoke is a rich gas during the early stages of the operation, and might be used as a source of heat if it were not that such plants are seldom in the neighborhood of industrial establishments.

In Belgium and Germany this system was long since discarded as wasteful and the coal is burned in retort ovens, by which is meant any construction wherein the coal itself does not burn, but where it is heated in a closed muffle by the combustion of the gases distilled from itself. The gases so distilled may be taken from the tops of the retorts and carried to purifiers, where the tar and ammonia are extracted and sold, in which case they are called by-product ovens. The profits from these by-products vary very much; in some years of high prices they are very attractive; in other years they are nothing.

In other cases the gas is taken directly from the upper part of the coal chamber to the combustion passages underneath. By this method the by-products cannot be obtained, but the advantage is gained that the gases reach the flues at a red heat, while in by-product work they are thoroughly cold. Consequently when no by-product work is attempted, less gas is needed to perform the coking and more heat is available for steam raising. It is also possible to use a leaner coal, containing less volatile matter. Thus we might say that if the gas be scrubbed free from tar and thoroughly cooled, the coal should contain 18 per cent. of volatile matter in order that sufficient calorific value be brought to the flues, while a coal with 15 per cent. of volatile matter would furnish sufficient gas, if this gas were brought red hot into the flues with all the tar in suspension. These figures are not to be accepted literally, as much depends on the nature of the volatile matter. I am informed by W. H. Blauvelt that some Semet Solvay ovens in Belgium are working on coal with only 17 per cent. of volatile matter, with profitable recovery of the by-products. In this country some Pocohontas coal has been worked with 18 per cent. of volatile constituents.

In Germany a very considerable proportion of the ovens have no by-product plant attached and some of these are new installations. At many other works the chemical industry is very profitable. This difference often arises from the great variation between the coal of different seams and mines in the same locality. In general, it may be said that the retort oven without by-products is the most advantageous system where the value recoverable from these products is small, and where the retort system yields a large increased percentage of coke in comparison with the bee-hive, or where the superior density which the narrower retort oven gives to a spongy coke is of advantage.

In every prospectus of retort ovens much is said of the great excess of gas which can be reckoned upon as a by-product, but a journey through the coke plants of Europe does not bear out this argument. All the European plants burn their gas under boilers and make no attempt to use it in any other way, and most of this steam so made is used in the chemical plant and the coal washer, the excess for general use not being important in a single instance. It should be stated that in most of the Westphalian ovens the coal is selected so as to get as cheap a mixture as will give good results, and the lower the volatile matter the greater will be the yield of coke, but this reasoning, however, does not apply to the ovens in Silesia, where the percentage of volatile matter is very high, but where the excess gas is of little importance. It has been the rule in America that the surplus gas has been much less than was expected, although the plant at Ensley, Ala., furnishes gas sufficient for the heating furnaces in the rolling mill, the coal containing 32 per cent. of volatile matter. With Pocahontas coal there is no excess.

It is possible to get a large amount of gas by a combination of two conditions:

(1) A high percentage of volatile matter.

(2) A neglect of the character of the coke, with a view of obtaining the greatest quantity of gas.

It will be evident that the gas expelled from the coal during the first stages of the operation will be very rich and in great volume, but there follows a time when it decreases, but it is necessary to continue the distillation in order to have the coke dense. During this latter period the coal is not self-supporting, in that the gas burned in the flues is more than the gas produced, and the freshly charged ovens nearby must make up the deficit, so that if the coke is to be used as ordinary fuel, as in locomotives, or for any similar purpose, it is well to pay no attention to quality; but for blast furnace work the extra time necessary may use up all the surplus gas.

It is possible to keep separate the product made during the early part of the process and use this in supplying cities with illuminating gas, reserving the later product, containing less illuminants, for burning in the flues, the high price commanded by illuminants making this a very attractive proposition.

There are many systems in use for building coke ovens, and it seems to the casual observer that the so-called patents are of little validity, but that the main point gained in employing any particular engineer is to get the advantage of his special knowledge. Some of the ovens are regenerative, while many plants have abandoned this arrangement, the main trouble with a regenerative construction being the loss of heat by leakage if the foundations give way, and in most of the plants that have come under my observation, whether regenerative or not, the deformation was very marked.

The general principles of coke oven construction have been discussed by W. H. Blauvelt,* and the following is quoted from his paper:

"While the principles of operation are the same, there are two distinct types of retort-ovens, viz., the vertical and horizontal flue types. In the former there are some thirty-odd vertical flues in each wall between the ovens. These are connected at the top and bottom by larger horizontal flues, running the length of the oven, the lower one being divided into two parts by a partition midway between the ends. The gas is burned in the lower flue, the flame rising through half the vertical flues and descending through the other half and escaping usually to regenerators of the ordinary reversing type, which heat the air for the combustion. The course of the gases is reversed about every hour and sent through the flues in the opposite direction.

"In the horizontal flue oven the gas is burned in horizontal flues, usually three in number, which are connected at the ends so as to form a continuous system, the gas being admitted through small pipes at the ends of the top and middle flues, where it meets the air for the combustion. The gases travel from above downward, pass under the bottom of the oven, through a simple recuperative arrangement for heating the air, and then to boilers, where steam is made for operating the plant."

In Fig. IX-C is given an example of the Semet-Solvay horizontal flue type, as erected at Ensley, Ala., while Fig. IX-D shows the regenerative Otto Hoffman ovens now building at the works of the Maryland Steel Company at Sparrow's Point, Md.

Of the total number of coke ovens in the United States in 1899 as given in the Census Report only about two per cent were of retort construction, while in Germany there were not 2 per cent. of bee-hives. This difference is due to several causes. One is that

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* *Trans. A. I. M. E.*, 1898.

the bee-hive oven makes a very superior coke from Connellsville coal, and there is a prejudice or belief that the retort coke will not be as good. Another reason is that the cost of the ovens is

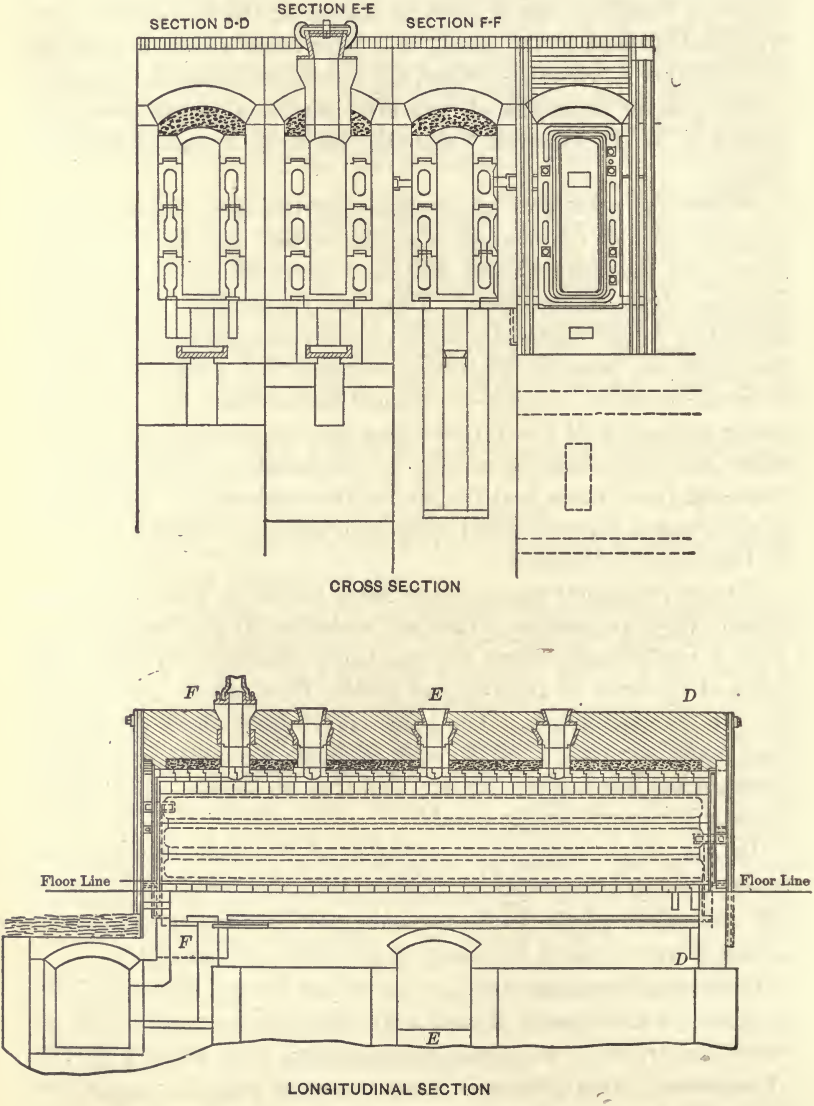

FIG. IX-C.—SEMET-SOLVAY COKE OVEN.

very much greater, and when the price of coke is low the companies have no money to spend, and when there is a boom, bee-hives are put up as being quicker to build and as paying for themselves in a year.

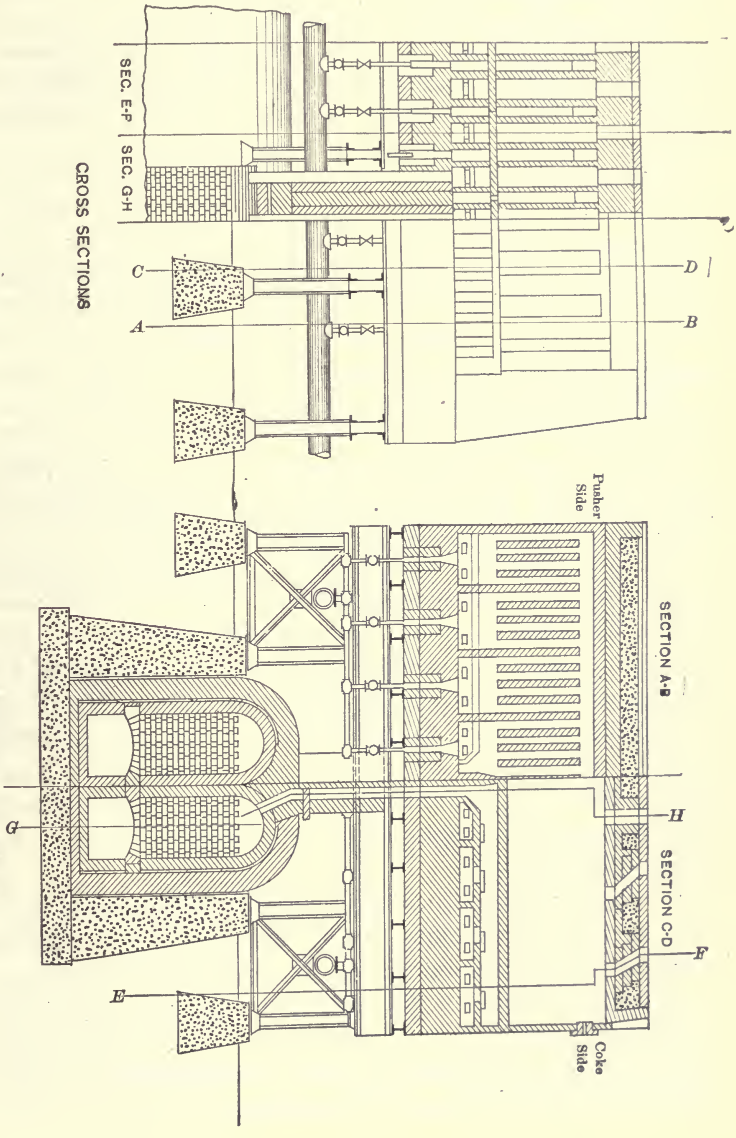

FIG. IX-D.—OTTO HOFFMAN COKE OVEN.

The prejudice against retort ovens crystallized around investigations made many years ago by the leading metallurgists of the Cleveland district in England who advised against the new method. Since then a new light has been seen, and Middlesborough is rapidly introducing the by-product ovens into many of her works.

The advantages of retorts appears very strongly in using a coal poor in volatile matter, for when such coal is coked in bee-hives, a great deal of the fixed carbon must be burned to supply heat, and the yield of coke is small; but with the closed oven the amount of heat required is less, and a smaller amount of combustible suffices and the only loss in weight is the volatile part. Thus with a rich coal the yield of coke is about the same in the bee-hive and the retort, the latter, however, giving an excess of gas for other uses; while with poor coals the yield of coke is much greater in the retort oven. It is not correct to say that the yield of coke can be accurately estimated from the laboratory tests on fixed carbon, for there is a complicated reaction in the retort oven, and probably also in the bee-hive, whereby the dense hydrocarbons are broken up after they are distilled and deposit carbon in the mass of coal, so that it is possible to produce more coke than there was fixed carbon in the coal. The proportion so made depends upon the molecular arrangement of each particular coal.

As indicated above, England has been slow in building retort ovens. They have been used for many years on the lean coals of South Wales, but it is only comparatively recently that they have come into general use in the Cleveland district and around Leeds. Rapid progress has been made within a few years. The total coke production of England is supposed to be from twelve to thirteen million tons, and the retort ovens now erected in the Kingdom have about one-quarter of that capacity. Table IX-G is taken from *The Iron and Coal Trades Review,* and shows the number of each type in England.

In Table XXIII-F, in Chapter XXIII, will be given a list of the coke ovens in each State of the Union, while Table IX-H gives detailed information concerning the retort ovens in operation or construction in 1901. The figures for the Otto Hoffman type are from an article by Dr. Schniewind in *The Iron Age,* July 18, 1901, while I am indebted to a private communication from W. H. Blauvelt for the data on the Semet-Solvay.

TABLE IX-G.

Coke Ovens in England in 1900.

	Annual capacity. Tons.
Coppee............2296 ovens..................	1,800 000
Semet-Solvay,...... 450 ovens....................	500,000
Simon Carves....................................	450,000
Otto..	350,000
Collin..	120,000
	3,220,000

TABLE IX-H.

List of Otto-Hoffman and Semet-Solvay Coke Ovens Erected or Projected in United States and Canada at Close of 1901.

Owner.	Location of Ovens.	Number of Ovens.	Daily Capacity. Tons.
Otto Hoffman—			
Cambria Steel Co........................	Johnstown, Pa...........	160	....
Pittsburgh Gas and Coke Co..........	Glassport, Pa............	120	....
New England Gas and Coke Co.......	Everett, Mass............	400	....
Dominion Iron and Steel Co..........	Sydney, Cape Breton....	400	....
Hamilton Otto Coke Co................	Hamilton, Ohio..........	50	....
Lackawanna Iron and Steel Co.......	Lebanon, Pa.............	232	....
Lackawanna Iron and Steel Co.......	Buffalo, N. Y............	564	....
South Jersey Gas. E. and T. Co........	Camden, N. J............	100	....
Maryland Steel Co.....................	Sparrow's Point, Md.....	200	....
Total..................................	....	2226	....
Semet-Solvay—			
Solvay Process Co......................	Syracuse, N. Y...........	30	150
Dunbar Furnace Co.....................	Dunbar, Pa...............	110	450
National Steel Co.......................	Sharon, Pa................	25	80
Tennessee Coal I. and R. Co...........	Ensley, Ala...............	240	1000
National Tube Co.......................	Wheeling, W. Va.........	120	500
Solvay Process Co......................	Detroit, Mich............	30	150
Total..................................	....	555	2330

SEC. IXf.—*Coal washing.*—There are many deposits of coal which contain a high percentage of ash or of sulphur or of both, and which consequently give a coke of inferior quality. This quality can be much improved by washing the coal before it goes to the coke oven, it being possible in this way to materially reduce the proportion of slate and sulphur. A considerable proportion of the slate can be separated from the coal without any difficulty, the extent of the purification depending upon the fineness to which the coal is crushed and the care taken in operating the machines.

The sulphur presents greater problems. In some cases it is present in coarse grains of iron pyrites, while in other cases it is in flat, thin films, which float in the water during the process of washing and thus accompany the coal in spite of the difference in specific gravity. Sometimes the sulphur is in the form of an organic compound, and this cannot be separated by ordinary methods.

There are two different kinds of coal washing plants; one depending on a combination of sieves and jigs; another where a bumping table is used. These two systems are both good and the underlying principles will be separately considered.

A.—Sieves and Jigs.—If a thousand bullets and a thousand feathers be dropped simultaneously into a wooden box ten feet high, the bullets will be found in a layer at the bottom of the box and the feathers will be on top, because the air obstructs very much the fall of the feathers, while its effect upon the bullets will be slight. The action of air in separating unlike substances is used in very few cases, the winnowing of wheat being the most familiar example. In the treatment of minerals, water is the agent used, but the principle is identically the same. It is inconvenient to have a high column of water and so an upward stream is substituted, down through which and against which the particles must fall. Taking for instance a mixture of slate and coal, where the pieces are of uniform size, it will be evident that if a shovelful is thrown into a strong upward current of water, the slate will get to the bottom quicker than the coal, owing to its greater weight. In practice the separation is rendered easier by having a very short column of water with a sieve at the bottom, and the water comes up through the sieve in pulsations, thus making a quicksand out of the mass and allowing each particle full freedom to find its proper place. When a mixture of slate and coal has been separated in this manner, and while it is being kept in the condition of quicksand by the continual pulsation of the water from beneath, the two minerals separate into well-defined layers and a stream of mixed coal and slate may be fed into one end of the box, while the slate may be drawn off through one orifice at the other end, and the coal through another orifice.

In this description it must be remembered that it is necessary that the pieces of slate and coal shall be of uniform size, for the rate of falling in water depends upon this as well as upon the specific gravity. A bullet will fall to the bottom of the ocean quicker than a pebble of equal size, but a rock two feet in diameter will fall faster than fine bird shot. This arises from the fact that both the area of resistance and the area of frictional surface increase only as the square of the diameter, while the weight increases as its cube. For this reason, a coal-washing plant of this kind should include a crusher to crush the coal to a certain size; it should then have an arrangement of sieves which will separate the crushed coal into several different lots, each lot being composed of pieces of nearly equal size; it must then treat each of these lots separately in pulsating water or by some equivalent method and collect the coal and slate separately from each of these lots. There will also be a certain proportion of very fine material which cannot be handled by any known economical method and which can only be collected in a settling basin.

The separation into lots of equal size is called "sizing," and the separation into lots having equal rates of falling in water is called "sorting." In the above description, it is stated that the coal is first sized and then sorted, but it is perfectly possible to first sort and then size. In practice the separation of slate and coal is never complete, because the particles are of very irregular shape, and it will be evident that a flat disc of slate or coal will not follow the same law of falling in water as a more compact body; that if it happens to fall edge downward it will fall faster than a sphere or cube, while if it remains flatwise, it will fall slower. For this reason, and because there are many pieces that are neither pure coal nor pure slate, but are a mixture of both, the coal will always contain some slate and the slate will always contain some coal. The greater the number of different "sizes" made, the more perfect the separation, but each "size" involves complication of the plant and increased cost of maintenance. In a very complete and economical coal-washing plant in Western Germany the coal in its natural state carries from 22 to 30 per cent. of ash. It is crushed and separated into six sizes on wet sieves. After the washing is completed the ash in the coal runs about 10 per cent., giving a coke containing from 12 to 14 per cent. The fine dust that is collected in settling basins can be used under boilers. The loss of coal in the slate is not over 3 per cent. and the total cost of the process is about 5 cents per ton.

At an English works the natural coal contains 30 per cent. of ash, but it is washed so as to give a coal of from 5 to 7 per cent., making a coke with 7 to 10 per cent. There is also some very fine stuff produced, running about 10 per cent. ash, which is put into coke. In addition to the slate that is separated, about 3 per cent. of the whole comes in the shape of middlings, or mixed slate and coal, which is thrown away. The very finest settlings contain 14 per cent. ash and are used for firing boilers.

B—The Bumping Table.—If a flat, horizontal table be oscillated back and forth by means of a cam and arrangements be made that it strikes a solid block of wood or metal every time it is set free by the revolution of the cam, there will be a bumping action produced, and if coal or other mineral be fed to such a table the material will not be moved at all during any part of the cycle of revolution except during the bump, at which moment every particle without regard to size or specific gravity will be thrown forward a certain distance. If now the table be inclined slightly at right angles to the bumping force and if water be allowed to flow in a sheet over this inclined plane, there will be two forces at work, the bumping action throwing everything lengthwise and the water flowing crosswise, carrying everything at right angles to the length. The result is a zig-zag course diagonally across the table. In the case of the smaller particles and with those of greater specific gravity, the water will have less effect, while the larger and lighter pieces will be washed rapidly across the table by the water. Thus the small and heavy particles will travel the entire length and be delivered from the end of the table, while the lighter and larger particles will be delivered from the side.

The material worked on such a table should be first sorted and were this done the production would be much increased and the separation made very much more perfect. In washing coal it is not the practice to do this preliminary sorting, as there is a great difference in the specific gravity of coal and of iron pyrites, and if all the material is crushed below one quarter inch, and if special arrangements be made for handling the fine stuff, both the ash and the sulphur may be much reduced at a very small cost.

Such tables have done very good work at Sydney, Cape Breton. The raw coal contains about 6.5 per cent. of ash and 2 per cent. of sulphur. As it leaves the table it contains from 3 to 4 per cent.

of ash and from 1.2 to 1.4 per cent. of sulphur. The refuse amounts to about 4 per cent. of the total and it carries 40 to 50 per cent. of ash and from 10 to 15 per cent. of sulphur, the remaining 35 to 40 per cent. being coal. Inasmuch as the coal contains one per cent. of organic sulphur, the results may be regarded as very good.

Any process of washing leaves the coal saturated with water, which is sometimes an objection owing to the amount of heat required in the coke oven to evaporate the moisture, but with many coals and in by-product ovens, the coke is much improved by using wet coal, so that there is no loss from this cause.

The purification of coal is of great importance in Alabama, both on account of the high percentage of ash and the high content of sulphur, and the adoption of good methods are advocated in a report of the Alabama Geological Survey by Wm. B. Phillips. He cites instances of proper washing, where coal averaging 17.69 per cent. of ash was brought down to an average of 6.72 per cent. The coke from untreated coal ran from 1.50 to 1.75 per cent. in sulphur, while with washed coal it averaged 0.74 per cent. over a period of six months.

Sec. IXg.—*General remarks on fuel utilization.*—The present condition of the steel industry is far from satisfactory in regard to fuel utilization. Of late years, however, much attention has been given to this subject and newer plants have been constructed with good equipment. Much attention has been given to this subject in some German plants, as, for instance, in the new works at Rombach, designed by Mr. Oswald, which is supplied with the most efficient boilers and engines, with steam superheaters, with a most complete electric outfit, while gas engines driven by furnace gas are being introduced.

A reduction in the amount of fuel can be effected in many ways.

a—*Power Fuel.*

(1) By the introduction of gas engines driven by blast furnace gas, or by gas from coal, whereby a much greater amount of power can be developed from a given amount of fuel. This change is now imminent, but is delayed by the great cost of the installation.

(2) By the use of the best compound condensing engines.

(3) By a proper equipment of boilers supplied with economizers.

(4) By better regulation of combustion in the boilers.

(5) By the use of high steam pressures.

(6) By the use of superheaters.

(7) By the use of a central power station of both boilers and engines to create power and to distribute electricity to all parts of the plant.

(8) By driving all pumps and small machinery, table rollers, etc., from this plant.

(9) By driving all rolling mills from a central power station, the rolling mills being driven by a motor. This change will come in the future.

b—*Furnace Fuel.*

(1) By the direct rolling of material, thereby avoiding extra heating. This is much more common in Europe than in America.

(2) By devices for quick handling to avoid cooling of the piece.

(3) By saving the heat in the escaping gases from regenerative furnaces by making the chambers larger.

(4) By saving the heat in the escaping gases from reverberatory furnaces, either by absorbing the energy in boilers, or in the entering blooms, as in the case of continuous furnaces.

The sum total of all these possible economies represents a dividend on the whole plant.

CHAPTER X.

THE ACID OPEN-HEARTH PROCESS.

SECTION Xa.—*Nature of the charge in a steel-melting furnace.*—In acid open-hearth practice the shell is first lined with nine inches or more of clay brick. The furnace is then heated to nearly the working temperature, and sand is spread in successive layers over the entire hearth. Each layer is heated to a full heat for about ten minutes or until it is "set" so as to be hard, the sand being selected so that it will give as dense and solid a bottom as possible. When finished, the thickness of the lining within the shell should be from 18 to 24 inches.

The area of the cavity for holding the charge will be determined by the size of the furnace, for the depth of the metal should be about 12 to 15 inches in a 5-ton furnace and from 18 to 24 inches when the charge is 30 to 50 tons. If the bath is very shallow, the oxidation is excessive, while if very deep, the rate of melting is slow.

The proportions of the constituents of the charge vary in different places. Sometimes pig-iron alone is used, but when scrap can be obtained it forms part of the mixture. It is always necessary, however, to have a certain amount of pig-iron as a source of supply of the foreign elements, which protect the iron from oxidation. The stock must be of known composition as far as sulphur and phosphorus are concerned, for there is no appreciable elimination of these elements, and the finished product will show a percentage equal to the average of the material charged.

The content of silicon, manganese and carbon is not limited by such narrow bounds, for these elements are oxidized during the process and their presence in greater or lesser amounts alters the working of the charge rather than the composition of the product. In the manufacture of soft steel it is the usual practice, when scrap is available, to regulate the proportion of pig-iron so that the melted bath shall be free from silicon and manganese, and shall contain from three-fourths to one per cent. of carbon. During the elimination of this element, the metal is in a state of continual ebullition, and its temperature and condition, as well as the character of the slag, may be completely controlled in preparation for recarburizing and casting.

If too small an amount of pig-iron is used in making up the charge, the molten bath will contain neither silicon, manganese, nor carbon, and will be viscous and pasty. Such a mass will be oxidized by the flame and the oxide of iron will scorify the bottom. At some furnaces it has been the custom to first charge and melt the pig-iron and then add scrap which has previously been heated in a separate furnace, but this practice is expensive and possesses no advantages over the charging of the entire heat at one time.

SEC. Xb.—*Chemical history of an acid open-hearth charge during melting.*—The amount of oxidation which takes place during melting is affected by many conditions, being increased by the presence of hydrogen in the gas, by a sharp flame, and by a port construction that allows free air to impinge upon the metal. It is also determined in great measure by the manner in which the stock is charged. The pig-iron should be spread as evenly as possible over the scrap, so that it will melt first and trickle over the hot steel, and thus each atom of iron will be protected by the contiguity of an atom of silicon or carbon for which the oxygen has a greater affinity.

Practically it is impossible to obtain perfect protection, and when only a small proportion of pig is used there will be spots where the scrap is entirely uncovered, and in these places large amounts of iron oxide will be produced. If this cinder forms a pool on the viscous surface of the charge, it will be mixed sooner or later with high-carbon metal, and an interchange will occur with reduction of iron, the result being the same as if mixture had taken place at an earlier stage; but if the fused oxide comes in contact with the hearth, scorification will ensue with formation of silicate of iron, and though at a later period this scoria may be mixed with high-carbon metal, the harm cannot be completely remedied. A portion of the iron may, perhaps, be reduced and a higher silicate be formed, but silica once having entered the slag is there to stay, and will permanently hold a greater or less amount of iron oxide.

The value of the elements found in pig-iron in protecting the scrap from oxidation will be in proportion to their ability to unite with oxygen. Calculating this we have the following table:

1 unit of carbon combines with 1.333 units of oxygen to form CO.
1 unit of silicon combines with 1.143 units of oxygen to form SiO_2.
1 unit of manganese combines with 0.291 unit of oxygen to form MnO.
1 unit of titanium combines with 0.176 unit of oxygen to form TiO_2.

This table represents a very broad truth, but it must not be translated too literally, for some elements are preferable to others. It is necessary that after melting the metal should be protected from the flame by a layer of slag containing about 50 per cent. of silica. If the charge is made up of one-quarter pig-iron carrying 1 per cent. silicon, the silica produced by oxidation, the sand attached to the pig-iron, and the material derived from the scouring of the hearth, are usually sufficient for the requirements of the cinder, but with very low-silicon pig-iron, free from adhering sand, it may be necessary to add additional silica to prevent the basic slag from making inroads upon the bottom. On the contrary, if the silicon in the pig-iron is very high, the slag will be viscous and infusible. The presence of manganese helps to counteract this viscosity, but in the absence of this element iron oxide must be added in the shape of ore, or formed from the bath by waste of iron.

TABLE X-A.

Elimination of Metalloids in an Open-Hearth Charge.

Nature of Sample.		Group I.	Group II.
Pig-iron pounds		11,700	20,700
Steel Scrap, pounds		45,550	36,800
Composition of original charge, per cent. (estimated)	Si	0.40	0.65
	Mn	0.90	0.85
	C	1.00	1.50
Metal when melted, per cent.	Si	.02	.05
	Mn	.09	.06
	C	.54	.64
Slag after melting, per cent.	SiO_2	50.24	49.46
	MnO	21.67	13.16
	FeO	23.91	33.27

The way in which the metalloids are eliminated during the melting will be best understood from the typical records given in Table X-A. Each column represents the average of a group of consecutive charges; Group I includes nineteen heats melted with soft-coal producer gas, and Group II six heats made with oil vapor.

It will be seen that the oil vapor is much more oxidizing than the coal gas, so that although the original charge was very much higher in oxygen-absorbing elements, the bath after melting had about the same composition in both cases. The slag shows a great variation in the oxides of iron and manganese; this arises from the fact that the amount of manganese was limited by the content in the charge, and since the slag required a certain proportion of bases, the deficit was made up by oxidation of iron.

SEC. Xc.—*Chemical history of an acid open-hearth charge after melting.*—After the melting it is necessary to oxidize the remaining carbon, manganese, and silicon, by keeping the bath at a high heat and adding iron ore in successive doses, thus forming silica and oxide of manganese which go into the slag, and carbonic oxide which escapes with the flame. This combustion of carbon produces a bubbling over the entire surface of the bath, continually exposing the metal to the flame, and aiding materially in keeping it at a high temperature. The union of the oxygen of the ore with the silicon and carbon sets free metallic iron which is immediately dissolved by the bath.

If the ore is added properly, it is reduced as fast as it is put in, as will be evident from Table X-B, which shows the history of the metal and the slag in the groups above considered. In Group I an average of 1020 pounds of ore was used on each heat to decarburize, while on Group II only 850 pounds was added. It will be seen that in spite of the addition of the ore the character of the slag remains unchanged. There is an increase of FeO, but this does not show an increase in basicity, for the volume of slag is increasing throughout the operation both from the wear of the hearth and the silica from the ore, so that in order that the composition of the slag should remain absolutely the same it would be necessary that there be a simultaneous supply of exactly the right proportions of both MnO and FeO. It is evident that this cannot happen, for the metal after melting is nearly free from manganese, and since the ore contains none there is no source of supply of this element. With the dilution of the slag, therefore, there is a vacancy left for a base, and iron oxide is the only available candidate. That this is the true explanation will be seen from the totals of MnO and FeO, which show that the slag at the end of the operation is almost identical with the slag after melting, since the sum of these factors represents the real basicity of the cinder.

TABLE X-B.

History of Metal and Slag in an Acid Open-Hearth Furnace.

Subject.		Composition, per cent.			
		Group I. 19 heats soft coal gas.		Group II. 6 heats oil gas.	
		After melting	End of operation.	After melting.	End of operation.
Metal.	Si	.02	.02	.05	.01
	Mn	.09	.04	.06	.02
	C	.54	.13	.64	.12
Slag.	SiO_2	50.24	49.40	49.46	49.36
	MnO	21.67	16.50	13.16	11.30
	FeO	23.91	29.79	33 27	34.11
	MnO+FeO	45.58	46.29	46.43	45.41

SEC. Xd.—*Quantitative calculations on acid open-hearth slags.*—The foregoing results are purely qualitative, and they do not show the alteration in the amount of the slag which takes place during the progress of the operation. It will be evident that it is out of the question to actually weigh the cinder at different periods, but, nevertheless, it is possible to approach the truth by the following method: The final slag, after tapping, is weighed when cold. By subtracting from this weight the MnO produced by the addition of the recarburizer and the sand derived from the taphole and ladle-linings, the amount of slag which was in the furnace before tapping may be computed. Given the analysis of the slag at that time, it is easy to calculate the weight of its various constituents, among which will be the manganese; if the ore contained no appreciable quantity of this element, the amount which in one form or another was present throughout the operation will be known; and since the percentage of manganese in the slag and in the metal can be determined by analysis, and the weight of the metal can be calculated for any stage of the work, all the requisite data are at hand for a determination of the weight of the slag at any time. With this determination as a basis, the quantitative estimation of the factors is a matter of simple arithmetic.

This process applied to the two groups of heats in Table X-B gives the results shown in Table X-C, where it is shown that although nearly twice as much pig-iron was added in Group II, as recorded in Table X-A, the greater oxidizing power of the oil flame took care of this extra amount, the result being plainly seen in the greater quantity of slag which was present after melting. When the bath was thoroughly fluid, the oil flame still acted more powerfully, but it was unable to burn any of the iron since the metalloids furnished ample protection, and the increase in the weight of slag during oreing is no greater in the one group than in the other. In

TABLE X-C.

Calculation on the Weight of Certain Open-Hearth Slags Mentioned in Table X-B and the Amount of FeO Reduced During Oreing.

Subject.	Group I.	Group II.
	Coal gas, pounds.	Oil gas, pounds.
Slag after tapping	4050	5670
Slag after melting	2810	4530
Ore added	1020	850
FeO in ore added	643	536
FeO reduced during oreing	336	313

Group I, 41 per cent. of the ore was reduced, while in Group II there was 45 per cent. These figures have no general significance, for, if the slag is slightly viscous after melting, a certain amount of ore will be necessary to confer fluidity and will not be reduced. Since this quantity will be a constant under given conditions no matter how much ore is afterward needed, it will be evident that it might be 90 per cent. of a small addition and only 10 per cent. of a large one.

SEC. Xe.—*Reduction of iron ore when added to an acid open-hearth charge.*—This reduction of ore is a matter of vital importance in using large proportions of pig-iron. Quite an amount of oxide is then necessary to satisfy the silicon of the pig as well as the sand adhering to it, but after the slag is formed there is no increase in its volume except from the impurities in the ore and the wear of the hearth, so that as fast as the ore is added its oxygen is transferred to the metalloids and its iron to the bath. This may be illustrated by Table X-D, which gives the records of heats which are not included in the tables just given, on each of which 1500 pounds of ore were added after melting to decarburize the metal.

TABLE X-D.

Data on Open-Hearth Slag and Metal at Different Periods of the Operation.

COMPOSITION OF THE SLAG.

Pounds of ore added.	Constituents, after addition of ore as shown in first column.	Number of Heat.				
		7596	7598	7606	7635	Average
None.	SiO_2, per cent.	50.27	51.96	52.43	52.94	51.90
500	“ “	49.27	51.10	55.82	51.72	51.98
1000	“ “	52.77	50.30	55.73	52.28	52.77
1500	“ “	50.97	51.48	55.66	52.90	52.75
None.	MnO, per cent.	14.91	21.65	15.61	21.84	18.50
500	“ “	15.20	19.09	15.31	20.44	17.51
1000	“ “	14.70	17.50	13.89	19.06	16.29
1500	“ “	14.22	16.72	12.40	16.36	14.92
None.	FeO, per cent.	31.23	22.59	27.14	23.18	26.03
500	“ “	30.68	26.12	25.11	24.21	26.53
1000	“ “	26.96	28.26	26.20	26.26	26.92
1500	“ “	31.70	26.03	26.96	29.13	28.45
None.	FeO and MnO, per cent.	46.14	44.24	42.75	45.02	44.54
500	“ “	45.88	45.21	40.42	44.65	44.04
1000	“ “	41.66	45.76	40.09	45.32	43.21
1500	“ “	45.92	42.75	39.36	45.49	43.38

COMPOSITION OF THE METAL.

Heat No.	Silicon, per cent.				Manganese, per cent.			
	After adding ore, as below.				After adding ore, as below.			
	None.	500 lbs.	1000 lbs.	1500 lbs.	None.	500 lbs.	1000 lbs.	1500 lbs.
7596	.07	.01	.01	.01	.10	.02	.02	.02
7598	.04	undet.	undet.	.01	.02	.02	.02	.02
7606	.04	.05	.03	.02	.08	.05	.03	trace.
7635	.13	.07	.05	.06	.19	.08	.09	.10

Samples were taken of metal and slag after every 500 pounds of ore. These groups and heats were not selected to show this special action, the investigation being made for other purposes; but the wonderful regularity in results, corroborated as it is by many other records, shows that in the magnificent alembic of the melting furnace, at the highest heat we know save that of the electric arc, at a temperature when wrought-iron melts like wax in the candle flame, the molecular relations are guided by fixed and unalterable laws. It is this stability of conditions that gives to the open-hearth melter the ground on which he can work out regular and reliable results, and which makes the process peculiarly fitted for the manufacture of structural material.

SEC. Xf.—*Pig-and-ore process.*—The amount of ore required for a charge will not follow closely the amount of carbon, since the flame is constantly at work, and ore is added when the melter thinks it advisable rather than when it is absolutely necessary. If the charge is hot it dissolves the ore rapidly and there is little chance for the flame to do its share of oxidation, while if the charge is cold only a small amount of ore will be added and the oxygen will be derived from the gases. Thus any attempt to make an arbitrary equation of the action must fail, but it may be broadly said that if the bath contains 1 per cent. of carbon, 1500 pounds of ore may be used in bringing it down to .05 per cent. The first 500 pounds will reduce it to about .80 per cent. of carbon, the second to .40 per cent. and the third will finish the work. If silicon and manganese should be as low during the interval between the first and second ore additions as at a later time, the burning of the carbon might be the same then as later, but either the presence of these protectors or the less favorable physical condition of the slag in a high-carbon bath retards the action at the start. When large quantities of high-silicon or high-manganese pig-iron are used, the first additions of ore are consumed by the unburned excess of these elements, and hundreds and even thousands of pounds of ore may be added after melting before the carbon is affected. Therefore, when it is necessary to charge nothing but pig-iron, it is advisable to have it contain as little silicon as possible, and even then the oxidation of carbon requires several hours. The ore is not lost, for the reduced iron makes up for the metalloids which are burned, so that the weight of the steel may equal or exceed the weight of the pig-iron charged.

The expense of the pig-and-ore process rests in the slow combustion of carbon, for it is impossible to hurry the work without causing violent boiling of the voluminous slag, producing scorification of the hearth and possibly a loss of metal through the doors. The process upon an acid hearth is much slower than on a basic bottom, for in the latter case a slag rich in iron does not have such disastrous results upon the hearth. Since the fuel consumption per hour is nearly the same during the period of oreing as it is during the period of melting, it is plain that there is a considerable decrease in product with an increased fuel ratio. By the use of a tilting furnace this difficulty may be lessened, for as soon as the silicon has been oxidized, the contents of the furnace may be emptied into the ladle and then the metal be immediately returned to the furnace with as little slag as desired. When most of the slag is thus removed, the action is much more rapid and there is no trouble from frothing. The tapping of slag from stationary hearths has always resulted unsatisfactorily, and the same is true of attempts to remove it from a tilting furnace by surface decantation, but this process of repouring requires no handling save the raising of the ladle in a vertical line so as to allow the metal to be returned to the furnace through the same hole from which it has just been tapped, and seems to solve the question of slag removal in a simple way.

SEC. Xg.—*Conditions modifying the character of the product.*—If the temperature of the metal is very high, the last traces of silicon will not be oxidized, for the affinity of silicon for oxygen is a function of the temperature. In the Bessemer converter the metal may contain as much as 1 per cent. of silicon if blown sufficiently hot, but in the open-hearth there is no chance for the bath to arrive at an intense degree of heat as long as a considerable percentage of this element is present; for superheating is not readily attained without a lively bath, and the bath will very seldom be lively as long as it holds a high content of silicon. Thus the open-hearth cannot rival the converter in producing high-silicon metal by non-combustion, but under suitable conditions the amount carried along in the metal may be quite appreciable, and, by holding the bath at a very high temperature with a silicious slag, there will even be a reduction of the silica of the hearth according to the equation

$$SiO_2+2C=Si+2CO.$$

This variation in affinity of Si for O plays an important part in the production of steel castings where a higher temperature is used than for ingots of ordinary size. The constant presence of a small proportion of silicon, due to the high temperature, tends to prevent the absorption of gases, and it is stated by Odelstjerna* that if at any time the metal is allowed to cool so that the last traces of silicon are burned, the gases which are absorbed cannot be expelled by a subsequent superheating.

I am of the opinion that Odelstjerna is correct in his statements, but that there may be other factors involved in a full explanation. It is certain that in the manufacture of small ingots which are to be rolled directly into plates, there are delicate adjustments of temperature and slag that are not easily explained by considering the history of silicon alone.

One of these factors, which may be cited by way of illustration,

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* *Trans. A. I. M. E.*, Vol. XXIV, p. 308.

is the extent and force of the oxidizing influence. It is the opinion of some metallurgists that the best quality of open-hearth steel can only be made when the burning of the metalloids is carried on at a very slow rate, so that the bath shall not contain an excess of oxygen at any time, and it is stated by Ehrenwerth* that a certain American works makes a practice of keeping a charge in the furnace a very long time when a very good quality of steel is desired. As a matter of fact, the works in question did carry out such a system at one time out of respect to foreign tradition, but found no advantage in so doing, and has long since discontinued the practice.

It is also an opinion, held by men of acknowledged reputation, that a high proportion of pig-iron in the original charge will give a superior product. If this is true, it probably arises from the fact that the presence of a high proportion of carbon after melting, with the consequent long exposure to the flame, will result in a thorough washing of the bath. I believe that there is a limit to this action, and that very little can be gained by raising the content of carbon in the melted bath above 1 per cent., for this proportion insures a vigorous boil.

It is difficult to see how the condition of the bath, after it has been run down from 1 per cent. of carbon to three-tenths of 1 per cent., can be any different from the condition which would have existed if the original content had been 2 per cent. It would seem probable that one or two hours of exposure of the completely liquid bath to the flame would give ample opportunity for any reactions which could be in progress, and the old adage that "enough is as good as a feast" might be applied to the present case. It is not unprofitable, however, to consider the conclusions from practical experience, however invalid they may appear, for they may sometimes represent a vital truth, albeit our point of view may not be high enough to allow a complete survey of the field.

SEC. Xh.—*History of sulphur and phosphorus.*—In the above records no account is taken of sulphur or phosphorus, but numerous determinations and universal experience prove that the content of phosphorus in the steel will be determined by the initial content in the charge. It is true that acid open-hearth slag may contain some phosphorus, and I have found one case where it held 0.04

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* *Das Berg- und Hüttenwesen auf der Weltausstellung in Chicago.* Ehrenwarth, 1895, p. 276.

per cent., but it would require a higher percentage than this to make a difference in the metal that could be detected by ordinary analysis, so that for practical purposes it must be assumed that every molecule of phosphorus that is present in the pig-iron, scrap and ore will appear in the finished metal.

The percentage of sulphur cannot be predicted with so much precision. Traces of this element may be burned during melting and pass away as sulphurous anhydride, but the proportion thus eliminated is small. On the other hand, there is a tendency to absorb sulphur from the flame. With fairly good coal this increment may be neglected, but with bad coal, and especially when the slow working of the furnace renders it necessary to expose the charge to the gases for a long time, the amount thus absorbed may be ruinous. It has been suggested with some reason that the addition of lime in the producer might retain at least a part of the sulphur in the ashes of the producer, so that it would not appear in the gas, but it would also give trouble by making a fusible ash. The ore is another source of contamination, for it generally contains a certain proportion of pyrites. As the ore floats on the surface of the bath some sulphur may be oxidized above the surface and the products pass away with the flame, but the remainder will be absorbed by the bath.

SEC. Xi.—*Method of taking tests.*—The condition and nature of the metal and slag are determined from time to time by taking samples from the furnace by means of a small ladle and casting test-ingots with a cross-section about one inch square. These are chilled in water and broken, and the carbon is estimated from the appearance of the fracture. The reliability of such a determination depends upon the constancy of the conditions of casting and chilling, and the expertness of the judge, but, roughly speaking, the content can be ascertained within 10 per cent. of the true amount.

SEC. Xj.—*Recarburization.*—When the desired point has been reached the recarburizer is added, this being almost invariably used in a solid state. It is generally heated red hot, but this is not essential, for, in making structural steel, "ferro" containing 80 per cent. of manganese is used almost exclusively, and the weight of the addition is so small that it chills the bath only slightly. The ferro may be added to the metal while in the furnace, and this method has the advantage that the bath can be thoroughly stirred after the recarburizer has melted, but it has the disadvantage that during the time the last pieces are fusing, the portions which melted first are losing their manganese to the oxygen of the slag and flame. In a hot furnace this action is very rapid, and although the entire addition may melt in less than a minute, a considerable proportion of manganese is lost by oxidation.

When the recarburizer is added in the ladle, it is evident that the latter action will not occur, but there will be a certain loss on account of the oxide of iron contained in the metal, and the function of the recarburizer is to remove this oxygen. The loss of manganese will be the same whether the addition is made in the furnace or in the ladle, but in the latter case the effects of slag and flame are absent. Hence it follows, all other things being equal, that the loss will be more regular when recarburization is performed in the ladle, and this is equivalent to saying that the content of manganese in the steel can be made more nearly alike throughout a series of heats.

The amount of manganese lost in recarburization not only varies with the way in which it is added, but also with the percentage of carbon and manganese in the bath. As would naturally be supposed, the amount of oxide in the bath is less with high than with low carbons, and so therefore the loss of manganese in recarburizing decreases as higher steel is made. It is found that the loss is less with smaller percentages of manganese, so that with the same bath, if 1.00 per cent. of Mn be added, there will be .60 per cent. in the metal, being a loss of .40 per cent., while if .50 per cent. be added the steel will have .40 per cent., being a loss of only .20 per cent. It seems as if with the lower manganese the action was not perfect, and that with each successive increment of ferro an additional atom of oxygen is removed. This fact holds good whether the recarburizer is added in the furnace or in the ladle.

The fear of non-homogeneity under the practice of adding the ferro in the ladle is not entirely unfounded when small heats are made and the metal is not very hot, but when charges of 20 to 50 tons of hot steel are properly poured and recarburized, the steel is thoroughly uniform. When metal is made very high in manganese, certain precautions must be taken, but in ordinary structural steels, when the manganese runs below .65 per cent., there is an all-pervading action throughout the melted mass which dispels all thought of non-homogeneity.

SEC. Xk.—*Advantages of the open-hearth process in securing homogeneity.*—In the low steel of the Bessemer process there is very little trouble from irregular distribution, although the more viscous slag sometimes holds pieces of the solid recarburizer and keeps them from melting until the steel is nearly all poured. The result is that when they do finally fuse, small streams of high manganese metal flow down into the upper part of the last ingot and form a hard spot in the steel. This does not and should not often happen, and most Bessemer soft steel is uniform throughout. In making high-carbon steel, however, the conditions of manufacture make the hearth far superior to the converter. The metal in the Bessemer process is always blown until nearly all the carbon is eliminated, since it has been found impracticable to stop the operation at any definite intermediate point. All the carbon content of the steel, therefore, must be added in the recarburizer, and absolutely perfect homogeneity can only be secured by absolutely perfect mixing. In the open-hearth, on the other hand, high-carbon steels are made by interrupting the process at the desired stage, and it is plain that no mixing is required as far as carbon is concerned, and about the same quantity of recarburizer will be used for a given manganese whether high or low steel is being made.

CHAPTER XI.

THE BASIC OPEN-HEARTH PROCESS.

SECTION XIa.—*Construction of a basic open-hearth bottom.*—The basic process, as herein discussed, consists in treating a charge of either melted or solid pig-iron, or a mixture of pig-iron and low-carbon metal, upon a hearth of dolomite, lime, magnesite, or other basic or passive material, and converting it into steel in the presence of a stable basic slag by the action of the flame, with or without the use of ore, and by the addition of the proper recarburizers, the operation being so conducted that the product is cast in a fluid state.

In the above specification that the slag shall be stable, no recognition is accorded that hybrid practice wherein a little lime is thrown into an acid furnace, near the end of the operation, with the intention of removing a part of the phosphorus by the temporary and uncertain action of a partially basic slag. Regular metallurgical results can only be obtained under regular conditions, and to this end the hearth should be made of material that will not be scorified by basic additions. The current belief that the lining of the bottom is the dephosphorizing agent is a complete mistake, for the highest function of the hearth is to remain unaffected and allow the components of the charge to work out their own destiny. In practice it is never possible to construct either an acid or a basic bottom so that it is entirely passive, for a slag which is viscous with silica will slowly attack a pure sand bottom, and a cinder which is mucilaginous with lime will gradually eat into a dolomite hearth.

For the construction of a permanent bottom, carbon, bauxite, lime, chromite, magnesite and dolomite, have been used. Magnesite gives the best results but it is very costly, and well-burned dolomitic limestone answers well enough. In some places the stone is used in its natural state, but this is a doubtful economy, the better plan being to thoroughly roast it in a kiln or cupola and then grind and mix with tar. The roof and walls being made of silica bricks, it is necessary to have a joint of chromite or other passive material between the acid and the basic work; but it must be understood that at the intense heat of a melting furnace, and in an atmosphere charged with spray of iron oxide, almost any two substances will unite if pressed together, so that the part of the joint which bears the weight of the superposed brickwork must be shielded from the direct action of the flame.

SEC. XIb.—*Functions of the basic additions.*—Given a hearth capable of resisting the action of metal and slag, the problem of the basic furnace is the melting and decarburization of iron as in acid practice, with the additional duty of removing a reasonable quantity of phosphorus and some sulphur. Under the oxidizing influence of the flame and ore, the phosphorus is converted into phosphoric acid (P_2O_5) which can unite with iron oxide, but the conjunction will be only temporary, for the carbon of the bath reduces the iron, leaving the acid helpless, and then the phosphorus in its turn is robbed of its oxygen and returned to the bath. But if lime is added, the acid can form phosphate of calcium, and since the oxide of this element cannot be reduced by the carbonic oxide, the phosphorus is never left without a partner, but forms part of a stable cinder.

This oxide of calcium is sometimes added in the form of common limestone, the carbonic acid being expelled in the furnace. It will be evident that this entails a considerable absorption of heat, and the melting must be delayed accordingly, but it has a compensating advantage in that the gas, in bubbling through the metal, keeps up a motion which facilitates chemical action, and also that the carbonic acid gives up part of its oxygen to the silicon, phosphorus, carbon and iron.

This oxidizing action allows the use of a greater proportion of pig-iron, and also aids in the removal of phosphorus, so that there seems to be good ground for using the cheap natural stone. I believe, however, that it is more economical to put it through a preliminary roasting and reduce by nearly 50 per cent. the amount of basic addition, for the rate of melting is thereby hastened, while the oxidizing effect can be obtained by the use of ore. It is true that ore costs more than stone, but, on the other hand, its full value is returned in metallic iron, and, moreover, it is possible to use a greater proportion of pig-iron on account of the reduced quantity of gas evolved, for the amount of oxidation done during melting, either by stone or ore, is limited by the frothing of the stock, and this is evidently determined by the amount of gas evolved in the reactions. Therefore, if ore produces less gas than stone in oxidizing a given quantity of carbon, then more pig can be used with ore than with stone. The reactions are as follows:

Limestone, $CaCO_3+C=2\ CO+CaO$.
Ore, $Fe_2O_3+3\ C=3\ CO+2\ Fe$.

Thus two volumes of gas are formed for each atom of carbon when stone is used, while only one volume is produced with ore.

The available oxygen in the ore is nearly twice as much as in the same weight of stone, so that by using a mixture of 500 pounds of burned lime and 500 pounds of ore, there will be the same quantity of basic earth, and the same oxidizing effect, as with 1000 pounds of raw stone, while there will be only half as much gas produced with a contribution of 300 pounds of metallic iron.

SEC. XIc.—*Use of ore mixed with the initial charge.*—The ore and lime are put into the furnace with the pig and scrap, so that the hearth will be protected during the melting and an active cinder be at work continuously. When high-phosphorus stock is used, the amount of oxidation to be done for a given weight of pig-iron is much greater than in acid practice. Thus in 10,000 pounds of low-phosphorus iron for an acid open-hearth, the oxygen absorbing power is as follows:

1.0 per cent. silicon=100 pounds Si, absorbing 114.3 pounds oxygen.
3.5 per cent. carbon=350 pounds C, absorbing 466.7 pounds oxygen.

Total oxygen absorption, 581.0 pounds

If pig-iron be used in basic work with the same content of silicon and carbon, but with the addition of 1.00 per cent. of phosphorus, there will be an additional absorptive power of 129 pounds of oxygen or a total of 710 pounds. If the first mixture were put into a furnace there would be about 40 per cent. of the work done during the melting (under the conditions shown in the preceding chapter), so after melting there would remain 60 per cent. of 581, or 349 pounds of oxygen to be given to the bath. In the second case, it is evident that the presence of phosphorus will not cause a greater action during melting, but that if all other conditions are similar, the total absorption will be the same, so that, after melting, the phosphoric bath will have an absorptive power of 349+129=478 pounds of oxygen, and there will be one-third more work to do during the period of oreing with the same proportion of pig.

These figures may seem somewhat abstruse, but they explain the very important fact that there is much more oxidation to do with phosphoric iron than with good stock, so that it is advisable to use ore mixed with the charge to perform a part of the work during fusion. On an acid hearth, when running exclusively on pig-iron, ore is sometimes added with the original charge, but there is always danger of this oxide uniting with the sand of the hearth before the metalloids can reduce it. In basic practice, on the contrary, the ore can do no harm, for it has little effect on the dolomite and soon reacts upon the silicon, phosphorus, and carbon.

TABLE XI-A.

Average Composition of Slag and Metal from Seventeen Basic Heats.

Test.	Metal.				Slag.					
	Composition, per cent.				Composition, per cent.					
	C.	Si.	Mn.	P.	SiO_2.	MnO.	CaO.	MgO.	FeO.	P_2O_5
A	.71	.06	.33	.046	19.21	11.12	42.16	6.64	13.68	5.149
B	.34	.01	.25	.022	16.37	10.36	42.78	7.87	16.29	4.848
C	.12	.01	.22	.013	15.08	9.01	42.16	8.45	20.34	3.850
D	.16	.01	.49	.018	15.75	14.11	39.05	10.40	16.65	2.961

SEC. XId.—*Chemical history of basic open-hearth charges when no ore is mixed with the stock.*—The addition of ore is not necessary when sufficient scrap is available, for the flame will supply oxygen to the metalloids, as will be shown by Table XI-A, which gives the average history of 17 heats when no ore was used with the original charge, and when tests of metal and slag were taken at four different epochs. The heats were all similar in character and were operated under similar conditions, and therefore the mixing of slags and metals to obtain average results is justifiable. Each charge was made up of about one-half pig-iron and one-half steel scrap, and contained 2.00 per cent. carbon, 0.40 per cent. silicon, 0.85 per cent. manganese, and 0.20 per cent. phosphorus. Tests of slag and metal were taken as follows:

(*A*) After complete fusion of metal without ore.

(*B*) At beginning of boil, after the addition of 1965 pounds of ore per heat.

(*C*) When the bath was ready for the recarburizer, 775 pounds of ore being added per heat between tests *B* and *C*.

(*D*) After casting.

SEC. XIe.—*Elimination of phosphorus during melting.*—The elimination of phosphorus during melting is a variable, depending upon the conditions of oxidation and the ability of the slag to absorb the phosphoric acid. Table XI-B will show in a general way the proportions of carbon and phosphorus that are oxidized during melting under different kinds of practice.

TABLE XI-B.

Elimination of Phosphorus and Carbon During Melting Upon a Basic Hearth.

Group.	Pounds of ore charged with stock, per ton of metal.	Number of heats in group.	Composition of metal, per cent.						Composition of slag after melting; per cent.	
			Phosphorus.			Carbon.				
			Initial.	After melting.	Per cent. eliminated.	Initial.	After melting.	Per cent. eliminated.	SiO_2.	FeO.
1	none.	17	0.20	.046	77	2.00	.71	65	19.21	13.68
2	none.	4	1.36	.594	57	1.50	.60	60	14.90	und.
3	none.	9	0.19	.023	88	1.80	.27	85	15.55	19.68
4	none.	9	0.19	.072	62	1.80	.78	57	19.98	12.20
5	300	3	2.50	.744	70	3.50	.59	83	11.96	8.61
6	115	6	0.55	.274	50	2.90	1.00	66	30.73	10.71
7	140	7	0.55	.402	27	2.90	1.48	49	34.22	10.95

SEC. XIf.—*Composition of the slag after melting.*—Neither the percentage nor the total amount of elimination during melting is a matter of vital importance, for whatever work is left undone during that period will be completed before tapping. In this removal of phosphorus after fusion, the composition of the slag is the important factor, and this will depend, primarily, upon the amount of silica, and, secondly, upon the lime added. The total supply of silica will determine the quantity of lime, and it will also determine the weight of the resultant cinder. Thus, if the final slag is to contain 16.67 per cent. of SiO_2 and 50 per cent. CaO, it is evident that the basic additions must contain $\frac{50.00}{16.67}$=three times as much available CaO as there is SiO_2 in the entire charge, and also that the final slag will weigh six times as much.

The composition of the cinder differs considerably, for when good stock is used it may contain over 20 per cent. of silica and still be capable of eliminating the impurities, but when much phosphorus is to be removed, the silica must sometimes be as low as 12 per cent., the proportion of CaO usually varying inversely with the silica. The amount of lime which can be taken up is limited, for at a certain point the slag becomes viscous, particularly when the scorification of the hearth supplies magnesia. Allowing for about 10 per cent. of MnO, 8 per cent. MgO, 18 per cent. FeO, and 4 per cent. Al_2O_3, etc., it may be roughly stated that with 12 per cent. of SiO_2 there will be about 48 per cent. CaO, while with 20 per cent. of SiO_2 there will be 40 per cent. CaO. In the attainment of this ratio between SiO_2 and CaO the purity of the lime is an important factor, especially when a slag low in silica is needed. Ordinary lime as it comes from the kiln contains a certain unexpelled percentage of CO_2, and, in the handling and exposure prior to use, it absorbs a certain amount of moisture, so that with the usual proportions of earthy impurities it will average about 80 per cent. of CaO.

SEC. XIg.—*Relative value of limes as determined by their chemical composition.*—The content of SiO_2 in the lime depends entirely upon the kind of stone used and the care with which the ash of the fuel is kept separate. When a choice must be made between a cheap and impure lime and a more costly article low in silica, the value of each may be calculated by finding the excess of CaO over what is necessary to satisfy its own acids. Two representative limes are assumed in Table XI-C, both containing 80 per cent. CaO, one with 3 per cent. and the other with 7 per cent. SiO_2, and the computation is made for two different slags.

TABLE XI-C.

Relative Values of Limes with 3.0 and 7.0 Per Cent. of SiO_2.

	Slag A.		Slag B.	
	Lime with 3 per cent. SiO_2.	Lime with 7 per cent. SiO_2.	Lime with 3 per cent. SiO_2.	Lime with 7 per cent. SiO_2.
SiO_2 in slag; per cent.	12.0	12.0	20.0	20.0
CaO in slag; per cent.	48.0	48.0	40.0	40.0
Ratio CaO to SiO_2 in slag	4.0	4.0	2.0	2.0
Total CaO in lime; per cent.	80.0	80.0	80.0	80.0
CaO in the lime which is needed to satisfy its own silica; per cent.				
4.0×3.0	12.0	......	......	......
4.0×7.0	......	28.0	......	......
2.0×3.0	......	......	6.0	......
2.0×7.0	......	......	......	14.0
CaO available for foreign silica; per cent	68.0	52.0	74.0	66.0
Relative value.	1.31	1.00	1.12	1.00

It will be seen that the pure lime is worth 31 per cent. more than the impure kind when a calcareous slag is to be formed, but if a more silicious cinder is permissible, as in the case when very little phosphorus is to be removed, the pure lime is worth only 12 per cent. more.

SEC. XIh.—*History of basic open-hearth slags.*—The proportions of SiO_2 and CaO are the main points in the construction of a basic slag, but there are other factors which exercise an important influence upon the result. Magnesia is always present from the wear of the hearth, but is rather undesirable, as it makes the slag viscous and has much less power to hold phosphorus than lime. Alumina comes from the impurities in the dolomite, lime and ore, but being usually in small amount may be neglected except when an analysis is expected to add up to 100 per cent. The same is true of the alkalies and small percentages of miscellaneous impurities. Manganese is usually present in the stock and serves a useful purpose in conferring fluidity upon the slag, so that, being a base itself, the total basic content can be higher than with a slag containing only silica and lime. It is also valuable in removing sulphur, for there is a tendency toward the formation of sulphide of manganese, which floats to the top of the metal where the sulphur, being exposed to the flame, is oxidized and passes away with the waste gases. This action is rather uncertain, and, in fact, the explanation is somewhat a matter of supposition, but it seems quite well proven that manganese, either metallic or in the form of ore, aids in the elimination of sulphur, and the above theory is in accord with certain well-known phenomena of liquation in the purification of pig-iron by the addition of spiegel, as described by Massenez.*

All the components thus far enumerated are in great measure fixed and determined agents in the transactions. It is true that manganese is sometimes reduced from the slag by the carbon of the bath, and also that a certain percentage may remain unoxidized in the metal, but aside from this it may be said that the oxides of aluminum, silicon and manganese exist in the slag in just the quantities that were added with the stock; but there are three other constituents, iron oxide, phosphoric acid, and sulphur, whose pres-

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* *On the Elimination of Sulphur from Pig-Iron. Journal I. and S. I.,* Vol. II. 1891, p. 76.

ence in the slag is determined by the conditions of manipulation and by the proportions of the other constituents.

Iron oxide is always present in greater or less extent, the exact amount depending upon the reducing power of the carbon of the bath. It matters not whether ore is added before melting, after melting, or not at all; there is a certain content of FeO which is demanded by the existing conditions, and that certain content will be present. An exception must be made in the case of ore added after the carbon is nearly eliminated, but aside from this there will be just as much iron oxide lost in the slag when no ore is used as when it has been added in proper quantity, and therefore it may be assumed that all the ore is a clear gain and that its iron is all reduced and added to the metallic bath.

The presence of iron oxide in either acid or basic slag is an anomaly, for in an ordinary acid charge it seems as if the oxidation of the silicon and manganese would be sufficient to produce a slag without other aid. Nevertheless we have found in the foregoing chapter that there is a force at work in an acid furnace which is constantly creating a slag with a composition of about 50 per cent. SiO_2 and 45 per cent. $FeO+MnO$. If more FeO is added, the carbon of the metal immediately seizes the oxygen and sets free metallic iron, but the same powerful action which so quickly accomplishes the destruction of this excess is not able to pass much below the limit even by exposure for hours without any addition of ore. There is an automatic adjustment to a fixed status which is one of the most wonderful phenomena of chemical physics. The only explanation I can offer is that it is an instance of the general law that all forces tend to work along the lines of least resistance, which, being interpreted for this case, means that a slag will seek to combine with anything that promotes fusibility. If given the opportunity a silicious slag absorbs either bases or silica, but preferably bases, and particularly those which impart the greatest fluidity. This action tends to continue indefinitely, and in an acid furnace, if the heat is not tapped after the carbon is burned, the formation of iron oxide will go on with great rapidity, and the fluidity of the slag will be greatly increased in spite of the cutting of the hearth. This latter action is a correcting condition, but it is not the controlling influence under ordinary circumstances, as is proven by the small amount of the scorification of the hearth during oreing. The real determinant is the carbon of the bath, and there is an equilibrium established between the oxidizing power of the flame, the reducing power of the metalloids, and the struggle after fluidity.

In the basic process there is a difficulty in making a slag composed entirely of silicate of lime, for this is much more viscous than a slag of the same percentage of silica containing other bases; there is a tendency, therefore, toward the absorption of iron oxide, but this is opposed by a contest on the part of the lime for the possession of the silica, and the result is a decrease in the percentage of iron when there is an increase in lime. Inasmuch as the substitution of CaO for FeO produces a more viscous slag, this would seem to invalidate the theory just advanced, but, as above indicated, the effect is due not to a change in the law but to the action of stronger forces. The more bases that are present, the less necessity is there for an additional amount, since the weight of silica necessarily remains constant, and, as the reducing action of the metalloids comes into play, the slag begins to be robbed of its iron, which at the same time is its most reducible and its most fusible base. The presence of oxide of manganese in the slag modifies without completely changing the relations just described, for, by furnishing an additional base and imparting greater fluidity, it tends to render the presence of iron oxide less necessary.

SEC. XIi.—*Automatic regulation of fluidity in basic open-hearth slag.*—This matter of fluidity is of vital practical importance, for the slag must run freely from the furnace, else the hearth will soon be filled; furthermore, the slag must be so basic that the hearth is not scorified. The two conditions, fluidity and basicity, determine the nature and amount of the basic additions, for the sum of CaO and MgO cannot much exceed 55 per cent. without producing a viscous cinder, neither can the percentage of SiO_2 fall below 10 per cent. unless unusual amounts are present of the oxides of iron, manganese, or phosphorus.

I have advanced this theory of the automatic regulation of fluidity with some hesitation, but it seems to account for a curious relation between the content of SiO_2 and FeO in a large number of basic slags, which are grouped and averaged in Table XI-D.

The phosphoric acid was not determined, but it may be taken for granted that an increased proportion of phosphorus in the charge will give higher phosphoric acid in the cinder, and the table shows that in the case of high phosphorus the combined SiO_2 and FeO runs about 27.5 per cent., with medium phosphorus about 35 per cent., and with low phosphorus about 36 to 37 per cent. It is quite true that a difference in manipulation would change the absolute percentages, but the attainment of a certain definite content of $FeO+SiO_2$ seems assured. This conclusion is verified by an examination of the individuals of the original records, for it is found that low SiO_2 is accompanied by high FeO and *vice versa*. This is

TABLE XI-D.

Relation Between SiO_2 and FeO in Basic Open-Hearth Slags.*

Group.	No. of heats in group.	Phosphorus in charge, per cent.	Phosphorus in ingot, per cent.	Limits of SiO_2 in slag, per cent.	Composition of slag; per cent.		
					SiO_2.	FeO.	SiO_2.+FeO.
1	8	1.35	.068	below 10	9.20	18.45	27.65
2	10	1.35	.088	above 10	12.54	14.93	27.47
3	15	0.19	.016	8 to 12 incl.	10.71	25.31	36.02
4	16	0.19	.017	13 to 14 incl.	13.84	21.81	35.65
5	19	0.19	.020	15 to 16 incl.	15.90	18.21	34.11
6	13	0.19	.022	17	17.32	17.97	35.29
7	16	0.19	.025	18 to 19 incl.	18.94	15.50	34.44
8	12	0.19	.023	20 to 22 incl.	21.57	13.58	35.15
9	7	0.19	.059	23 to 27 incl.	25.48	9.04	34.52
10	16	0.10	.014	10 to 13 incl.	12.28	22.18	34.46
11	14	0.10	.012	14	14.47	22.78	37.25
12	15	0.10	.016	15	15.54	21.10	36.64
13	20	0.10	.017	16	16.46	21.32	37.78
14	19	0.10	.015	17	17.47	19.24	36.71
15	12	0.10	.012	18	18.32	20.02	38.34
16	11	0.10	.018	19	19.41	17.66	37.07
17	14	0.10	.020	20	20.53	14.92	35.45
18	21	0.10	.016	21	21.51	14.58	36.09
19	17	0.10	.019	22	22.46	13.41	35.87
20	11	0.10	.022	23	23.41	12.40	35.81
21	9	0.10	.028	24	24.48	11.05	35.53
22	12	0.10	.042	25 to 29 incl.	26.37	10.58	36.95

TABLE XI-E.

Maxima and Minima in the Individual Heats Composing the Groups in Table XI-D.

Initial phosphorus in charge; per cent.	Slag showing maximum SiO_2; per cent.		Slag showing maximum FeO; per cent.	
	SiO_2.	FeO.	SiO_2.	FeO.
1.35	16.50	6.99	9.46	27.72
0.19	27.35	6.63	9.53	34.47
0.10	29.15	8.27	15.66	34.36

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* The full records of the above charges will be found in Sec. 45 of my paper on *The Open-Hearth Process*, in *Trans. A. I. M. E.*, Vol. XXII, p. 436 *et seq.*

shown by Table XI-E, which is composed of the extreme cases of high and low percentages of SiO_2 and FeO, found in the individual heats which compose the groups in Table XI-D.

It would be entirely wrong to suppose that an increase in SiO_2 has reduced the FeO by simple dilution, for a reduction in FeO from 20 per cent. to 10 per cent. would imply a permanent addition of SiO_2 equal to the entire volume of the slag, and this is manifestly absurd. The conclusion seems inevitable that SiO_2 and FeO replace one another in some way, and that one fulfils some function of the other. As FeO is basic and SiO_2 is acid, this function cannot possibly be related to the basicity of the slag or any strictly chemical status, and the only explanation which suggests itself is that both confer fluidity and that there is an automatic regulation of this quality in accordance with the theory before elaborated.

SEC. XIj.—*Determining chemical conditions in basic open-hearth slags.*—Just as oxide of iron exists in slag in accordance with favorable conditions rather than with the initial character of the charge, so the content of phosphoric acid is governed by the chemical environment. As a general law it may be said that the capacity of a cinder for phosphoric acid increases with the proportion of bases it contains, and that lime is the most potent of these bases. The most important modification of this law is the necessity for a certain fluidity, since a slag which is very viscous does not seem to be as effective as one which is rendered fluid by oxide of manganese or iron. Thus, although lime is immeasurably superior to oxide of iron as a dephosphorizing agent, nevertheless, as I have shown elsewhere,* a slag containing a slightly higher percentage of FeO is more efficient.

One of the more important determinants of the capacity of slag for phosphorus is the phosphorus itself. The absorption of phosphoric acid is not a case of simple solution (if such a phenomenon exists) like that of salt in water, but it is a union of acid and base, and, therefore, each molecule of phosphoric acid which enters the slag decreases its capacity for more in exactly the same way that silica would. It is impossible to prove this conclusively by ordinary averages, for the additions of lime are usually regulated by the demands of the silica rather than of the phosphorus, and it is

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* *The Open-Hearth Process. Trans. A. I. M. E.*, Vol. XXII, p. 446.

a coincidence if the maximum content of phosphoric acid is present.

Moreover, the precise determining conditions vary with each particular combination of the remaining elements, with the intensity of the reducing conditions, and with the duration of the exposure. Thus Table XI-F gives examples of slags which were produced under abnormal conditions; the samples were taken from an open-hearth furnace soon after melting, and before an extreme temperature had been reached to give the carbon of the bath its full reducing power to break up unstable compounds.

TABLE XI-F.

Unstable Basic Open-Hearth Slags.

Slag.	Composition, per cent.			
	SiO_2.	P_2O_5.	FeO.	SiO_2.+P_2O_5.
1	37.53	2.01	10.26	39.54
2	34.05	3.08	18.45	37.13
3	32.45	3.33	9.36	35.78
4	30.26	5.99	10.08	36.25
5	25.21	8.34	11.88	33.55
6	20.60	10.97	10.90	31.57
7	17.31	16.60	12.15	33.91
8	15.07	23.06	10.53	38.13

These slags are especially selected as being extreme instances of high phosphorus for a given silica, and they are therefore valueless as an indication of what may be expected in regular practice. They do show, however, that there is no such thing as a critical percentage of silica, since a cinder with 37 per cent. SiO_2 may hold 2 per cent. P_2O_5.

TABLE XI-G.

Normal Basic Open-Hearth Slags.

Slag.	Composition, per cent.			
	SiO_2.	P_2O_5.	FeO.	SiO_2.+P_2O_5.
1	20.72	6.36	16.20	27.08
2	19.04	8.24	20.16	27.28
3	12.40	13.73	12.60	26.13

The slags in Table XI-G, although selected somewhat arbitrarily, are fairer examples of the results of regular work. In both Table XI-F and XI-G there is a column headed "SiO_2+P_2O_5," and the constancy of this total under similar conditions, even with slags of widely varying character, indicates that the total acid content of the slag is the measure of its power to absorb phosphorus.

SEC. XIk.—*Elimination of sulphur.*—A certain proportion of phosphorus is likely to be volatilized by the heat and carried away in the waste gases. This renders futile any attempts to make accurate quantitative calculations on the chemical history, but otherwise the action is of little importance since it cannot be relied on for purification of the metal. This volatilization occurs in greater measure in the case of sulphur, but here also it is entirely impracticable to eliminate any appreciable proportion by this method alone, since volatilization occurs only from the slag, and the action, therefore, presupposes the transfer of sulphur from the metal to the cinder, and this in turn presupposes a condition which will purify the metal without the *ex post facto* intervention of volatilization.

The removal of sulphur can be accomplished in at least four ways, which will be considered *seriatim.*

(1) By the addition of metallic manganese and liquation of sulphide of manganese. The extent of this reaction is very uncertain, but usually the addition of 0.60 to 0.75 per cent. of manganese in the form of recarburizer reduces the sulphur content about 0.01 per cent.

(2) By the use of manganese ore, which, being reduced by the metalloids of the bath, furnishes metallic manganese. The ore should be added with the original charge in order that it may be thoroughly mixed with the metal. It is very difficult to isolate the effect of this agent from the contemporaneous action of the basic slag with which it must be associated, but there is no doubt that it aids in the purification.

(3) By the action of a very limey cinder. In a former paper* I gave the results of experiments in removing sulphur by ordinary lime slags. The cinder, during melting, was kept high in silica to economize lime, and part of this slag was removed after fusion, and fresh lime added. Notwithstanding the high acid content, the slag after melting held quite an appreciable proportion of sulphur. The final slag, being richer in lime, removed a greater quantity and the results seem to show that, as the silica decreases, the capacity for sulphur increases, but the relation is not as regular as might be

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* *The Open-Hearth Process. Trans. A. I. M. E.,* Vol. XXII, p. 446.

wished, and it must be acknowledged that many points are still obscure. The records are given in Tables XI-H and XI-I.

TABLE XI-H.

Basic Open-Hearth Slags after Melting, Arranged According to their Sulphur Content.

Charge Number.	Initial sulphur, per cent.	Sulphur in metal after melting, per cent.	Composition of slag after melting, per cent.				
			S.	SiO_2.	FeO.	CaO.	MnO.
1546	.43	.28	.28	37.53	10.26	34.53	4.66
1611	.20	.14	.26	32.63	10.17	36.25	und.
1608	.28	.17	.22	31.30	10.98	41.45	und.
1628	.20	.16	.21	33.20	9.45	und.	und.
1648	.20	.14	.21	34.37	6.57	und.	und.
1567	.28	.18	.20	30.26	10.08	45.26	5.42
1646	.20	.15	.18	33.97	11.61	und.	und.
1626	.20	.11	.18	36.43	5.04	und.	und.
1564	.28	.10	.17	32.45	9.36	45.05	5.49
1555	.28	.22	.14	30.63	13.41	39.17	7.15
1630	.20	.09	.14	25.57	8.01	und.	und.
1606	.28	.19	.12	35.79	18.00	33.13	und.
1569	.28	.19	.08	34.05	18.45	35.09	6.25

TABLE XI-I.

Basic Open-Hearth Slags before adding Recarburizer, Arranged according to their Sulphur Content.

Charge number.	Initial sulphur, per cent.	Sulphur, after melting.		Sulphur in ingot, per cent.	Composition of slag before adding the recarburizer, per cent.				
		Slag, per ct.	Metal, per ct.		S.	SiO_2.	FeO.	CaO.	MnO.
1608	.28	.22	.17	.095	.61	12.73	26.91	43.99	und.
1611	.20	.26	.14	.054	.58	10.45	26.19	45.85	und.
1555	.28	.14	.22	.086	.56	13.78	26.91	42.14	4.85
1606	.28	.12	.19	.100	.54	12.90	31.14	38.58	und.
1569	.28	.08	.19	.089	.48	15.90	18.63	und.	und.
1630	.20	.14	.09	.062	.43	16.26	19.98	49.50	und.
1546	.43	.28	.28	.120	.36	18.67	24.84	37.23	4.44
1567	.28	.20	.18	.062	.33	14.85	23.49	45.74	4.54
1564	.28	.17	.10	.089	.33	19.18	16.11	49.98	4.58
1648	.20	.21	.14	.090	.26	17.97	23.94	44.41	und.

(4) By oxychloride of lime. A process has been devised by E. H. Saniter* whereby sulphur is eliminated from basic open-hearth metal by the use of oxychloride of lime. It is important to note, however, that "in order to attain this result it is necessary, at an early period after the charge is melted, to obtain an exceedingly basic slag, and to add a suitable quantity of calcium chloride to

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* *On a New Process for the Purification of Iron and Steel from Sulphur. Journal I. and S. I.*, Vol. II, 1892, p. 216; also, *A Supplementary Paper on a New Process on Desulphurizing Iron and Steel. Journal I. and S. I.*, Vol. I, 1893, p. 73.

it"; and it is further specified that "by a very basic slag is not meant what has hitherto been considered as such, but a step in advance of that with about 50 to 60 per cent. of lime." This point is also insisted upon by Stead,* who reviews the experiments and states that the chloride is used "in conjunction with an excess of lime over and above what is usually employed." He gives analyses of slag and metal for two charges, and a summary of these is given in Table XI-J. The results of a more complete investigation of one charge are shown in Table XI-K, the data being taken from a paper by Snelus.†

TABLE XI-J.

Elimination of Sulphur by Calcium Chloride.

Heat.	Composition, per cent.							
	Metal.		Slag.					
	Sulphur.		After adding $CaCl_2$.			At time of tapping.		
	Initial.	In steel.	SiO_2.	CaO.	S.	SiO_2.	CaO.	S.
1	.37	.047	10.75	54.65	1.25	10.20	48.98	.65
2	.17	.055	14.45	44.34	.53	11.75	47.86	.57

TABLE XI-K.

Detailed Data on the Elimination of Sulphur by Calcium Chloride.

Open-hearth charge: 80 per cent. white iron, 20 per cent. scrap, the whole averaging about .30 sulphur.

Time of taking sample.	Composition of metal, per cent.		Composition of slag per cent.		
	C.	S.	SiO_2.	CaO.	S.
After complete fusion	.20	.320	18.30	49.24	.315
1 hour after melting	.09	.181	15.00	49.60	.576
4 hours after melting	.06	.093	11.60	55.64	.659
Steel, 5½ hours after melting .	.10	.040	10.80	57.00	.645

The sulphur after melting is higher than the calculated initial content, but this is probably due to incorrect sampling and to the absorption of sulphur from ore and gas, since the percentage of

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* *On the Elimination of Sulphur from Iron. Journal I. and S. I.*, Vol. II, 1892, p. 260.

† *Report upon the Saniter Desulphurization Process. Journal I. and S. I.*, Vol. I, 1893, p. 82.

sulphur in the slag shows that a considerable amount was taken from the metal. After melting, the carbon was reduced to .20 per cent., and one hour later it was .09 per cent., but it was necessary to hold the charge in the furnace for four and one-half hours after complete decarburization, and to dose it with calcium chloride in the proportion of 50 pounds to the ton of metal, in order to remove the sulphur, a delay which is decidedly objectionable. The oxychloride, however, conferred fluidity upon the cinder, and made it possible to carry as high as 57 per cent. of CaO, and it is probable that this increased mobility and corresponding activity rendered the lime more efficacious in absorbing sulphur. This point is not satisfactorily settled, for notwithstanding the learned discussions and investigations following Saniter's experiments,* the inner history of desulphurization is still unwritten.

A quantitative investigation that I made into the elimination of sulphur by weighing and analyzing the slags from three of the charges given in Table XI-H, showed that about 36 per cent. of the sulphur was unaccounted for, having probably been carried away as sulphurous acid (SO_2) in the waste gases. The fact that both sulphur and phosphorus thus escape in an intangible form and in uncertain quantities, renders quantitative work on basic slags very unsatisfactory. Moreover, a sample of slag is not always representative, for on some heats portions of the basic additions remain sticking to the hearth, while on others old accumulations of such deposits dissolve in a charge to which they do not belong.

SEC. XII.—*Removal of the slag after melting.*—When the stock is properly charged, the greater part of the basic addition becomes an active agent during the melting of the charge. Especially when ore is used the intense action oxidizes a considerable proportion of the phosphorus during the melting, and the slag after fusion contains oftentimes a high percentage of phosphoric acid. The idea has occurred to numberless metallurgists that this first slag should be removed in order to get rid of its phosphorus and silica and thus give the opportunity for a new and purer slag having a greater dephosphorizing power. There are certain practical difficulties in the way, for the height of the metal in the hearth is always varying with the filling of the bottom and with the frothing of the charge, so that there is danger of losing metal if a taphole is opened much

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* *Report upon the Saniter Desulphurization Process. Journal I. and S. I.*, Vol. I, 1893, p. 82.

below the level of the upper surface of the slag; on the contrary, if the slag is tapped from its upper surface there is no force to the stream and it is constantly chilling as it runs. In spite of these troubles the partial removal of the slag is not uncommon.

Complete removal can be accomplished by the use of a tilting furnace, for the entire charge can be poured out and only the metal returned to the hearth. Under ordinary conditions this manipulation is unnecessary, but it may not be unprofitable to consider the rules that apply, whether the whole or only a part of the slag be removed during the progress of the operation.

Given a pig-iron containing a considerable proportion of silicon and with low phosphorus, it will be an advantage to have the first slag as high in silica as possible so as to avoid the addition of a corresponding quantity of lime. This practice, however, cannot be carried to an extreme, for if the amount of lime is reduced to such an extent that the slag after melting contain much over 30 per cent. of silica, the hearth will be badly scorified. If melted pig-iron is used, this difficulty disappears, for ore may be added to a bath of pig at the rate of over one ton per hour and the silicon be rapidly oxidized. The slag so produced in the absence of a full supply of lime may run about 30 or 35 per cent. of silica and 25 to 35 per cent. of iron oxide. This would scorify the hearth if left long enough in the furnace, but it should be removed after the silicon is oxidized, for during the oxidation of carbon from a content of 3 per cent. down to about 1 per cent. the frothing is very violent, and if the slag is not removed there will be considerable trouble and delay.

If the pig carries much phosphorus or sulphur, the first slag which it is intended to remove should not be too rich in silica, for under these conditions the full content of the impurities will remain in the metal after the tapping of the slag and it will be necessary to make a large volume of cinder to remove them during the second stage of the operation. The better way in this case is to make the first slag rich enough in lime to carry a good proportion of phosphoric acid and sulphur, and liquid enough to pour well. The second slag can then be made from fresh lime, and it will be evident that it will more readily absorb the impurities than a cinder which is already partly satisfied.

SEC. XIm.—*Automatic formation of a slag of a given chemical composition.*—In such practice there might appear to be a difficulty in properly regulating the composition of the second slag, but the records in Tables XI-H and XI-I show that such is not the case, for, in the heats there given, a part of the slag was removed soon after melting. Quite a difference will be found between the first and second slags, but this is because the first slag was purposely made high in silica in order to save lime. When it is required to maintain a similar composition throughout the heat, it can be done in basic as well as in acid practice, as shown by the average slag analyses of 27 heats in Table XI-L.

TABLE XI-L.

Average Slag Analyses of Twenty-seven Basic Open-Hearth Heats.

Slag.	Composition, per cent.			
	SiO_2.	P_2O_5.	CaO.	FeO.
After melting	14.35	15.53	45.07	9.00
Before tapping	12.40	13.73	45.40	12.60

Four-fifths of the lime was added with the charge, and the remainder, together with 400 pounds of ore, was used after melting, but in spite of the incorporation of this basic material into the slag during the interval between the two stages at which the samples were taken, it will be seen that by careful supervision and through the action of the internal chemical forces, a remarkably uniform composition was maintained, which proves conclusively that the manipulations of the basic process may be as completely under control as the operations upon the acid hearth.

SEC. XIn.—*Recarburization and rephosphorization.*—Recarburization is carried on in the same way as in acid work, and is subject to the same general laws. A complicating condition is often added when either the stock or the ore contains any considerable proportion of manganese, for the decarburized metal may then hold as much as .20 or .30 per cent. of Mn. Not only must this be allowed for in making the final addition, but it will also be found that the bath contains less oxygen under these circumstances, and therefore there will be less loss of metallic manganese during the reaction.

In basic practice there is a factor not present in acid work, in the danger of rephosphorization, or the return of phosphorus from slag to metal. In the basic Bessemer this is a source of considerable trouble, but in the open-hearth the recarburizer is almost always added in a solid state and the metal probably contains less oxygen, so that the reaction is less violent. Moreover, during the solution of the ferro, the slag is constantly at work with its dephosphorizing influence, so that the sum total of the reactions may even show a decrease in phosphorus. Other things being equal, it would seem probable that a slag containing a high percentage of phosphoric acid will hold this component less firmly than a purer cinder, and I have tried to illustrate this point* by experiments, the results of which may be summarized as follows:

(1) With slags containing under 5 per cent. P_2O_5 and not over 20 per cent. SiO_2, the rephosphorization need not exceed .01 nor average over zero per cent.

(2) With slags containing from 5 to 10 per cent. P_2O_5 and not over 19 per cent. SiO_2, the rephosphorization need not exceed .015 nor average over .005 per cent.

(3) With slags containing from 10 to 15 per cent. P_2O_5 and not over 17 per cent. SiO_2, the rephosphorization need not exceed .02 nor average over .005 per cent.

(4) With slags containing from 15 to 20 per cent. P_2O_5 and not over 12 per cent. SiO_2, the rephosphorization need not exceed .02 nor average over .01 per cent.

In using phosphoric stock it is not safe to presuppose the elimination of phosphorus below .04 per cent. until the carbon has been lowered to about .08 per cent. Hence, to make rail steel it is necessary to eliminate the carbon to that point and then add the required amount of recarburizer, as in the Bessemer process. It is impracticable to use melted spiegel-iron in open-hearth practice, unless there are a great number of furnaces, because the charges come so irregularly and at such long intervals that a cupola becomes chilled, but it has been found possible to add finely divided carbon in the ladle, its absorption by the metal being so rapid that the results are quite regular.

Several ways of doing this have been devised, the most successful of which has been very fully described by Dr. Wedding.† Powdered "anthracite" coal is mixed with about 7 per cent. of burned lime and with sufficient water to make a plastic mass, and is then formed into bricks. These are dried thoroughly to expel all the

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* *The Open-Hearth Process. Trans. A. I. M. E.,* Vol. XXII, p. 484.

† *Stahl und Eisen.* 1894, pp. 473 and 533; also 1895, p. 570.

uncombined water, and are then ready to be fed into the ladle as the heat is poured.

The escape of the combined water in the lime causes the bricks to crumble to pieces when in contact with the melted steel, but this crumbling is gradual, so that the carbon is fed to the metal continuously and the bath is able to absorb it as fast as it is set free. This moisture also creates a constant motion of the bricks and acts as a mechanical stirrer.

It should be noted, however, that the kind of coal which is referred to by Dr. Wedding is a rather hard bituminous coal and not at all what is known as "anthracite" in America, and that the practice at different works leads to the conclusion that coke dust or other similar forms of carbon answer equally well.

CHAPTER XII.

SPECIAL METHODS OF MANUFACTURE AND SOME ITEMS AFFECTING THE COST.

SEC. XIIa.—*The manufacture of low phosphorus acid open-hearth steel at Steelton.*—The early history of the open-hearth in the United States is confined entirely to the making of acid steel, very little basic metal being made until after 1890. A large proportion of the output went into boiler plate and quite a quantity into forgings, while there was a considerable tonnage of high carbon steel, which was ultimately sold under the name of "cast steel," this term being perfectly truthful in one sense and entirely untruthful in another, as it was intended to convey the idea that the metal was made in a crucible.

The ordinary grades of boiler steel and forgings were made of stock running from .08 to .10 per cent. of phosphorus, while metal for fire boxes and special forgings, as well as some of the high carbon steel, was made of low-phosphorus stock, usually a mixture of Swedish pig-iron and charcoal blooms. A certain quantity of low-phosphorus pig-iron was made in America, and during the latter part of the acid epoch a considerable quantity was manufactured of what is known as "washed metal." This is made by treating melted pig-iron in a furnace lined with iron ore and lime and eliminating most of the silicon, sulphur and phosphorus and about half the carbon. The pig-iron is the same grade as is used in the basic open-hearth furnace, and the "washed metal" process is essentially the same as the basic open-hearth process of to-day. It differs from it in the following particulars:

(1) In the basic open-hearth furnace, the bottom is made as durable as possible and it is desired that it shall not be cut away by the action of the metal and slag. The iron ore needed to oxidize the metalloids and the lime needed to make a basic slag are both added with the charge, and the reactions take place in a

definite way very similar to the fusions made by a chemist in a platinum crucible, the crucible playing no part in the reaction. In the washed metal process the bottom is not durable, but is intended to be the source of supply of the ore and lime needed to oxidize the metalloids and to supply a basic slag.

(2) The washed metal furnace is not allowed to reach a very high temperature, because the slag is not stable and at a higher temperature the hearth would be cut away, the reactions would be more violent and the phosphorus would leave the slag and go back into the metal. In the open-hearth furnace the phosphorus does not go back, because the slag is stable, by which is meant that it contains a sufficient proportion of lime to make a permanent compound with the phosphorus so that it is not readily reduced by carbon. Such a slag needs a high temperature for complete fusion and this temperature cannot well be carried in the washed metal furnace.

(3) The washed metal furnace is tapped when the metal contains about 2 per cent. of carbon, because if the carbon be run down any lower a much higher temperature would be needed, and because this kind of product suits the demands of the trade.

It has been stated that the standard low-phosphorus open-hearth steel of former days was made from either low-phosphorus pig-iron and charcoal blooms or washed metal and charcoal blooms, and it has been shown that this washed metal was the product of a basic process. The charcoal blooms were also of basic origin, because they were made in a primitive Tubal Cain sort of way by the action of a basic oxidizing slag on melted metal.

After the general introduction of the basic open-hearth process it became possible to buy in the open market a supply of low-phosphorus steel scrap at a very moderate price, and this steel scrap rapidly took the place of the high-priced charcoal blooms and practically stopped their manufacture. Thus while the advent of the basic open-hearth furnace rendered it possible to produce a low-phosphorus steel very much cheaper than it had ever been produced before, it also cheapened the cost of low-phosphorus acid open-hearth steel by giving it cheap scrap.

This is true, however, only to a certain extent, for the basic furnaces themselves need scrap and use most of the available supply. Moreover, the different plants for making steel castings are always in the market, and some of the plate mills use steel plate scrap to pile with puddled iron to make wrought-iron plate, so that it is difficult to find sufficient low-phosphorus scrap to keep a large acid open-hearth plant in continual operation, and even if this could be done, the low-phosphorus pig-iron, which must be used, costs from three to five dollars per ton more than the ordinary Bessemer grade.

In order to overcome these commercial difficulties we have introduced at the works of The Pennsylvania Steel Company an adaptation of the old washed metal process. The pig-iron is charged, either liquid or solid, in a basic lined furnace and almost all of the silicon and phosphorus and part of the sulphur and carbon are eliminated. At this stage of the proceeding it is washed metal, and in olden times would have been run out in chills, cooled off and afterward charged into the acid furnace, but in this new practice it is poured into a ladle, and, while still fluid, is poured directly into the acid furnace. A certain amount of scrap may be used in the basic furnace, or in the acid furnace, or in both; but the main point is to have no basic slag enter the acid furnace and to be sure that the dephosphorized metal, when it goes into that furnace, shall contain as much carbon as is usually present in an acid bath after the stock is melted. We thus have the transferred charge starting off on its acid journey in just the same condition it would have been in if it had been melted in the acid furnace, so that the reaction, the slag, and the whole history from that moment, are the reactions, the slag and the history of the acid open-hearth furnace.

This practice is not feasible in most open-hearth plants, since no arrangements are usually provided for transferring metal in this way, but the demands of engineers for pure acid open-hearth steel made it necessary to equip a plant to supply this special product at a moderate cost. In order to show that the composition of the metal and slag in the transfer process is the same as in the usual acid furnace, I had samples taken from the bath during different stages of the operation. The metal was tapped from the basic furnace when it contained from 2.50 per cent. to 3.50 per cent. of carbon, and transferred in a molten state to the acid furnace. When the carbon was about 1.00 per cent. the taking of samples was begun. It is seldom that a charge in an acid furnace is higher than this when it is melted, so that the records may fairly be compared with the ordinary acid heat after complete fusion.

TABLE XII-A.

Composition of Metal and Slag in the Acid Furnace when Washed Metal is Transferred in a Molten State from a Basic to an Acid Furnace.

Note: Samples over 1.10 per cent. in carbon omitted.

Heat No.	Composition of Metal, per cent.				Composition of Slag, per cent.				
	C	Si	S	P	SiO_2	MnO.	FeO	MnO+FeO	SiO_2+MnO+FeO
A.......	1.00	.02	.033	.025	50.57	12.16	32.04	44.20	94.77
	.71	.01	.037	.025	49.91	11.08	32 58	43.66	93.57
	.30	.03	.037	.029	55.76	9.75	28.05	37.80	93.56
	.19	.02	.033	.025	55.44	9.22	30.15	39.37	94.81
B.......	.80	.03	.025	.009	47.71	3.46	44.64	48.10	95.81
	.31	.03	.020	.008	53.90	4.30	37.62	41.92	95.82
	.21	.02	.021	.008	51.50	7.67	35.55	43.22	94.72
C	.95	.02	.020	.019	51.08	12.94	29 79	42.73	93.81
	.70	.02	.020	.019	45.38	9.04	40.05	49.09	94.47
	.54	.03	.021	.022	50 01	9.10	35.55	44.65	94.66
	.23	.03	.020	.021	52.61	10.92	30.87	41.79	94.40
D.......	.77	.03	.026	.010	53.52	10.92	28.98	39.90	93.42
	.45	.03	.029	.011	52.22	8.34	32.58	40.92	93.14
	.31	.03	.029	.012	52.50	7.36	36.54	43.90	96.40
E.......	.90	.02	.040	.034	51.82	6.52	37.44	43.96	95.78
	.60	.01	.034	.031	50.27	7.44	38.79	46.23	96.50
	.17	.02	.034	.030	51.66	5.51	39.51	45.02	96.68
F.......	1.09	.02	.027	.008	42.50	9.89	41.76	51.65	94.15
	.72	.02	.027	.008	51.20	10.17	33.75	43.92	95.12
	.24	.02	.027	.008	56.61	9.60	29.61	39.21	95.82
G	.75	.01	.028	.010	46.95	11.46	39.24	50.70	97.65
	.46	.01	.028	.010	51.02	10.44	33.93	44.37	95.39
	.26	.01	.029	.010	54.80	11.58	28.17	39.75	94.55
H.......	.95	.01	.022	.026	42.21	14.34	37.98	52.32	94.53
	.62	.02	.024	.030	49.66	12.65	32.65	45.30	94.96
	.25	.02	.023	.028	50.28	11.72	31.41	43.13	93.41
I.......	.70	.02	.030	.011	45.16	15.14	35.46	50.60	95.76
	.43	.02	.028	.010	47.65	9.89	36.99	46.88	94.53
	.22	.03	.029	.011	57.23	9.36	26.91	36.27	93.50

The results on nine heats are given in Table XII-A, and they may be compared with figures given in Table X-B. This latter table shows, under Group I, the composition of slag and metal as found some years ago in an acid furnace running on the usual pig, scrap and ore process. A comparison of the results is shown in Table XII-B.

TABLE XII-B.

Comparison of Data in Tables X-B and XII-A.

		Group I. Table X-B	Transferred Steel.	
			Min. Max.	Av.
After Melting	Carbon in metal	.54	.70 to 1.09	.88
	SiO_2 in slag	50.24	42.21 to 53.52	47.95
	$FeO+MnO$	45.58	42.73 to 52.32	47.13
	$SiO_2+FeO+MnO$	95.82	93.42 to 97.65	95.08
End of Operation	Carbon in meta	.13	.17 to .31	.23
	SiO_2 in slag	49.40	49.40 to 50.28	53.62
	$FeO+MnO$	46.29	36.27 to 45.02	41.30
	$SiO_2+FeO+MnO$	95.69	93.41 to 96.68	94.92

It should be stated that the last sample was not always taken just before tapping. Thus in heat D, Table XII-A, the final carbon was not .31 per cent., but the last sample was taken at that point and for the purposes of the investigation, this was deemed sufficient. It will be seen that the composition of the slag, both at the earlier periods and at the later epoch, corresponds closely to that taken in former experiments, and if samples had been taken with lower carbons so as to correspond with the .13 per cent. in Group I, Table X-B, it is likely that there would have been even a still closer resemblance, as the percentages of metallic oxides would probably have increased.

SEC. XIIb.—*The pig and ore basic process.*—In the year 1901 the United States produced 3,618,993 tons of basic open-hearth steel, while in the year 1895, when this book first appeared, the total production of acid and basic open-hearth steel put together was only 1,137,182 tons, and in 1894 the total was 784,936 tons. The great increase was caused by an enormous expansion in the field of structural work. This field rapidly extended, owing to the cheapness of the material and to various other causes, among which might be mentioned the invention of steel skeleton office buildings, and the demand for heavier railroad bridges caused by heavier rolling stock. The introduction of steel cars also accounts for a very great demand, as well as the phenomenal growth of the tin plate business, while many smaller industries like the making of car springs constitute in the aggregate a tonnage which can hardly be credited.

In early days the open-hearth furnace looked for its supply of scrap to the mills that rolled Bessemer ingots, but since 1879, when the open-hearth first began to be an important producer, the output of Bessemer steel has increased only tenfold, while the product of the melting furnace has increased ninety fold.

With this enormous increase in product there is naturally a demand for melting scrap, which in some localities cannot always be supplied. It is a common belief that a basic furnace can handle anything that may be picked up in a junk yard, but experience teaches that while it is undeniably true that it *can* do so, it teaches just as undeniably that there is no economy in using bad material unless it can be bought for a much lower price per ton. In some foreign countries the only pig-iron available is one containing a high percentage of phosphorus. When there is plenty of steel scrap to mix with such an iron, it can be used without much trouble, but when it must be used alone the product of the furnace is lessened materially and the cost greatly increased. In America there is no incentive to use a high phosphorus mixture, except in the Alabama district and in Cape Breton. The ores of the Lake Superior region furnish an iron which is so low in phosphorus that this element is always eliminated in the basic furnace to below .04 per cent., which is the established standard, but in using the irons of Alabama, Tennessee and Kentucky much care is necessary or the steel may hold more than the allowable amount. The phosphorus problem is one which can be met by careful attention to the slag, by seeing that it receives sufficient lime, that it is rendered fluid by iron oxide, and that it is in sufficient quantity to hold the phosphorus in a state of stable combination.

The removal of phosphorus is a local issue, in which some districts have no interest, but the question of working a large proportion of pig-iron is one which nearly all large works are sometimes driven to face. In an ordinary stationary furnace the use of an entire charge of pig-iron is very objectionable on account of the excessive frothing of the metal and slag. From the time that the metal is thoroughly melted, when it may contain about 3 per cent. of carbon, until the proportion is reduced to about 1½ per cent., the bath resembles soda water more than pig-iron, and it tries to flow out of the doors and to occupy about twice the room it should.

In Steelton we have solved the difficulty caused by this frothing by using the tilting furnace rotating about a central axis. (See Section VIIId.) The pig-iron is brought in a melted state from the blast furnace and poured into the open-hearth furnace, a sufficient quantity of iron ore and lime being added. During the combustion of silicon no violent reaction occurs, but immediately afterward a general movement takes place, whereupon the furnace is tipped over until the metal is thrown away from the doors and up on the back side. In this way the capacity of the furnace is practically doubled, while the flame enters and goes out as usual. The furnace is kept in this position for two or three hours, or longer, until the bath has quieted down. Meanwhile the slag is trying to froth out of the ends of the furnace and down the ports, but to do so it must flow over the open joint between the port and the furnace. This joint is not wide, but special provision is made to allow the slag to run out through a small hole and fall down beneath the end of the furnace in a slag pit. In this way a very considerable quantity is removed and the time of operation considerably lessened.

At some works the slag is removed by means of a small tap-hole or through the regular door, but under these circumstances the stream continually chills and must be carefully tended. In the arrangement above described there is little tendency to chill, for the flame is constantly playing back and forth through the ports and the slag opening is in the immediate course of the hottest flame. This practice of using direct metal has been in more or less continuous use for several years on furnaces of fifty tons capacity. Working in this way the iron of the ore is reduced in such quantity that the product of steel, counting both ingots and scrap, exceeds the weight of pig-iron charged by from 4 to 6 per cent. when the charge is entirely pig-iron.

There is nothing new in this practice, the only feature which distinguishes it from work done at many other places at many times in the past being the use of a tipping furnace rotating round a central axis. With the Wellman furnace it would be impossible to tip the furnace in the manner described, and while this would not prevent the use of melted pig-iron for the entire charge, it would materially increase the difficulties unless the furnace were charged to only half its capacity. It is not necessary that the iron should be brought in a melted state from the blast furnace, as the same general line of procedure can be followed when it is charged cold. Table XII-C shows the results obtained from two series of heats, in one of which most of the metal was charged cold, while in the other the metal was all fluid. In these series especial care was taken to have the weights accurate and to know the composition and the weight of the slag produced. I do not consider that any results on loss are worthy serious study unless the exact amount of pure metallic iron put into the furnace is known and unless this equals the weight of metallic iron in the ingots, the scrap and the slag. In addition to this it is well to know the total amount of CaO put into the furnace in the form of limestone, burned lime or dolomite, and see whether this agrees with the amount of CaO which is indicated by the weight and composition of the slag. In the following two series these conditions were attained and the amount of CaO used was found to check the records of the slag, while the balance sheet of metallic iron agrees within one-fifth of one per cent. In individual heats no such accuracy can be obtained, and it is often impossible on a series of heats, as the wearing of the hearth or the accumulation of slag will give a gain or a loss. In Table XII-C the term "first slag" signifies that which flows through the port opening, and is thus removed entirely from the furnace during the progress of the operation, while "second slag" means the final cinder as it comes from the furnace at the time of tapping:

TABLE XII-C.

Record of "All-Pig" Basic Open-Hearth Heats at Steelton.

	First Series. Pounds.	Second Series. Pounds.
Liquid metal (1.4 per cent. Si)...	156,200	405,287
Iron cast in chills..........	352,210	....
Iron cast in sand..........	36,020	....
Recarburizer..........	3,600	4,725
Total metal charged..........	548,030	410,012
Ore (66.3 per cent. Fe)..........	144,100	116,300
Ingots..........	551,200	429,000
Scrap..........	13,800	1,355
Total steel..........	565,000	430,355
First slag..........	27,130	73,600
Second slag..........	17,140	41,500
Total slag..........	44,270	115,100

Composition of first slag.....	Sio_2....	24.04	23.67
	CaO....	11.84	18.14
	FeO....	41.63	45.00
Composition of second slag..	SiO_2....	11.78	16.14
	CaO....	41.90	37.26
	FeO....	26.93	25.94

Taking as a basis the weight of pig-iron and recarburizer, the weight of ingots and scrap together was 103.1 per cent. in the case of the cold metal, and 104.95 per cent. with liquid metal. These figures, of course, neglect entirely the weight of ore charged, but it is customary to speak of such practice by saying that the gains were 3.1 per cent. and 4.95 per cent. respectively. This subject will be again referred to in other sections of this chapter.

In the case of the cold pig, the first and second slags together carried away 7.3 per cent. of all the metallic iron put into the furnace, including the iron in the ore. In the case of the melted iron, this loss was 7.4 per cent. The silicon in the pig-iron was 1.4 per cent., which is rather high for basic practice. Had it been lower there would have been less silica produced, less lime would have been necessary, less slag would have been produced, and less iron would have been lost in the cinder. The slag is not exactly proportionate to the silicon in the iron, as there are other sources from which silica is supplied, but it seems from calculation that had the silicon in the pig-iron been reduced one-half, to a content of 0.70 per cent., the volume of slag would have been only two-thirds as much, and this would mean that it would carry away less than 5 per cent. of the total iron in the charge, which would mean a gain of 2.5 per cent. in the weight of ingots over the actual practice and give a total gain in weight of 7.5 per cent. It is true that less ore would be required with lower silicon, but on the other hand, a lower percentage of silicon means a higher content of metallic iron in the pig-iron, which is bound to show itself in a greater product. The practice of using direct metal in an open-hearth furnace is one in which the open-hearth is only half the operation. The blast furnace is the other half, and the cost sheet of both must be considered in making up the cost of ingots.

SEC. XIIc.—*The Talbot Process.*—The last section described the difficulties encountered in the use of the pig and ore process in a furnace that cannot be tilted while in operation, like the ordinary stationary hearth or the Wellman type. A way of overcoming this trouble has been carried out by Mr. Talbot at the Pencoyd Iron Works, at Philadelphia.* The pig-iron is melted in a cupola and is poured into a Wellman furnace. When the charge is ready to tap, a portion of the steel, and a portion only, is poured into

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* *Journal I. and S. I.*, Vol. I, 1900.

the ladle and cast into ingots. The remainder, which may be one-half or two-thirds of the whole, is kept in the furnace and a new supply of cupola iron is added to it. Taking the case of a 50-ton furnace and assuming that thirty tons of low carbon metal is retained and twenty tons of pig-iron added, it is clear that the average of the new bath will contain about 1.5 per cent. of carbon, which will be quite a manageable mixture.

A point in this practice which might trouble the average open-hearth man is the impossibility of repairing the lower portion of the hearth, or even of knowing what condition it is in. The slag line can be repaired after part of the charge has been removed, but the lower part of the bottom is always covered by liquid metal. It is claimed, however, that this covering of steel acts as a protection by keeping away the slag and oxide of iron, and that no repairs are necessary to the "flat."

Considerable stress is laid on the addition of iron oxide before the addition of pig-iron in order to create a violent reaction and quickly oxidize the metalloids, and it is even claimed by Mr. Talbot that this oxidation produces heat and is thus an important factor in the operation. It will be shown in Section XIIe that this is a great mistake and that the reaction absorbs much energy. Were it not so, there would be no difficulty in eliminating silicon and carbon in the open-hearth furnace by ordinary methods, for a charge can be decarburized with great rapidity by shoveling ore into the furnace continually; the reactions take place and the silicon and carbon are oxidized as fast as can be desired, but this cannot be continued because there is such an absorption of heat that the bath becomes cold and time must be given for it to get hot.

It is difficult to see how the time necessary for decarburization can be shortened by preheating and melting the ore, and having a sudden and violent reaction with a consequent chilling. The decarburization itself will take place in much less time, but the total time necessary to melt the ore, to complete the reaction, and to heat up the charge after the reaction will probably be longer than if the ore were added after the pig-iron is charged.

Table XII-D is condensed from Mr. Talbot's paper showing the history of the metal and slag in the furnace. There are five heats given in full in his paper and one other heat in part, but I have quoted only two, as they are fairly representative of all those described. The heats given by Mr. Talbot are not consecutive, and it is only natural to suppose that he selected those which ran along without any mishaps. It is also natural to suppose that the general average would show a somewhat less output per hour of actual operation. This supposition is corroborated by the information given in the paper on the results from two weeks' work, for while the average of the five heats indicates an output of 92 tons per day, the record for a fortnight gives an average of only 493 tons per week, which if continued would give 2136 tons in a month.

TABLE XII-D.

Reactions in the Talbot Process.

Note: For convenience I have started both heats at 12:00 o'clock.

Time.	Sample.	Weight lbs.	Composition of Metal.					Composition of Slag.			
			C	S	P	Mn	Si	Fe	SiO_2	P_2O_5	MnO
	Heat No. 254—										
12:00	Slag from previous heat.	....	..	....	......	....	....	10.49	11.68	13.26	7.00
12:30	Scale	3,600	....	....	......	....	....	......	......	......	......
1:05	Bath and slag	90,000	0.06	.051	.026	0.08	....	25.57	8.68	9.44	......
1:10	Cupola iron	23,700	3.80	.082	1.012	0.26	0.18	......	......	......	......
1:18	Bath and slag	113.700	0.49	.053	0.132	0.15	....	11.87	12.10	16.45	......
1:20	Ore	2,200	.	....	......	....	....	......	......	......	......
1:20	Limestone	1,440	...	....	......	....	....	......	......	......	......
1:35	Bath and slag	113,700	0.38	.056	0.111	0.14	....	10.39	12.62	17.05	......
1:40	Cupola iron	12 000	3.80	.065	0.980	0.43	0.25	......	......	......	......
1:47	Bath and slag	125,700	0.71	.057	0.144	0.14	....	10.71	12.32	15.56	......
1:50	Cinder	2,500	....	....	......	....	....	......	......	......	.....
1:50	Limestone	2,250	....	....	......	....		......	......	......	......
3:30	Ore	1,100	....	....	......	....	....	......	......	......	......
3:30	Limestone	1,000	....	....	......	....	....	.....	......	......	......
3:40	Manganese Ore	800	....	....	......	....	....	......	......	......	......
4:30	Bath and slag	125,700	0.07	.025	0.035	0.17	....	13.95	......	......	......
4:35	Cupola iron	3,000	3.80	.065	0.980	0.43	0.25	......	......	......	......
4:40	Bath and slag	128,700	0.11	.033	0.041	0.18	....	11.59	......	......	......
4:40	Steel and slag tapped	....	0.16	.050	0.036	0.50	....	11.81	11.55	12.03	7.83
	Heat No. 306—										
12:00	Slag from previous heat.	....	....	....	......	....	....	14.29	11.70	12.03	5.12
12:40	Scale	3,800	....	....	......	....	....	......	......	......	......
1:10	Bath and slag	95,000	.06	.053	0.045	0.06	....	43 37	5.18	4.17	......
1:15	Cupola iron	14,000	3.80	.052	0.976	0.24	0.36	......	......	......	......
1:25	Bath and slag	109,000	0.11	.052	0.062	0.06	....	21.17	11.22	10.82	......
1:40	Bath and slag	109,000	0.07	.057	0.049	0.05	....	23.16	9.95	9.83	......
1:45	Cupola iron	17.200	3.80	.057	1.004	0.26	0.35	....	......	......	......
2:00	Bath and slag	126,200	0.34	.052	0.111	0.08	....	18.05	12.08	12.45	......
2:05	Cinder	2.300	....	....	......	....	....	......	......	......	......
2:05	Limestone	2,700	....	....	......	....	....	......	......	......	......
3:50	Manganese ore	400	....	....	......	....	....	......	......	......	.....
4:35	Bath and slag	126 200	0.07	.049	0.022	0.08	....	21.54	......	......	......
4:40	Cupola iron	6,100	3.80	.057	1.004	0.26	0.35	......	.....	......	......
4:50	Bath and slag	132,300	0.07	.047	0.030	0.10	....	16.28	......	......	......
4:55	Steel and slag tapped	....	0.14	.050	0.038	0.45	....	18.39	10.94	12.26	5.44

It is stated by Mr. Talbot that the output was decreased by the necessity of repairing the cupola at the week end, so that liquid iron was not available until Monday night, the furnace being run on cold stock meanwhile. I can hardly look upon this fact as of much importance, for the rate of output with liquid metal is no greater than should be obtained from such a furnace on cold stock. The furnace in which the work was done would actually hold 70 tons, as shown by the record that 156,000 pounds were in the furnace at one period of the operations, and also by the direct statement of Mr. Talbot that it was rated at 75 tons capacity. The results therefore show that a 75-ton furnace can make steel at the rate of 2100 gross tons per month. This would hardly seem to be anything extraordinary and more than one works is now operating furnaces of less capacity and making fully as much or more on all pig heats. Moreover, it is not always that open-hearth furnaces are supplied with iron containing only 0.58 per cent. of silicon, this being the average of all the iron used in the heats cited by Mr. Talbot.

The statement that there is nothing extraordinary in the output of the Talbot furnace will be questioned by some, for in the discussion of the paper before the Iron and Steel Institute it seemed to be assumed that there was something unusual in the records given and the same impression is conveyed by Mr. Talbot. Thus, in some remarks on the paper, I stated what had been done with direct metal at Steelton, and Mr. Talbot asked why the practice had not been continued when "such a splendid opportunity had been presented for increasing the output." As a matter of fact, I had not stated or intimated that the output had been increased to any wonderful extent, for we had done nearly as well on cold metal. Thus I find a time in 1896 when we were running 97.5 per cent. of cold pig-iron in a 50-ton furnace and the output was 437 tons in one week, which is at the rate of 1894 tons per month. It is not possible to give the records for long periods, because at other times a larger proportion of scrap was used. This fact may explain why no great effort was made to separate furnaces so that some would be on direct metal exclusively, as Mr. Talbot seemed to think so advisable. The use of direct metal is not revolutionary, and is not even new; it is advantageous to a certain extent, but it does not save as much time as might be expected.

In the same way it will not do to lay much stress on the gain in weight from the iron ore, which is brought forward so prominently by Mr. Talbot. It is a mistake to regard this as in any way characteristic of the method. Section XIIg will take up at length the discussion of this subject, while Sections XIIe and XIIf also bear upon the matter.

Table XII-E.

Data on Rate of Production and Elimination of Sulphur in Talbot Furnace.

Heat.	Rate of Production.		Elimination of Sulphur.	
	Weight of ingots; lbs.	Time from tap to tap. Hours-Min.	Calculated average sulphur in metal charged.	Sulphur in finished steel.
254	37,405	3—50	.041	.038
264	39,100	4—25	.048	.038
285	39,085	4—40	.058	.050
306	37,410	4—55	.054	.050
408	38,650	4—30	.049	.054
Total	191,650	22—20	....	....
Rate per 24 hours	92 tons.	....	....	....

It will be seen from Table XII-E that there was very little elimination of sulphur in any of the heats. This shows that the slag was kept fluid and not very basic, and under these conditions the furnace will run much faster and make more product than if a better steel is made. It is not extra good practice to start with iron containing only 0.58 per cent. of silicon and .05 per cent. of sulphur, and not eliminate any of the latter impurity. As a matter of fact three out of the five heats given by Mr. Talbot would not fill the standard American specifications for boiler plate.

It may be urged that there was no necessity of elimination when the content was low at the beginning. This reasoning, however, will hardly apply to the results given on pages 59 and 61,* where Mr. Talbot gives the results of two weeks' working and the composition of fifty-five heats of steel. Of these the sulphur content was as follows:

7	heats	between	.040	and	.049	per	cent.
20	"	"	.050	"	.059	"	"
21	"	"	.060	"	.069	"	"
3	"	"	.070	"	.079	"	"
3	"	"	.080	"	.089	"	"
1	heat				.090	"	"

If the slag had been made more basic, and sufficient time allowed for the elimination of sulphur, and if during all this time the

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* *Loc. cit.*

reactions had been consummated in the presence of this more basic and more viscous and more voluminous slag, the time of the charges would have been considerably increased and the amount of fuel and all other costs correspondingly greater. In the operations of the Talbot furnace as described, the iron was melted in a cupola and this tended to increase the sulphur by absorption from the coke, but on the other hand, it gave an opportunity to select the iron that was treated, and it is quite certain that a blast furnace could not be relied upon to furnish regularly a better iron than was used in the operations recited by Mr. Talbot.

It is not a pleasant task to criticize a new method on the basis of results obtained in the earlier stages of practice, for improvements will naturally come from experience, but on the other hand it is to be remembered that a new process, when carefully tended by the eager and intelligent care of an inventor, often shows results far in excess of the average obtained in after years by alien hands. It should be said in justice to Mr. Talbot that, while my views herein expressed as to the limited value of the Talbot process are shared by a great many American metallurgists, in England it has met with great approval from eminent men. It remains for the future to decide whether there is much gained. A process or practice may be successful and yet be of no very great advantage over other similar methods. I have described a method used at Steelton for handling heats of all pig-iron. The process is successful, but the gain from it does not revolutionize anything, and it has been worked side by side with the scrap practice as temporary circumstances determine. Such conditions are understood by business men, but they are apt to be overlooked by those who devise new processes.

SEC. XIId.—*The Bertrand Thiel process.**—There has been developed at Kladno, in Bohemia, a system of handling phosphoric pig-iron which has had the same misfortune that falls to the lot of most new methods. It has been over-heralded. It embodies some principles which are not new, but which have been worked out as well as the existing conditions will allow. There were two open-hearth furnaces at Kladno, and they were on two different levels, making it possible to tap from one furnace into the other by means of a runner. The higher furnace is used to remove the

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* This section, in an incomplete state, has been read by Mr. Bertrand.

silicon, part of the carbon and most of the phosphorus, while the second furnace completes the process. Four years ago, when the practice at Kladno had not been reduced to the precision it has reached since, Mr. Bertrand published* the results of twelve heats, which show that the metal was in the first or primary furnace an average of 4 hours and 50 minutes, and in the second furnace an average of 2 hours and 20 minutes.

The proportions of pig-iron and scrap are quite unimportant, as scrap may be used in either, or in both, or in neither of the furnaces. It is considered the best practice, however, to charge mostly pig-iron in the first furnace, using sufficient ore to give a good reaction and to oxidize the metalloids, and to charge some scrap in the second furnace. The stock in the second furnace is partly melted when the steel runs down to it from the primary furnace, and there is a quick and violent reaction. Care is taken to allow no slag to run from the first to the second furnace, and in this way the phosphorus, which has been eliminated in the first furnace, is kept out of the operation from that time forward. The second furnace starts with a semi-purified metal and with a new and clean slag. Following is a summary of the data given by Mr. Bertrand:

	Metal.				Slag.		
	C	P	Si	Mn	SiO_2	P_2O_5	FeO
Pig iron	3.8	1.6	1.0	1.0	....	....	....
From first furnace	2.2	0.4	.05	0.5	26.30	12.23	9.49
From second furnace	....	....	....	....	13.23	11.78	14.26

The average sulphur in the finished steel is .042 per cent., but it is stated by Mr. Bertrand that all the pig-iron contained less than .05 per cent., so there would seem to be very little elimination of this element. The average phosphorus in the steel is .067 per cent. The twelve heats may be divided as follows, in their content of this element:

1 heat .021 per cent.
2 heats between .03 and .04 " "
2 " " .04 " .05 " "
2 " " .05 " .06 " "
1 heat .075 " "
1 " .086 " "
1 " .098 " "
1 " .170 " "

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* *Journal I. and S. I.*, Vol. I. 1897.

This shows that out of these twelve heats one heat was so high in phosphorus that it could not be sold in America, while seven more were above the established standard for American basic steel. Attention is called to this fact, not so much to criticize the process, for it has been stated that the work had hardly passed beyond the experimental stage, as to illustrate that on the continent of Europe the specifications on structural steel are in no manner as severe as in America. In this country a charge known to contain .17 per cent. of phosphorus would immediately be remelted and would never be spoken of as steel. On the other side of the water it needs only to pass certain physical tests and it will unhesitatingly be accepted by Lloyds, in England, or by a hundred engineers on the Continent.

The Kladno practice has been much improved since this paper of Mr. Bertrand and the later results have been given in a paper by Mr. Hartshorne,* who has kindly given me the original reports from which his paper was written. The pig-iron used was nearly all molten and carried about 1.5 per cent. of phosphorus, while the average metal from the primary furnace ran as follows in phosphorus:

17	heats	below			.10	per	cent.
45	“	between	.10	and	.20	“	“
10	“	“	.20	“	.30	“	“
5	“	“	.30	“	.40	“	“
2	“	“	.40	“	.50	“	“
1	heat	not given.					
80							

The slags from the primary furnace contained from 20 to 23 per cent. of phosphoric acid and the following proportions of iron (Fe):

4	heats	between	6	and	7	per	cent.
22	“	“	7	“	8	“	“
16	“	“	8	“	9	“	“
12	“	“	9	“	10	“	“
7	“	“	10	“	11	“	“
2	“	“	11	“	12	“	“
1	heat	“	12	“	13	“	“
4	heats	“	13	“	14	“	“
3	“	“	14	“	15	“	“
1	heat	“	17	“	18	“	“
8	heats	not given.					
80							

During about two weeks the furnaces made an average per twenty-four hours of 7.6 heats of 12.3 tons each. This is about 94 tons per day for the two furnaces, or 47 tons for each, the maxi-

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* *Trans. A. I. M. E.*, Feb., 1900.

mum capacity of the larger being given as 13 tons. The content of phosphorus in the steel was as follows:

18	heats	below	.01		per cent.	
24	“	between	.01	and	.02	per cent.
21	“	“	.02	“	.03	“ “
8	“	“	.03	“	.04	“ “
2	“	“	.04	“	.05	“ “
4	“	“	.05	“	.06	“ “
1	heat	“	.07	“	.08	“ “
1	“	“	.08	“	.09	“ “
1	“	“	.11	“	.12	“ “

In a private communication from Mr. Bertrand I received corroboration of the foregoing practice and he gives in detail the results on two representative heats, one being made from an iron with about 1.30 per cent. of silicon, and the other with the more usual amount of 0.50 per cent. The higher silicon necessitates a larger addition of lime and reduces the content of phosphoric acid in the slag from the primary furnace, this being an objection when the slag is to be sold as a fertilizer. A condensation of the results is given in Table XII-F.

TABLE XII-F.

Representative Heats under Present Practice at Kladno.

Private Communication, February, 1901.

	Composition of Metal. Per cent.					Composition of Slag. Per cent.		
	C	Si	Mn	P	S	SiO_2	P_2O_5	Fe
Heat A—Primary furnace:								
At charging	3.50	.50	.47	1.35	......	......	......	......
1 hr. after charging	3.45	.15	.42	.93	......	20.00	15.67	11.20
2 hrs. 20 min. after charging, transferred to second furnace	2.50	.04	.10	.09	......	19.16	18.88	6.00
Secondary furnace:								
1 hr. after transfer	.35	.02	.05	.02	......	14.66	9.70	18.00
2 hrs. after transfer, tapped	.15	.02	.32	.01	......	13.00	4.99	13.50
Heat B—Primary furnace:								
At charging	3.50	1.30	.39	1.25	.025	......	......	......
1 hr. after charging	3.50	.31	.20	.99	tr	26.00	10.37	13.00
2 hrs. 10 min. after charging, transferred to second furnace	2.70	.01	.06	.17	tr	24.33	15.83	6.00
Secondary furnace:								
1 hr. after transfer	.31	tr	.10	.02	tr	13.33	14.40	11.00
2 hrs. after transfer, tapped	.16	tr	......	.02	tr	11.43	5.67	15.75

In a later communication from Mr. Bertrand, in February, 1902, he states that the presence of manganese in the pig-iron has an important bearing on the elimination of phosphorus, and it also saves time, as the slag is rendered more liquid so that the hearth remains cleaner after tapping. When there is no manganese in the pig-iron the phosphorus may be reduced to about .02 per cent., but by having 2 per cent. of manganese the proportion of phosphorus may be worked down to 0.005 per cent. in the finished steel. Such a low content is not unusual in America, but it is necessary to consider that the pig-iron at Kladno carries 1.5 per cent. of phosphorus.

The arrangements at Kladno are defective because it is necessary to bring molten iron from the blast furnace to the primary furnace in two ladles instead of one, and this primary furnace is of only 13 tons capacity, while the secondary furnace can hold 20 tons. This, however, is not the whole story. There must always be difficulties and expense where one furnace is dependent on one other furnace. One is making bottom and the other must be tapped, or the other is making bottom and the one waiting to be charged. Only by having several furnaces supplying several furnaces will such an arrangement reach its state of highest economy, and it is difficult to see how this can be done by a system of runners. It would seem as if the transfer must be made by means of ladles.

The Bertrand Thiel process would seem to be most applicable to pig-irons containing a considerable quantity of phosphorus, for the slag from the primary furnace is then of considerable value as a fertilizer on account of its phosphoric acid, and the return from this source is of no small consequence. In the northern part of the United States, where there are no pig-irons containing high percentages of phosphorus, this primary slag would be of no value, but in the South or in Cape Breton it might be an important by-product.

SEC. XIIe.—*The heat absorbed by the reduction of iron ore.*—It has been stated in Section XIIc that the reduction of iron ore by a bath of melted pig-iron does not create heat, but absorbs it, and this can be proven by finding the heat produced by the oxidation of the silicon and carbon, and the heat absorbed in the dissociation of the iron oxide. Inasmuch as it has before been stated that Mr. Talbot is in error* in supposing that this reaction produces heat in

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* For Mr. Talbot's views see *Journal I. and S. I.*, Vol. I, 1900, p. 38. I quote two representative passages: "And thus facilitates rapid chemical action, by which more heat is produced." "It will be seen that both the reducing and heat giving power of these constituents is not a mere piece of theory, but a practical fact." It may be noted that Mr. Bertrand at Kladno recognizes the great cooling effect of ore reactions.

his method of practice, it may be well to take as a basis of calculation the data given by Mr. Talbot showing the composition of the pig-iron and of the slags produced, as they represent usual and representative conditions of general open-hearth practice in America. It will therefore be assumed that the pig-iron contains 1.00 per cent. of silicon and 3.75 per cent. of carbon, it being stated that this is the pig usually melted at Pencoyd, and one ton, or one thousand kilogrammes, will be taken as a basis.

It will also be assumed that the ore is pure ferric oxide (Fe_2O_3) and the problem is to find how much ore is to be added. It is easy to calculate just how much oxygen is necessary to burn the silicon, but in addition to this a certain amount of FeO will combine with the SiO_2 to form a slag, and the relative proportions of these two substances depend upon many conditions. In the acid furnace it would not be far wrong to assume that equal weights would be called for, a condition which would roughly be expressed by the formula $5\ SiO_2\ 4\ FeO$. In the basic furnace the conditions are more complicated, as many bases are present, but as a matter of fact the relation of SiO_2 and FeO is in a general way about the same as in the acid slag. In the present case there is no need to theorize, since the necessary data are at hand; we are discussing the use of oxide of iron in the Talbot process and in the description of this process* the composition is given of thirteen different slags after the reaction with iron oxide is completed. Taking the average of these thirteen slags, we have the following:

SiO_2=12.75 per cent.=5.95 per cent. Si.
Fe=15.13 per cent.

Thus we find that when iron oxide reacts upon a bath of pig-iron, under the conditions related by Mr. Talbot, the silica coming from the oxidation of silicon and from other sources enters the slag and carries ferrous oxide with it in such proportions that 5.95 kilos of silicon accompany 15.13 kilos of metallic iron, which is in the proportion of 10 kilos Si to 25.43 kilos Fe. The relative weights of the oxides concerned will be as follows:

10 kilos Si=25.43 kilos Fe=32.69 kilos FeO=36.33 kilos Fe_2O_3

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* *Journal I. and S. I.*, Vol. I, 1900.

This is to say, that for every ton of pig-iron containing one per cent. or 10 kilos of silicon, the slag will require 32.69 kilos of ferrous oxide (FeO), while 36.33 kilos of ferric oxide (Fe_2O_3) must be added to supply it.

It will be found by simple subtraction that the reduction of 36.33 kilos Fe_2O_3 to 32.69 kilos FeO sets free 3.64 kilos of oxygen which unites with the silicon. But 10 kilos of silicon demand 11.43 kilos of oxygen, and therefore 11.43—3.64=7.79 kilos of oxygen must be supplied by further additions of ore, and since we have already satisfied all the demands of the slag, these further additions must be reduced to the state of metallic iron. These 7.79 kilos of oxygen therefore call for the addition of 25.97 kilos of Fe_2O_3,producing 18.18 kilos of metallic iron.

The statement, therefore, is as follows:

1000 kilos pig-iron contain 10 kilos of silicon.

This silicon requires 11.43 kilos of oxygen.

The 11.43 kilos of oxygen are supplied by ferric oxide, part of which is reduced to metallic iron, while the other part is reduced from Fe_2O_3 to FeO, this latter oxide combining with the silica and entering the slag.

The amount of iron reduced to the metallic state has been shown to be 18.18 kilos and the amount of heat absorbed in dissociating this from oxygen will be equal to the amount of heat formed by its union with oxygen, which will be 18.18×1746=31,742 calories.

The amount of iron present in the slag as FeO has been shown to be 25.43 kilos, and the amount of heat absorbed in converting this iron from the state of Fe_2O_3 to the state of FeO will be the difference between the amount of heat produced by burning this same amount of Fe to the state of FeO and by burning it to Fe_2O_3. This is as follows:

$$25.43\times(1746-1173)=14{,}571.$$

The total absorption of heat is as follows:

	Calories.
From Fe reduced to metallic state..................	31,742
From the reduction of Fe_2O_3 to FeO.................	14,571
Total absorption	46,313

The total production of heat will be the amount formed by the oxidation of 10 kilos of silicon plus that created by the union of the resulting silica with oxide of iron, so that the whole account stands thus:

	Calories.
Heat produced by oxidation of 10 kg. of silicon......	64,140
Heat produced by union of 21.4 kg. SiO_2 with FeO..	3,317
	67,457
Absorption by reduction of iron oxides............	46,313
Net heat produced..........................	21,144

Oxidation of Carbon:

Making the same assumptions as were made in the calculation of silicon, we have the following: 3.75 per cent. of 1000 kilos=37.5 kilos carbon, requiring 50.0 kilos oxygen. To supply 50.0 kilos oxygen will require 166.7 kilos Fe_2O_3. These 166.7 kilos Fe_2O_3 contain 116.7 kilos Fe, and the amount of heat absorbed in dissociating 166.7 kilos Fe_2O_3 will be the same as the heat created in burning 116.7 kilos Fe to Fe_2O_3, which is

$$116.7 \times 1746 = 203,758 \text{ calories.}$$

The amount of heat produced will be the amount created by the burning of 37.5 kilos carbon to carbonic oxide (CO), which is $37.5 \times 2450 = 91,875$.

The net result, therefore, of the oxidation of the carbon by ferric oxide is as follows:

	Calories.
Heat absorbed	203,758
Heat created	91,875
Net heat absorbed..............................	111,883

Silicon and Carbon Together:

The combined effect of the oxidation of the silicon and carbon has been shown to be as follows:

	Calories.
Heat absorbed in burning carbon......................	111,883
Heat created in burning silicon......................	21,144
Net heat absorption..............................	90,739

There are two other factors that must be taken into consideration. When one kilogramme of carbon unites with metallic iron the combination produces 705 calories. Similarly the union of 1 kg. of silicon with iron produces 931 calories.* Conversely when by the reaction of ore upon the bath the carbon is taken away

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* E. D. Campbell; *Journal I. and S. I.*, May, 1901.

from the iron, there must be a similar absorption of energy. In the present case it will be as follows:

Absorbed by silicon.............	10×931=	9,310
Absorbed by carbon............	37.5×705=	26,438
Total		35,748
Brought down from above.....		90,739
Total absorption		126,487

To translate these figures into a form that may be intelligible to a greater number, it has been shown that if the metalloids in molten pig-iron are to be oxidized by iron ore alone without any assistance from the flame of the furnace, then for every ton (2240 pounds) of pig-iron there must be added about 500 pounds of iron ore and the reaction will absorb so much more heat than will be produced that the metal will be 770° C. (say 1380° F.) colder at the end of the work. Of this total of 500 pounds of ore, about 367 pounds will be taken care of by the carbon, while about 80 pounds will furnish the oxide of iron to form a slag with the silica produced.

This assumes that the iron ore is added in a liquid state so that no heat is necessary to heat or melt the addition. It does not assume that the carbon is oxidized to carbonic acid (CO_2), for this is entirely out of the question. The reactions discussed are internal and must take place in the metal itself or within the covering of slag, and under these conditions carbonic oxide only can be formed. This may be subsequently burned in the furnace or regenerators, but while such combustion may decrease temporarily the amount of fuel consumed, it can have no influence on the immediate heat history of the metal.

If, however, we do assume the untenable proposition that the carbon is burned to carbonic acid (CO_2) then calculation shows that things are worse than before, for 333.4 kilos of ore must be added to supply the increased amount of oxygen needed by the carbon, instead of 166.7 kilos, as shown before, and this more than makes up for the extra heat produced. Under this assumption the figures for carbon are as follows:

	Calories.
Heat absorbed by reducing ore......................	407,516
Heat created in burning to CO_2.....................	304,988
Net heat absorbed..........................	102,528

Thus it is clear that the reaction between oxide of iron and pig-iron in an open-hearth furnace, even when the oxide is in a fluid state, does not heat the bath, but cools it, and it follows that as the flame is the only heating agent, the more rapid the reaction the lower will be the resultant temperature of the bath.

The absorption of heat by the reduction of iron ore may be illustrated in a Bessemer converter. It is quite certain that the addition of three hundred or four hundred pounds of ore at the beginning of the blow will have as much cooling effect as the addition of one thousand pounds of steel scrap. It is hardly likely that the fusion of the ore takes so much more heat than the fusion of steel, and the oxygen should be a source of heat, as it assists in burning the silicon more quickly and renders unnecessary the admission of a great volume of nitrogen that would enter if air had to be supplied. We are driven to the conclusion, therefore, that the cooling effect is due to the absorption of energy in the separation of iron from its oxygen. It may seem as if the union of this oxygen with silicon should be a source of heat, but if the silicon is present, it would be burned anyway by the blast whether the ore is added or not, and therefore the heat produced by it will be the same in either case, save a certain gain from the absence of nitrogen.

SEC. XIIf.—*The amount of ore needed to reduce a bath of molten pig-iron.*—In the last section it was found by calculation that for every ton of pig-iron there is needed 500 pounds of ore to oxidize the silicon and carbon, and of this amount 80 pounds will be used in supplying the oxide of iron for the slag. This calculation assumed that the ore was pure Fe_2O_3, which, of course, is never true, and it did not allow for the presence of silica from other sources. Every pound of silica present in the charge will claim for its own a certain amount of FeO in order to form a slag, and this calls for an increased amount of ore. It was also assumed that the pig-iron contained one per cent. silicon, and it is necessary to change the figures if there is a different content of this element. No allowance was made, moreover, for the action of the flame, as the last section was devoted exclusively to the heat generated or absorbed by an internal reaction. It may be well, therefore, to see how theoretical calculations agree with practical results.

In Section XIIb were given some data on the use of pig-iron in basic furnaces at Steelton. It was shown that in charging

544,430 pounds of pig-iron, most of it being cold, the ore used amounted to 144,100 pounds, which is 593 pounds per ton, while with liquid metal the ore was 643 pounds per ton. This is somewhat more than was found by the previous calculation, but there are two things to be taken into consideration: (1) the action of the flame, (2) the fact that the metal described in Section XIIb contained 1.4 per cent. silicon and 0.6 per cent. manganese. Table XII-G shows the amount of oxygen needed for the charges shown in Section XIIb.

TABLE XII-G.

Oxygen Needed for Pig-Iron Charges.

	Cold Pig Pounds.	Direct Metal. Pounds.
Pig iron	544.430	405.287
Silicon 1.4 per cent	7,622	5 674
Carbon 3.75 per cent	20,415	15,198
Manganese 0.6 per cent	3,267	2.432
Fe in slag	44,270	34.130
Oxygen for silicon	8.710	6.485
Oxygen for carbon	27,220	20,264
Oxygen for manganese	950	707
Oxygen for Fe in slag	12.650	9,751
Total oxygen needed	49,530	37,207
Fe_2O_3 needed	165,100	124,020
Ore needed (94 per cent.)	175.640	131 940
Ore used	144.100	116,300

Thus it is shown that in the case of the cold pig-iron, the ore used was 82.0 per cent. of what was theoretically necessary, while in the case of the liquid metal, it was 88.1 per cent. It is quite natural that a charge of cold pig-iron should show a lessened use of ore, as part of the oxidation is done by the flame during the melting. The difference will be even greater than is shown here, for the series which has been called "cold pig" was really composed of nearly 30 per cent. of molten metal, as shown in Section XIIb. Thus in the case of the liquid metal, the amount of ore called for by theory agrees within 12 per cent. of the amount actually used.

I have found a similar agreement in calculating the results of the eighty heats mentioned in Section XIId in the discussion of the Bertrand Thiel process. The average heat contained 27.140

pounds of pig-iron, nearly all of which was charged in a molten state. The average amount of ore used was 7466 pounds, corresponding to an addition of 616 pounds to the ton. But it is necessary to note that the pig-iron used in the Bertrand Thiel process at Kladno was of the following composition in per cent.:

C 3.5 P 1.5 Si 1.0 Mn 0.4

Such an iron will demand 24 per cent. more oxygen than an iron containing 1.0 per cent. Si, 3.75 per cent. C, and 0.6 per cent. Mn, and it should also be noted that in the Bertrand Thiel process much oxygen is supplied by the flame as it fuses and oxidizes the scrap in the secondary furnace, while some oxygen is furnished by the limestone.

I find also a close agreement in the records published by Mr. Talbot for his process. The six heats given by him are not consecutive, but it will be found that the composition of the metal before the first addition of pig-iron and the composition after the last addition were very similar, as shown by the following averages:

	C.	P.	Mn.
First metal	.06	.030	.10
Last metal	.13	.035	.15

It would seem fair, therefore, to add together the amounts of pig-iron and ore for the six heats, and since these additions were of nearly uniform weight, to average the figures showing the chemical composition. The results thus obtained are given in Table XII-H, all estimated figures being enclosed in parentheses:

TABLE XII-H.

Oxygen used in the Talbot Furnace.

Total pig iron in six heats	212,100 pounds.	
Average composition	C 3.75	P 0.85
	Mn 0.60	Si 0.58

Additions.	Pounds.	Per cent. metallic iron.	Pounds free oxygen.
Scale	22,400	74 5	4.768
Ore	15,100	58.0	3 754
Cinder	13,800	66.8	2,634
Manganese ore	2.500	(20.0)	620
Limestone	23,240	....	2,700
Total	....	....	14,476

The above figures show that the additions of ore and limestone account for 14,476 pounds of oxygen. This assumes that the carbonic acid set free by the decomposition of the limestone is broken up when in contact with melted pig-iron and that one atom of oxygen is set free.

The amount of silica present can be found approximately as shown in Table XII-I.

TABLE XII-I.

Silica in the Talbot Furnace.

		SiO_2 Per cent.	SiO_2 Pounds.
Scale........................	22,400	0.50	112
Ore........................	15,100	3.00	453
Cinder........................	13,800	8.00	1,104
Manganese ore...........	2,500	(8.00)	(200)
Limestone........................	23,240	(1.00)	(232)
From roof and walls (est.)...	....	....	(50)
Dolomite additions (est.)....	....	....	(40)
From oxidation of silicon...	....	....	2,636
Total........................	....	....	4,827

It has already been remarked that the average of the slags showed 12.75 per cent. SiO_2 and 15.13 per cent. Fe=19.45 per cent. FeO. According to this proportion, the presence of 4827 pounds of SiO_2 in the slag would call for 7364 pounds FeO=5728 pounds Fe to combine with it, and 1636 pounds of oxygen would be held by this iron and not be available for oxidizing the metalloids. The calculation, therefore, shows that 14,476—1636=12,840 pounds of oxygen are available. The amount of oxygen required by the different elements in the 212,100 pounds of pig-iron will be as shown in Table XII-J:

TABLE XII-J.

Oxygen in the Talbot Furnace.

Element.	Per cent.	Pounds present.	Oxygen needed, pounds.
Si	0.58	1,230	1,406 = 2,636 lbs. SiO_2
C	3.75	7.954	10,605 = 18,559 lbs. CO
P	0 85	1,803	2,327 = 4,130 lbs. P_2O_5
Mn	0.60	1,273	370 = 1,643 lbs. MnO
	5.78	....	14,708

Thus it is found that 14,708 pounds of oxygen are necessary to burn the metalloids in the iron, while 12,840 pounds of available oxygen have been added in the ore and limestone. This leaves 1868 pounds to be supplied by the flame.

It will be noted that the amount of oxygen theoretically necessary according to the figures of Mr. Talbot agrees very closely with the amount actually added and available, the discrepancy being less than 13 per cent.; and we have found that the figure given for Steelton agreed within 12 per cent. In the case of the Bertrand Thiel process, the difference was about 16 per cent., but in that case full allowance was not made for the oxidizing effect of the limestone on account of its being partially burned in a partly charged furnace.

Thus it seems certain that these calculations are not all guesswork and often there can be found corroborative testimony. For instance, Mr. Talbot gives the composition of the final slags in the furnace at the end of five different weeks. The average of these shows 39.07 per cent. CaO, the minimum being 37.65 per cent. and the maximum 40.69 per cent. In the heats we have been considering the total additions of limestone were found to be 23,240 pounds, giving about 13,000 pounds of CaO, and if the slag contained 39.07 per cent. of CaO the weight of the slag would necessarily be 33,300 pounds. In our calculations we found that there were 4827 pounds of silica added and the slag was supposed to contain 12.75 per cent. of SiO_2. This calls for 37,860 pounds of slag, so that the weight of the slag as found by these two entirely different methods agrees within about 12 per cent. Again, on an entirely different series of twenty-seven heats Mr. Talbot gives the weight of the slag, and if we calculate this so as to be in proportion to the weight of metal discussed in the foregoing investigation, the slag would weigh 42,000 pounds, when, by our two theoretical calculations founded on other heats at other times, it would be 33,300 and 37,860 pounds. Variations in the composition of the pig-iron might easily account for greater discrepancies than these.

We may therefore say with some degree of certainty that in the pig and ore process, with molten pig-iron in a basic furnace, the oxidation of the metalloids is mainly due to the ore and very little to the flame. When pig-iron is charged cold, there is more oxidation during melting and the amount of ore necessary will be reduced. When a mixture of pig and steel scrap is charged, the time of melting is lengthened and the stock is exposed longer to the flame and the proportionate amount of oxidation done by the gases is greater.

SEC. XIIg.—*Gain in weight by reduction of iron from the ore.*—When iron ore is added to an open-hearth bath, the metalloids are oxidized and the iron is reduced. This fact was explained and illustrated several years ago in the first edition of this book, and it was explained and illustrated elsewhere a score of years ago. It is only mentioned here because judging from the current issues of the metallurgical journals it seems to be the proper thing to rediscover it every few years. A certain amount of the iron oxide is lost by being carried off in the slag and this amount varies both with the amount and with the nature of the slag. An open-hearth slag will usually carry about a certain percentage of iron, and it goes without saying that under these circumstances the greater the quantity of slag the greater the loss of iron from that cause. Every pound of silicon in the pig-iron produces silica and thereby increases the amount of lime necessary and also increases the amount of iron that must accompany the resultant cinder. Every pound of silica in the ore and in the lime, and every pound that comes from the erosion of the bottom or the melting of the roof increases the volume of the slag and the loss of iron. Given the weight of silica present, together with the percentage of silica in the slag, and the weight of the slag may be found by simple division. A simpler way of making a rough estimate of the weight of a basic slag is to double the amount of burned lime used, or if limestone is added, the weight of the slag will be about 25 per cent. more than the weight of the stone. This relation arises from the facts that limestone is a little over half CaO and burned lime is somewhat less than half CaO, owing to incomplete burning and to absorbed moisture. The open-hearth slag contains from 35 to 45 per cent. of CaO and hence the proportions above given will hold good for a rough calculation. The slag will also carry as a rule about 16 per cent. of iron, so that in a general way it is easy to form an idea of what is carried away irrevocably in the cinder. For special investigation it is, of course, necessary to have actual weights and chemical analyses.

In Section XIIb there were given data on pig and ore practice at Steelton, where the gain in working cold pig was 3.1 per cent. and the gain with liquid metal 4.95 per cent. It was also pointed out that the high content of silicon in the pig-iron caused a large loss of iron in the slag and that with low silicon the loss would without doubt have been about 7 per cent.

In a paper by Mr. Talbot* there are given data on the use of pig-iron with 0.58 per cent. of silicon. Two series of charges are given in detail, on one of which the weight of the slag is given. Table XII-K gives calculations on the actual amounts of metallic iron, most of the percentages being taken from the paper just mentioned; all estimates are marked by enclosing the figure in parentheses. The weight of the slag in the second series is calculated so as to give the same weight of slag per ton of pig-iron as was given for the first series.

TABLE XII-K.

Distribution of the Metallic Iron in the Talbot Furnace.

Additions, material.	Per cent. Iron.	First Series.		Second Series.	
		Total added.	Pounds Metallic Iron.	Total added.	Pounds Metallic Iron.
Liquid pig	....	1,053,100	....	1,045,900	....
Cold pig	....	31,150	....	19,400	....
Total pig	93.94	1,084.250	1,084,544	1,065,300	1,000,743
Scrap	99.25	22,750	22,579	49,300	48,930
Ferro	(12.00)	4,140	497	4,440	533
Silico	(75.00)	2,260	1,695	2,200	1,650
Ore	58.00	89,810	52,090	112,400	65,192
Cinder	66.80	70,150	46,860	40,000	26.720
Scale	74.50	91,100	67,795	77,600	57,812
Manganese ore	(20.00)	23,250	4,650	7,600	1,520
Total	....	....	1,214,710	....	1,203,100
Ingots	....	1,146,294	....	1,130,950	....
Scrap	....	37,805	....	50,500	....
Total	99.25	1,184,099	1,175,218	1,181,450	1,172,589
Metallic iron not appearing as product	....	....	39,492	....	30,511
Slag = (15.13) per cent. Fe.	....	219,000	33,135	(215,200)	32,560
Iron unaccounted for	....	....	6,357	Excess by calculation.	2,049
Per cent. unaccounted for.	....	....	00.52	Per cent. excess	0. 17

In the discussion of Mr. Talbot's paper, Mr. Monell gave some figures of the work done at Homestead, but the data were not complete and a calculation along the same lines as the foregoing leaves 5.4 per cent. of the metallic iron unaccounted for. Mr. Harts-

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* *Journal I. and S. I.*, Vol. I, 1900.

horne in his paper on the Bertrand Thiel process* gives a summary for the work at Kladno for the week ending December 9, 1899, but this also is incomplete and the figures indicate that 8.2 per cent. has disappeared. It is only by the most careful weighing that the records can be of any value on this question of loss. Every one acquainted with the practical operation of a steel works knows how shortages appear at the semi-annual stock account. It is easy to make a mistake of one per cent. in weighing the stock for the furnace or in weighing the ingots. It will sometimes happen that scales will balance properly under a light test load and be in error with heavy loads. Sometimes the stockers will guess at the weight of ore when no one is looking and there are many other possible causes of trouble. The difference between a gain of 3 per cent. and 4 per cent. in an open-hearth furnace is a very important matter, but it is necessary sometimes to find out whether it is in the operation of the furnace or in the keeping of the accounts.

One important point in such investigations is to get the weight of scrap made. Theoretically it is easy to put it on scales and weigh it, but practically it is impossible to weigh a scull while it is in the ladle and difficult to keep record of it for future weighing. At Steelton many heats are made bottom cast where a considerable percentage of scrap is made in the sprues, and this scrap, as well as all sculls and pit scrap, go to certain special furnaces for remelting. It thus happens that an accurate account of all this scrap is necessary to get an accurate account of the product and of the loss and gain. As a matter of fact, such an accurate account has never been rendered, for we have found that in the past the amount of such scrap used far exceeded the amount reported as made. I have published figures stating the gain of metal under Steelton practice which were entirely wrong on this account, for after correcting for a subsequently discovered surplus, the gain was 1.5 per cent. higher. I give this as an illustration of the errors that may arise when the loss is found by subtracting the product from the stock used. It is exactly as if we should determine the percentage of silicon in pig-iron by determining the phosphorus, manganese, sulphur, copper and metallic iron, and then subtracting their sum from one hundred and calling the remainder silicon. Every one recognizes the error involved in making what is called a

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* *Trans. A. I. M. E.*, February, 1900.

"determination by difference." This method has its uses and the determination of the loss and gain has considerable value and is correct within certain limits, but it must not be accepted too implicitly. In all scientific or important investigations the slag should be weighed and analyzed, and then if the loss of metallic iron in the slag agrees with the iron not otherwise accounted for, there is a check on the whole calculation showing that the weights are right for both metal and slag, and the results may then be accepted as correct. The results given by Mr. Talbot answer these conditions and are therefore quoted here as corroborative of the experiments made at Steelton.

The whole matter of gain and loss in open-hearth practice is at the best a question of terms. Usually the weight of the ore is not reckoned in the calculation. Thus in a heat of all pig-iron there will be 50 tons of iron and 12 tons of ore, and if the ingots produced weigh 50 tons we say the loss is *nil*, disregarding entirely the 12 tons of ore containing over 7 tons of metallic iron. If on the other hand we add the weight of the ore, we are again wrong, for this ore contains 5 tons of oxygen, silica and water, which should by no means be charged as metal. If the actual content of metallic iron be calculated in the ore addition, then the percentage of water must be found and allowed for, and if this refinement be carried out, then certainly we must subtract the carbon and silicon in the pig-iron, which will amount to 5 per cent. of the total. In the practical conduct of a steel plant these data are not absolutely necessary, but they become of value in the discussion of different methods. Thus Mr. Talbot refers with much insistence to the gain in his process, and the fact may escape notice that a large part of the oxide additions is made up of scale containing by his own records 74.5 per cent. of metallic iron. In the case of a 50-ton charge using 12 tons of ordinary ore, carrying 62 per cent. of iron, in the wet state, the amount of metallic iron in this addition will be 7.44 tons. If the same quantity of rich scale be used, the amount of iron so added will be 8.94 tons, a difference of 1.50 tons of metallic iron in a charge of 50 tons, or 3 per cent. of the weight of ingots.

Thus the use of rich scale instead of ordinarily rich ore means an extra gain of 3 per cent. in the weight of ingots, and there is no glory to be given to the process on account of it because it is inevitable. Scale was used to bring down a bath of pig-iron long before an open-hearth furnace was built. It has less oxidizing power per unit of iron than hematite ore so that it is possible to use more than would be used of rich ore and the extra iron is clear gain.

SEC. XIIh.—*Increment in cost due to waste in the Bessemer process.*—In the operation of the Bessemer converter there is a loss of about 8 per cent. in the weight of the metal when the iron is carried in a molten state from the blast furnace to the vessel. When the iron is remelted in cupolas this loss is two per cent. more. It is evident that it will always be necessary to remelt the iron over Sunday and on holidays, so that for illustration and for the sake of simplicity it will be assumed that the loss will average 10 per cent. Many steel works exceed this figure. On this assumption, and taking no other factors into consideration, it is plain that the cost of the metal needed per ton of steel exceeds by 10 per cent. the cost per ton of the pig-iron. In other words, if the cost of pig-iron is $10.00 per ton, the cost of pig-iron needed to make a ton of steel is $11.00, which is an increase of 10 per cent. As long as the loss is 10 per cent., and the value of the pig-iron is $10.00, just so long will this item of cost exist, and no labor-saving or fuel-saving devices can affect it in the least. Similar items of cost appear in the rolling mills due to waste and scrap, and here again the amount cannot be affected by economies in fuel or labor. In order to distinguish this class of items from all others, I call them "increments," as they are augmentations of cost due to purely metallurgical conditions, and must be attacked on entirely different lines from all other items of expense.

Taking the increment in the Bessemer process, it seems clear at first glance that it will increase with the cost of pig-iron. If the waste is 10 per cent., and the pig-iron costs $10.00 per ton, then the increment should be $1.00 per ton, represented by the one-tenth of a ton of pig-iron which has been lost in the converter. If, on the other hand, the pig-iron costs $12.00 per ton, then the increment should be $1.20 per ton.

Needless to say, this apparently simple calculation is nullified by the necessity of accounting for the recarburizer, and when this is figured out, we arrive at the singular paradox that in rail steel the increment bears no relation whatever to the cost of pig-iron, but is determined entirely by the value of the spiegel, this relation being caused by the coincidence that the amount of spiegel added at the close of the operation exactly equals the waste during the blow. In the calculation of low steels, the cost of the pig-iron has a bearing on the result. In order to demonstrate the proposition, two examples will be taken with different values for pig-iron, but the same value for spiegel, and two examples with the same value for pig-iron, but different values for spiegel.

	A	B
10 tons pig-iron	@ $10.00=$100.00	@ $12.00=$120.00
1 ton spiegel	@ 20.00= 20.00	20.00
10 tons of steel	$120.00	$140.00
1 ton of steel	12.00	14.00
Increment	2.00	2.00

Showing exactly the same increment whether the pig-iron cost $10.00 or $12.00.

	C	D
10 tons pig-iron	@ $10.00=$100.00	@ $10.00=$100.00
1 ton spiegel	15.00= 15.00	@ 20.00 20.00
10 tons of steel	115.00	120.00
1 ton of steel	11.50	12.00
Increment	1.50	2.00

Showing that the increment is exactly 10 per cent. of the price of spiegel, and this will hold good no matter what prices are taken.

In the case of soft steel the conditions are quite different, for the ferro-manganese contributes very little to the weight and does not make up for the loss. Assuming in each case an addition of one-tenth of a ton of ferro to a 10-ton heat, a calculation may be made on the increment, in the same way as was just done for rail steel.

	A	B
10 tons	@ $10.00=$100.00	@ $12.00=$120.00
.1 ton	@ 60.00= 6.00	6.00
9.1 tons steel	=$106.00	$126.00
1 ton steel	= 11.65	13.85
Increment	1.65	1.85

Showing that the increment was 20 cents higher when the price of pig-iron was raised $2.00, being just 10 per cent. of the increase in price. This will hold good for other values. If the pig-iron is $14.00 per ton, the steel will cost $16.04, an increment of $2.04, which is 39 cents more than with $10.00 pig-iron, or almost exactly 10 per cent. of the increase.

Thus in the case of soft steel, the increment will increase or decrease directly with the rise or fall in the price of pig-iron, while in rail steel made by the addition of spiegel, the increment will bear no relation to the price of pig-iron, but will be 10 per cent. of the price of the spiegel.

The relative cost of rail steel and soft steel will depend upon the relative prices of spiegel and ferro-manganese as compared with the cost of pig-iron, and therefore no rule can be laid down here; but under ordinary conditions, it will be found that there is little difference in the increment in the two kinds of steel. Neither is there much difference in the other costs. In making rail steel, it is necessary to run cupolas, but, on the other hand, the product of the mill is increased 10 per cent. at a small cost.

Sec. XIIi.—*The increment in the open-hearth process.*—The increment in the Bessemer process is determined by two factors, the percentage of loss and the cost of recarburization. In the open-hearth process two other elements enter: the cost of the ore and the iron reduced from it. To illustrate the method of finding the value of the increment, it will suffice to take two different kinds of practice, one where the mixture is mostly scrap, as is usually the case in acid furnaces and often in basic work, and another where the charge is entirely pig-iron on a basic hearth. The figures are assumed arbitrarily, but will represent conditions which are quite common.

(1) Acid furnace:

10 tons pig-iron	@$11.00	$110.00
30 tons scrap	@ 11.00	330.00
1/3 ton ferro	@ 60.00	20.00
½ ton ore	@ 4.00	2.00
39.12 tons steel (3 per cent. loss)		462.00
Cost per ton of steel		11.81
Cost of pig and scrap		11.00
Increment		.81

(2) Basic furnace:

40 tons pig-iron	@ $11.00	$440.00
1/3 ton ferro	@ 60.00	20.00
12 tons ore	@ 4.00	48.00
41.54 tons steel (3 per cent. gain)		$508.00
Cost per ton of steel		12.23
Cost of pig-iron		11.00
Increment		$1.23

If a gain of 4 per cent. be assumed, the increment will be $1.11. It will easily be seen that a change in the price of ore will make a considerable difference, but it will be necessary to put the ore down to $2.50 per ton in order to make the increment in the basic furnace as low as it is in the acid, if the loss in the latter is only 3 per cent. Whether the assumptions agree or not with any particular practice, the calculations will illustrate what is meant by the increment in open-hearth work. It is the increase in cost which comes from the waste of the stock itself and the additions that are necessary for the operation.

SEC. XIIj.—*Increments in the rolling mills.*—The increments in the rolling mills are made up of two factors: the waste by oxidation and the loss in scrap. In many cases these two items are of about equal value. The iron oxidized in the heating furnaces is partly recovered as cinder, which is sometimes of little value, being mixed with the material forming the furnace bottom. The rest falls from the ingot while it is in the rolls, and this is an extremely rich oxide. All these products, however, are of comparatively small value per ton compared with the steel itself, and hence the increment due to this waste is considerable.

Assuming that the value of an ingot going into the heating furnace is $16.00 per ton and that the waste is 2 per cent., and assuming that one-half of this waste is in heating furnace cinder containing 50 per cent. of iron and worth $2.00 per ton, and that the other half of the waste is in scale containing 65 per cent. of iron and worth $4.00 per ton, we have the following calculation:

100 tons of ingots	@ $16.00			$1600.00
2 tons cinder	@ 2.00	=$4.00		
1.54 tons scale	@ 4.00	= 6.16		
Total value of by-products		$10.16		
Cost of 98 tons steel				$1589.84
Cost per ton of steel			$16.22	
Cost of ingots			16.00	
Increment from oxidation			$0.22	

In addition to the oxidation there will be an increment due to the scrap made at the shears. Assuming in the present case that this amounts to 8 per cent. of the weight of the ingot, we may combine the two increments of scrap and waste together as follows:

100 tons of ingots	@ $16.00		$1600.00
8 tons scrap	@ 11.00	$88.00	
Cinder and scale (see ante)		10.16	
Total value of by-products			98.16
Cost of 90 tons of blooms			$1501.84
Cost per ton of blooms			16.69
Cost of ingots			16.00
Total increment			.69

Thus under these conditions the total increment is 69 cents per ton, of which 22 cents are due to the oxidation and 47 cents to the scrap.

It will be evident that an increase in the cost of the raw material rolled will invariably mean an increase in the increment, since the value of scale and scrap will not keep pace with the price of blooms or billets. A rough calculation can always be made by ignoring altogether the value of the cinder and scale. The increment due to 2.0 per cent. of waste would then be 2.0 per cent. of $16.00 or 32 cents. Likewise the cost of 8.0 per cent. of scrap would be 8.0 per cent. of the difference between ingots and scrap, which in the present case has been taken at $5.00 per ton, or 40 cents. Adding the two together, we get 72 cents, which is sufficiently close to the figure of 69 cents obtained by the longer method.

It will be seen that the amount of the increment depends in great measure upon the value assigned to scrap, and that, therefore, the cost in the rolling mill may easily be manipulated by the system of bookkeeping.

Sec. XIIk.—*The duplex process.*—It has been explained that neither an acid nor a basic Bessemer converter can make steel from a pig-iron containing from .10 to 1.50 per cent. of phosphorus, while the use of all pig-iron in a stationary basic open-hearth furnace is not altogether advantageous. It is an easy and attractive solution of the problem to first desiliconize and partially decarburize in a Bessemer converter, either acid or basic and then finish in an open-hearth furnace, either acid or basic. At one works in Europe this practice has been carried on for some years, and it goes without saying that the operation is practicable and a very easy way of making steel from phosphoric pig-iron. I believe, however, that usually it is an expensive way for more than one reason. Considering the first step in the process, the treatment in an acid converter, the loss will be very nearly as much as in the making of steel.

The silicon will, of course, be entirely oxidized and this means that the full quantity of slag will be formed. It may be that the slag will be somewhat more viscous if the charge is not entirely decarburized, but under these conditions the amount of shot in the slag will be more than when the slag is liquid. It is probable that the total loss of iron, counting that which is chemically combined and that which is mechanically held will be a constant, whether the slag be viscous or liquid. The carbon must be reduced to about one per cent. if the open-hearth furnace is to do its share of the work in quick time, and we therefore have the following result:

Loss in weight in the converter:

		Per cent.
Silicon		1.50
Carbon		3.00
Iron in slag.		
Combined	1.8	
Shot	0.7	2.50
Total		7.00

Calculation of increment in converter:

100 tons pig-iron	@ $11.00	$1100.00
93 tons metal cost		1100.00
1 ton metal		11.83
Increment		.83

Calculation of increment in open-hearth furnace:

40 tons metal	@ $11.83	$473.20
½ ton ore	@ 4.00	2.00
1/3 ton ferro	@ 60.00	20.00
39.12 tons steel	(3% loss)	495.20
1 ton steel		12.66
Increment		.83

Synopsis:

Increment in converter	0.83
Increment in open-hearth	0.83
Total increment	1.66

I have assumed a very small use of ore in the open-hearth furnace, but it has been shown elsewhere that the increment is about the same whether much or little is used, as the gain in weight from reduction of iron balances the cost of the ore. Whatever changes are made in the figures, it seems certain that the increment in the converter must be very nearly the same as in the ordinary manufacture of steel, with the exception of the recarburizer, and this, of course, is found in the cost sheets of the open-hearth furnace. With this item omitted, we find that the increment in the duplex process will be the sum of the increments in the Bessemer and open-hearth processes.

It is necessary, therefore, that the duplex process should offer positive economies to offset the higher increment charge, and this it fails to do. The cost of running a Bessemer plant for this purpose will be almost exactly the same as for making soft steel. There is scarcely an item save that of molds which will not be the same as if the molten metal poured from the converter were to go to a rolling mill. But it does not go to a rolling mill; it goes to an open-hearth furnace, must be heated, ored, treated like any other charge and will take half the time that would be given to an ordinary heat if allowance is made for the interval of making bottom and other delays, which will be a constant for any charge. We have then practically all the increment of the Bessemer except the recarburizer, and all the increment of the open-hearth, including the recarburizer; we have the total working costs of the Bessemer except the molds, and at least half the working costs of the open-hearth. The sum of these items will exceed the cost of making steel by either the Bessemer converter alone or the open-hearth alone. It does not follow from these arguments that this process is everywhere inapplicable, but it is certain that the local conditions should be thoroughly studied before it is adopted.

CHAPTER XIII.

SEGREGATION AND HOMOGENEITY.

SECTION XIIIa.—*Cause of segregation.*—Every liquid has a critical point in temperature below which it may not cool without freezing into a solid state. This transformation takes place by the rearrangement of the molecules into crystals, and in this rearrangement there is a very strong tendency for each crystal-forming substance, whether it be an element or a compound, to separate from any other substance with which it may be mixed. This tendency will result in a very perfect isolation when the substances have little affinity for each other and freeze at widely different temperatures. Under these circumstances, if the temperature be very slowly lowered, the more easily frozen substances will almost completely crystallize out, leaving the more fusible in a liquid state.

It will be evident, however, that the completeness of the separation will be lessened by a hastening of the rate of cooling, or a greater similarity between the freezing points of the mixed substances. It will also depend upon the proportion of the ingredients, for it will be more difficult for a crystal to form when its constituent molecules must find their way out of a large mass of a foreign medium, and such a crystal after so forming will be more likely to contain a certain proportion of the associated substances. Under unfavorable circumstances, as when the rate of cooling is rapid, or when the substances have nearly the same freezing temperature, or when they have an affinity for each other, the differentiation may be so much interfered with that there is no appreciable separation of the components.

All these unfavorable conditions are present in the solidification of steel.

First, the temperature of a charge, when it is poured from a converter or from a furnace, is seldom more than 50° C. above the point of incipient congelation.

Second, the absolute temperature is so high, when compared with everything with which it comes in contact, that both conduction and radiation proceed with excessive rapidity.

Third, in the manufacture of ingots for plates, beams, angles, and other rolled or hammered structural material, it is the universal practice to cast the steel in direct contact with a thick iron mold, and the absorption of heat from the outside of the liquid is so rapid that a solid envelope is almost instantly formed, while the conducting power of this envelope is so great that the heat is continually carried from the interior to the surface.

Fourth, the different substances that compose the steel have so many strong affinities for each other, and combine in so many ways, that it is a gratuitous hypothesis to assume the existence of a definite carbide, or sulphide, or phosphide of iron, or a carbide, sulphide, or phosphide of manganese.

No matter how high or how low the content of metalloids in the steel, there is always a tendency toward the separation of crystals which are lower in carbon, sulphur, and phosphorus than the average, so that it is logical to conclude that there is a tendency for pure iron to crystallize, but that this is prevented by the strong affinity it has for carbon, sulphur, phosphorus, silicon, manganese and copper. This affinity, taken in conjunction with the rapid cooling, almost prevents the differentiation until a very thick envelope has formed on the outside of the ingot to check the loss of heat. Moreover, the process of segregation is self-corrective to some extent, since with every step in the contamination of the interior liquid there is an increasing tendency to the formation of impure crystals.

The liquid center is not entirely homogeneous, for, as the impurities are eliminated from the solidifying envelope, they form alloys or compounds which are more fusible and of lower specific gravity than the steel itself, so that they float on the surface of the interior lake. As the level of the metal sinks during solidification, this scum will be deposited as a film on the walls of the pipe cavity, while the history will end by the solidification of a highly impure mass in the apex of the inverted cone.

When there is only a small proportion of sulphur, or phosphorus, or carbon, their hold is so firm that the iron cannot tear itself away, but when present in larger proportion the affinity of the surplus is weaker. This will explain why the tendency to segregation increases with an increase in the content of metalloids. Manganese, copper and nickel do not come into this class, for their chemical similarity to iron prevents their separation.

Under ordinary circumstances the extent of the purification is so slight that it reduces the content of impurities in any part of the ingot but very little below the average, even though it may result in the serious contamination of the small region which is the last to solidify. This arises from the fact that the surplus is concentrated in a very small quantity of steel. Thus, if the ingot weighs 4000 pounds and contains 0.50 per cent. of carbon, the first 3900 pounds of steel which solidifies should contain 19.5 pounds of carbon, while the last 100 pounds should contain only 0.5 pound; but if there is a separation of two per cent. of the impurities during the chilling of the 3900 pounds, then this first portion will hold only 19.5—0.39=19.11 pounds of carbon, being a content of 0.49 per cent. The last 100 pounds will hold not only its fair proportion of 0.5 pound of carbon, but also the 0.39 pound rejected by the earlier solidifying part, and it will therefore contain 0.89 per cent. of carbon. Thus a considerable degree of irregularity can be accounted for without assuming any attempt on the part of the metalloids to isolate themselves from the iron, but by supposing a regular separation of iron in obedience to the fundamental laws of crystallization.

It has been stated that in addition to this simple history of the elimination of iron there is probably a definite process of separation and liquation on the part of the metalloids, which sometimes makes itself known in the formation of a very impure spot in the center of the mass. The exact circumstances under which this occurs to an excessive degree are not known. It is true that slow cooling aids in the work, and that the most marked cases are found in large masses of metal, but it is also true that both these conditions may exist without any marked irregularity.

The separation of the metalloids probably does not take place to any great extent until the external envelope of the ingot is of a considerable thickness, so that cooling is retarded. When it does occur, the compounds which are formed, being lighter than the mother metal, rise to the top, thereby making the upper part of the ingot somewhat richer in metalloids than the normal. It will also follow that the lower part of the ingot will contain less than the average content of alloyed elements, since whatever excess is in the top must have been taken from the bottom.

For this reason the center of an ingot is not always homogeneous, but this irregularity is considerably lessened in the subsequent working of the steel, particularly if it is heated for a long time, as in the case of large ingots, and also if it undergoes two different heatings and coolings, as in the case of ingots which are first rolled into slabs or blooms, and then reheated to be rolled into plates or angles. During each heating and rolling and cooling there must be a redistribution and equalization of carbon in obedience to the laws of cementation, and since the largest ingots are kept longest in the heating furnaces, it follows that this one condition of larger mass, which is favorable to segregation, is partially self-corrective.

The best-known paper on the irregularity of steel is by Pourcel,* but, unfortunately, it reads like an *ex parte* argument to prove that because some steels exhibit serious irregularities, therefore all steels have the same fault. It is not my intention to err in the opposite direction and attempt to disprove segregation because some steels are homogeneous, but I shall try to show that the facts are not all on the wrong side when viewed from a practical standpoint.

For instance, millions of tons of rails have been made, containing three or four times the amount of carbon that is usually present in structural steel, and consequently presenting tenfold the opportunity for segregation, and these rails have also contained more phosphorus than should be found in the best quality of angles, plates or shapes.

Notwithstanding that no attempt has been made to remove any segregated portion of the ingot, there have been very few, if any, failures of rails which can be ascribed to the liquation of the metalloids. Some rails have been laminated, some have shown hard spots due to insufficient mixing of the recarburizer, some have been too high in phosphorus, carbon or manganese, some have been overheated, and many more have been broken from lack of a proper roadbed, but segregation has never taken definite shape in the rail manufacture.

I shall try to show that all steels do not exhibit excessive concentration of impurities, that the highly segregated portions of an ingot are often very small isolated areas in the interior of the mass,

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* *Segregation and its Consequences in Ingots of Steel and Iron. Trans. A. I. M. E.*, Vol. XXII, p. 105.

and that by using a steel of low phosphorus it may safely be assumed that the finished material is practically uniform.

SEC. XIIIb.—*Examples of segregation in steel castings.*—The most extreme instances of irregularity would naturally be expected in large masses of steel which have been cast in sand, and which have thus cooled very slowly and quietly. In the paper above mentioned, Pourcel states that in the pipe cavity of such a casting a cake of metal was discovered which seemed to be separate from the surrounding walls. The composition of this formation, together with that of the walls of the pipe cavity and of the mother metal, is given in Table XIII-A. It should be noted in this connection that the original metal contained a much higher proportion of phosphorus than should be present in steel castings, so that the conditions were favorable to segregation.

TABLE XIII-A.

Example of Extreme Segregation in Pipe Cavity; from Pourcel, *loc. cit.*

Origin of test.	Composition; per cent.				
	C.	Si.	S.	P.	Mn.
Ladle test	.240	.336	.074	.089	.970
Wall of pipe cavity	.680	.326	.325	.318	1.490
Cake, two inches thick in pipe cavity	1.274	.410	.418	.753	1.080

As testimony in an opposite direction, I found no evidence of segregation in a steel roll made by The Pennsylvania Steel Company. This was a plain cylinder 20 inches in diameter, with a total length of 31 feet. A piece four feet long was cut from the top, this amount having been added for a sink-head, and samples of the metal were taken at different depths as the cutting progressed from

TABLE XIII-B.

Composition of a 20-inch Steel Roll, Cast in Sand, made by The Pennsylvania Steel Company, 1893.

Place from which sample was taken.	Composition; per cent.				
	C.	P.	Mn.	S.	Cu.
Two inches from outer surface	.42	.050	.46	.026	.12
Five inches from outer surface	.51	.053	.46	.029	.11
Seven inches from outer surface	.48	.064	.46	.026	.10
Nine inches from outer surface	.47	.053	.46	.026	.14

the outside to the central axis. There were no signs of piping at this point, so that the conditions are not exactly similar to those just cited from Pourcel, but inasmuch as the general practice is to remove all the honeycombed portion of such a casting, the investigation seems to be in the line of practical work. The results of analysis are given in Table XIII-B.

SEC. XIIIc.—*Examples of segregation in ingots cast in iron molds.*—Under the old system of plate manufacture, still carried out in some American works, an ingot is rolled directly into a plate at one heat, and when the sheets are of ordinarily large size, the weight of each ingot is arranged to give just one plate. It is of great importance to find whether such ingots are uniform throughout, and Table XIII-C gives the results of investigations which have been made under my supervision.

TABLE XIII-C.

Examples of Segregation in Plate Ingots.

Thickness of ingot in inches.	Part of ingot from which sample was taken.	Composition; per cent.		
		Carbon, by combustion.	Phosphorus.	Sulphur.
10	Preliminary test	und.	.053	.030
	Center, 6 inches from top	.187	.075	.065
	Center, 12 inches from top	.150	.067	.054
	Center, 18 inches from top	.179	.067	.054
	Center, 24 inches from top	.183	.062	.049
	Center, 3 inches from bottom	.145	.058	.044
10	Preliminary test	und.	.064	.051
	Center, 3 inches from top	.247	.061	.044
	Center, 6 inches from top	.364	.088	.097
	Center, 9 inches from top	.340	.078	.069
	Center, 12 inches from top	.295	.078	.069
	Center, 18 inches from top	.272	.081	.064
	Center, 3 inches from bottom	.275	.070	.057
10	Outside, 3 inches from top	.135	.007	.018
	Center, 3 inches from top	.278	.007	.029
	Center, 6 inches from top	.212	.008	.034
	Center, 12 inches from top	.205	.008	.034
	Center, 18 inches from top	.199	.008	.029
	Center, 3 inches from bottom	.159	.007	.017
	Outside, 3 inches from bottom	.164	.007	.020
10	Outside, 3 inches from top	.160	.054	.035
	Center, 3 inches from top	.230	.096	.067
	Center, 6 inches from top	.199	.084	.060
	Center, 9 inches from top	.213	.090	.068
	Center, 12 inches from top	.206	.090	.071
	Center, 3 inches from bottom	.184	.066	.042
	Outside, 3 inches from bottom	.185	.065	.031

Under another system of plate rolling, as practiced at the larger American mills, and quite extensively abroad, it is the practice to make larger ingots which are rolled into slabs, these latter being reheated for the plate train. It would naturally be supposed that these slabs would show greater segregation phenomena than are found in ordinary plate ingots, but this assumption is hardly sustained by Table XIII-D, which gives the results obtained by drilling into the axial line of slabs rolled from large ingots, made by

TABLE XIII-D.

Examples of Segregation in Large Ingots made by The Pennsylvania Steel Company.

The ingots were rolled into a slab, and this was drilled on the center line. Test A is taken just below the top crop end, B is taken one-third way down the ingot, and C from the bottom of the ingot.
The carbon in all ingots was between .15 and .25 per cent.

Heat number.	Size of ingot: inches.	Thickness of slab; in.	Origin of test	Depth at which drillings were taken; in.	Composition; per cent.				Depth at which drillings were taken; in.	Composition; per cent.				Depth at which drillings were taken; in.	Composition; per cent.			
					P.	S.	Mn.	Cu.		P.	S.	Mn.	Cu.		P.	S.	Mn.	Cu.
8188	32x38	5	A	1	.027	.017	.52	und.	2	.041	.026	.57	und.	3	.026	.017	.52	und.
8192	32x38	7	A	1	.019	.021	.56	und.	2	.018	.019	.56	und.	3	.018	.021	.60	und.
10037	32x38	6½	A	1	.058	.037	.77	und.	2	.059	.037	.77	und.	3¼	.060	.040	.85	und.
8201	32x38	6	A	½	.033	.029	.49	und.	1½	.034	.036	.49	und.	2½	.034	.032	.49	und.
			B	½	.037	.033	.49	und.	1½	.038	.038	.48	und.	2½	.046	.047	.49	und.
8202	32x38	6	A	½	.030	.022	.42	und.	1½	.033	.022	.43	und.	2½	.031	.022	.42	und.
			B	½	.039	.023	.43	und.	1½	.038	.026	.42	und.	2½	.040	.026	.42	und.
9584	32x24	10	A	1	.011	.026	.48	.13	3	.015	.036	.50	.14	5	.017	.049	.51	.14
			B	1	.014	.037	.50	.13	3	.014	.038	.51	.14	5	.016	.042	.50	.14
			C	1	.014	.030	.48	.13	3	.013	.032	.48	.12	5	.013	.030	.47	.14
9581	32x24	7	A	1	.010	.021	.42	.10	2	.010	.021	.45	.09	3½	.013	.036	.44	.08
			B	1	.009	.019	.47	.10	2	.010	.020	.42	.11	3½	.012	.035	.43	.10
			C	1	.009	.020	.42	.09	2	.009	.023	.42	.09	3½	.009	.021	.45	.09
8471	32x24	8	A	1	.020	.020	.37	.04	3	.033	.035	.36	.04	4	.037	.039	.39	.05
			B	1	.024	.025	.39	.05	3	.024	.024	.42	.03	4	.024	.024	.39	.04
			C	1	.026	.023	.36	.05	3	.027	.024	.39	.04	4	.026	.023	.38	.05
8478	32x24	7	A	....	.010	.021	.39	.10	2½	.014	.024	.38	.12	3½	.011	.021	.39	.11
			B	1	.012	.022	.37	.12	2½	.012	.026	.38	.12	3½	.017	.042	.38	.11
			C	....	.013	.020	.37	.12	2½	.012	.025	.40	.11	3½	.012	.024	.38	.12
8479	32x24	6	A	....	.013	.022	.35	.11	2	.024	.035	.40	.12	3	.032	.040	.34	.12
			B	....	.019	.023	.36	.12	2	.020	.027	.35	.11	3	.020	.033	.35	.11
			C	....	.015	.020	.36	.10	2	.017	.031	.36	.10	3	.023	.029	.43	.10

The Pennsylvania Steel Works. The points just below the top crop end, and one-third way down the ingot, are assumed to include the most contaminated region. The concentration shown in these cases probably marks the extent of the action of simple crystallization, while more extreme cases would represent the liquation of small quantities of fusible impure compounds. The content of carbon is not given, for a color determination is worthless when an accurate comparison is to be made, while in the present case the probability of error is unusually great, since the condition of the carbon will not be alike in the center and on the outside of a slab, owing to the difference in the rate of cooling. On the other hand, the estimation by combustion is so tedious that it is not always practicable to make such a large number of analyses.

SEC. XIIId.—*Attainment of homogeneity in plates.*—The fact that plates are not homogeneous when rolled from ordinary ingots does not become evident under the ordinary systems of inspection, since, as a general thing, only one piece is taken from the sheet, and this comes from the edge, but it will be shown by Table XIII-E that the variations are by no means unimportant. The first instance is taken from Pourcel,* the next three are from Cunningham,† while the last two are from my own investigations.

The data on heat 11,393 were obtained by rolling an ingot on a universal mill into a long plate. The upper third of this plate was sheared into 16-inch lengths, and tests taken along the center line and the edge. A strip was also cut from the bottom end of the plate in the center and on the edge.

The tests of heat 10,768 were cut from a "pitted" plate. The flaws in the bars render worthless any records of elongation, but the chemical results are valuable, while the determinations of tensile strength are probably approximately correct. The ingot was rolled on a shear mill to a thickness of three-quarter inch. The plate was only 112 inches long after trimming, so that the seven tests represent the entire length of the sheet.

A great deal of this irregularity between different parts of the same plate may be avoided by rolling from a slab as described in the previous section. It would, of course, be untrue to say that segregation can be avoided by making a larger ingot, or that it can be counteracted by a greater amount of work upon the steel, but it

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* *Loc. Cit.*

† *Trans. A. I. M. E.*, XXIII, p. 626, *et seq.*

is nevertheless true that a slab will usually give a much more uniform plate.

TABLE XIII-E.

Physical and Chemical Properties of Different Portions of Plates Rolled from Ordinary Plate Ingots.

Heat No.	Part of ingot corresponding to the place from which test was taken.		Ultimate strength; lbs. per sq. inch.	Elong. in 8 inches; per cent.	Reduction of area; per cent.	Composition; per cent.			Authority.
						C.	P.	S.	
Not given.	Top	edge	65426	32.0	...	.24	.050	.025	Pourcel.
		center	66848	27.0	...	.32	.100	.061	
	Bottom	edge	59636	33.0	...	.25	.060	.028	
		center	59310	32.5	...	.25	.060	.022	
Not given.	Top	edge	53600	30.7	55.9	.15	.021	...	C'nningham.
		center	53000	32.0	58.6	.17	.023	...	
	Middle	edge	52600	28.2	58.7	.15	.018	...	
		center	55900	28.5	55.0	.16	.022	...	
	Bottom	edge	55300	31.5	57.9	.16	.019	...	
		center	60200	24.5	48.1	.16	.024	...	
Not given.	Top, edge		75900	9.5	...	.22	.064	...	C'nningham.
	Second piece, edge		69700	20.0	...	.20	.058	...	
	Third piece, edge		64200	25.0	...	.18	.034	...	
	Fourth piece, edge		65700	25.0	...	.19	.043	...	
	Fifth piece, edge		65000	27.0	...	.21	.036	...	
	Sixth piece, edge		63700	25.5	...	.19	.038	...	
	Seventh piece, edge		66600	23.8	...	.20	.039	...	
	Eighth piece, edge		61400	26.0	...	.17	.030	...	
	Ninth piece, edge		66600	24.0	...	.19	.040	...	
	Bottom		64600	23.8	...	.19	.040	...	
Not given.	Edge		59200	22.5	60.8	.08	.077	.040	C'nningham.
	4 inches from edge		66600	24.5	59.1	.08	.151	.063	
	8 inches from edge		67100	23.0	54.7	.09	.141	.085	
	Center		66500	20.0	52.0	.09	.153	.085	
11393	Preliminary test		56000	...	...	...	.077	.045	Author.
	Top	edge	61600	28.75	45.9	...	.128	.078	
		center	65420	25.00	44.6	...	.087	.082	
	Second test	edge	63360	27.00	45.8	...	.110	.068	
		center	61490	27.00	44.3	...	.107	.063	
	Third test	edge	62020	25.25	38.6	...	.110	.068	
		center	60330	28.50	53.7	...	.109	.064	
	Fourth test	edge	59860	26.50	45.8	...	.098	.056	
		center	59460	29.50	52.5	...	.098	.045	
	Fifth test	edge	58940	28.50	49.9	...	.098	.056	
		center	59160	27.50	52.0	...	.096	.057	
	Sixth test; ⅓ way from top of ingot	edge	59320	27.00	47.5	...	.097	.055	
		center	58920	28.75	51.2	...	.097	.042	
	Bottom	edge	54660	34.75	66.4	...	.073	.033	
		center	53850	29.00	61.0	...	.070	.031	
10768	Preliminary test		65600	...	...	...	.059	.049	Author.
	Top	edge	62180	...	...	...	.088	.057	
		center	63840	...	...	...	.095	.058	
	Second test	edge	61140	...	...	...	.075	.048	
		center	62900	...	...	...	.083	.045	
	Third test	edge	56090	...	...	...	.051	.031	
		center	61280	...	...	...	.081	.045	
	Fourth test	edge	63480	...	...	...	.051	.033	
		center	60620	...	...	...	.084	.050	
	Fifth test	edge	53400	...	...	...	.051	.032	
		center	61420	...	...	...	.090	.051	
	Sixth test	edge	56920	...	...	...	.062	.038	
		center	61000	...	...	...	.080	.043	
	Bottom	edge	56220	...	...	...	.065	.042	
		center	60220	...	...	...	.075	.038	

This will be shown by Table XIII-F, which gives the results obtained by testing the edge and the middle of several universal-mill plates which were made from slabs from the same ingot. A careful record was kept of the position of each slab, and the tests were cut from the top end of each plate. Thus the list of tests from the successive plates gives the same information as if one long slab had been rolled into one plate and had then been cut up for testing. The segregation in the central axis is shown by a slightly higher content of metalloids, and by a higher tensile strength, but the variations between parts of the same plate, and the variations

Table XIII-F.

Physical and Chemical Properties of Different Portions of Open-Hearth Universal Mill Plates, Rolled by the Central Iron Works from Pennsylvania Steel Company Slabs.

Note.—Plate No. 1 represents the bottom of the ingot, the others being numbered consecutively toward the top.

Heat No.	No. of plate.	Part of plate.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Composition; per cent.		
							P.	S	Mn.
2905 Acid.	1	Edge, Middle,	33030 35880	54040 55000	29.50 27.50	59.1 61.8	066 .074	040 .040	.39 38
	2	Edge, Middle,	33240 34870	54000 55540	29.50 29.00	63 8 61.3	.068 .074	044 039	36 .37
	3	Edge, Middle,	32570 34670	53220 55420	31 00 30.50	62.5 62.1	.068 .074	.040 040	.37 .36
	4	Edge, Middle,	33430 35240	53400 56450	31.25 30.50	60.6 58.4	.054 074	.040 .045	.37 .35
	5	Edge, Middle,	33270 34660	54080 56840	30 75 33.00	60.7 57.1	080 .088	.047 052	.36 .35
	6	Edge, Middle,	33520 35090	54380 57380	31.00 29.25	57.3 56 7	077 087	.050 .048	.37 .38
	7	Edge, Middle,	33150 35110	54120 58180	29 25 26 25	59.5 56.2	.071 083	.046 060	.36 .36
9765 Basic.	1	Edge, Middle,	34050 31900	55360 54440	29.50 31.50	63.2 64.2	.007 .007	.038 .032	45 .43
	2	Edge, Middle,	33580 32460	55350 53780	30.50 31.75	59 2 63.6	008 007	.045 .031	45 43
	3	Edge, Middle,	33210 33170	56340 55240	28 75 32 50	57.8 63.1	.007 008	.040 035	.45 .43
	4	Edge, Middle,	33580 32550	56580 56020	30.50 30.25	56.5 60.4	.007 008	.036 036	.45 .43
	5	Edge, Middle,	33580 32800	56340 57240	28.75 30.00	58 2 58 6	007 .008	042 .040	.46 .44

between different plates, are much less than is shown in Table XIII-E for plates rolled directly from ingots.

The usual way of testing is to take a strip from a corner of the plate, and Table XIII-G gives the records so obtained from one-quarter-inch sheets, which were rolled from basic open-hearth slabs made by The Pennsylvania Steel Company. The ingots from which the slabs were made varied in section from 26″x24″ to 38″x32″, and weighed from 6 to 10 tons each. A record was kept of the part of the ingot from which each slab came, and the corresponding plates were tested both in the natural and in the annealed states.

The table gives only the results on the annealed bars, for by the reheating and cooling the artificial effects of cold finishing were avoided, and all the test-pieces were brought to a common ground of comparison. The plates of any one heat are all of one thickness, the discard of other sizes accounting for the many missing members. In each case the order in the list follows the order in the

TABLE XIII-G.

Physical and Chemical Properties of Annealed Bars cut from Plates Rolled from Basic Open-Hearth Slabs, which were cut from different parts of 10-Ton Ingots.

NOTE.—Carbon was determined by color and is therefore unreliable.

Heat number.	Thickness of plate.		Part of ingot from which slab was cut.	Ult. strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Chemical composition; per cent.			
								C.	P.	Mn.	S.
5633. 20-ton heat.	All 1/4 inch.	1st ingot.	Top,	49080	31830	36.75	65.3	.11	.015	.31	.027
				48330	31170	32.00	63.6	.15	.018	.32	.020
				47750	29980	34.50	67.0	.16	.015	.32	.022
				48500	31760	29.50	66.3	.13	.013	.31	.023
				47810	31110	33.00	68.1	.12	.015	.31	.023
				46970	30690	35.00	64.5	.12	.015	.31	.019
			Bottom,	48200	31000	32.50	64.3	.11	.017	.31	.025
			Average,	48091	31077	33.32	65.6	.13	.015	.31	.023
		2d ingot.	Top,	49380	32080	33.00	64.2	.10	.016	.31	.025
				48010	28760	33.00	65.7	.16	.018	.35	.023
				48760	32030	33.75	64.9	.13	.018	.31	.026
				49170	32010	32.00	64.2	.13	.015	.32	.024
				49040	29940	31.75	60.7	.12	.014	.31	.025
				47670	30090	33.00	63.8	.14	.013	.34	.019
			Bottom,	46860	31380	32.50	65.3	.11	.013	.32	.021
			Average,	48413	30899	32.71	64.1	.13	.015	.32	.023

TABLE XIII-G—Continued.

Heat No.	Thick. of plate.		Part of ingot from which slab was cut.	Ult. strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 in.; per cent.	Reduction of area; per ct.	Chemical composition; per cent.			
								C.	P.	Mn.	S.
5658. 20-ton heat.	All 1¼ inch.	1st ingot.	Top,	51040	32710	31.00	63.8	.13	.014	.48	.014
				51660	33080	30.50	64.1	.12	.014	.46	.021
				51620	32180	33.00	62.8	.13	.018	.42	.025
				51760	32230	32.50	63.3	.14	.011	.44	.024
				51200	31730	31.50	61.1	.13	.017	.41	.024
				50470	32310	32.75	61.8	.12	.006	.45	.023
				50260	33340	32.50	62.6	.10	.012	.45	.020
			Bottom,	50820	32320	33.00	62.1	.10	.016	.47	.021
			Average,	51104	32488	32.00	62.7	.12	.014	.45	022
		2d ingot.	Top,	52160	32450	32.00	57.0	.14	.009	.45	.025
				52050	31330	32.00	60.7	.12	.017	.46	.024
				52240	32940	33.00	62.6	.11	.018	.47	.023
				50600	33020	31.00	61.0	.11	.013	.46	.016
				50820	32240	32.25	61.2	.12	.014	.44	.022
				50360	32470	32.50	63.5	.13	.005	.45	.023
				50530	32240	32.75	60.0	.12	.013	.46	.016
			Bottom,	49880	31850	34.50	62.8	.11	.012	.46	.016
			Average,	51080	32318	32.50	61.1	.12	.013	.46	.021
8217. 50-ton heat.	All 1¼ inch.	1st ingot.	Top,	52620	32860	31.00	60.2	.16	.019	.44	.032
				52210	36130	32.50	65.0	.16	.019	.43	.032
				50940	31780	32.00	65.7	.14	.016	.44	.028
				50360	30590	28.75	60.0	.15	.019	.44	.029
			Bottom,	50000	31840	31.50	56.4	.14	.016	.44	.025
			Average,	51226	32640	31.15	61.5	.15	.018	.44	.029
		2d ingot.	Top,	51880	36380	32.50	65.5	.14	.017	.42	.029
				53060	30660	28.75	55.2	.15	.024	.44	.033
				52820	35450	27.00	62.2	.16	.021	.44	.031
				52970	32540	31.25	58.9	.15	.017	.44	.030
				52870	31340	31.75	57.9	.15	.019	.44	.032
				50860	30070	32.50	61.4	.15	.019	.44	.029
				50000	33730	35.00	62.7	.14	.017	.44	.029
			Bottom,	50950	31280	35.50	64.5	.14	.016	.44	.025
			Average,	51926	32681	31.73	61.0	.15	.019	.44	.030
8226. 50-ton heat.	All 1¼ inch.	1st ingot.	Top,	54160	38230	26.00	61.5	.13	.039	.32	.050
				53840	38210	27.25	60.1	.13	.033	.28	.058
				54460	38070	28.25	61.4	.12	.038	.32	.050
				51200	35500	31.00	64.0	.13	.023	.28	.028
				53000	38370	30.50	60.9	.12	.031	.37	.051
				51740	37310	31.00	64.9	.11	.031	.31	.047
				52420	37200	27.50	65.2	.11	.030	.29	.046
			Bottom,	53020	37600	31.25	66.3	.12	.033	.29	.050
			Average,	52980	37561	29.09	63.0	.12	.032	.31	.048
		2d ingot.	Top,	54070	38520	27.50	64.4	.12	.036	.34	.058
				54130	38350	30.25	63.8	.13	.037	.31	.053
				51520	36090	26.00	65.6	.13	.036	.31	.057
				52520	38130	30.25	63.8	.11	.031	.31	.048
			Bottom,	52980	37770	31.00	66.0	.12	.031	.29	.044
			Average,	53044	37772	29.00	64.7	.12	.034	.31	.052
		3d ingot.	Top,	54850	37830	30.00	61.9	.13	.037	.26	.056
				54480	36560	28.75	63.8	.13	.035	.20	.048
				53960	38520	29.50	63.3	.12	.034	.32	.047
				53580	37860	28.75	63.8	.12	.033	.32	.045
			Bottom,	53130	37260	25.75	54.3	.12	.031	.32	.047
			Average,	54000	37606	28.55	61.4	.12	.034	.30	.049

TABLE XIII-G—Continued.

Heat No.	Thick. of plate.		Part of ingot from which slab was cut.	Ult. strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 in.; per cent.	Reduction of area; per ct.	Chemical composition; per cent.			
								C.	P.	Mn.	S.
8233. 50-ton heat.	All ¼ inch.	1st ingot.	Top,	50270	36880	31.75	60.3	.12	.027	.35	.032
				51630	36510	32.00	64.0	.11	.023	.36	.027
				49180	35130	30.75	58.3	.11	.019	.37	.027
				50240	36090	29.25	59.2	.11	.024	.36	.030
			Bottom,	53520	36150	31.00	63.4	.13	.014	.43	.031
			Average,	50968	36152	30.95	61.0	.12	.021	.37	.029
		2d ingot.	Top,	53010	37030	27.50	61.1	.12	.027	.33	.039
				53620	39140	25.75	61.1	.13	.027	.38	.035
				51520	34270	25.50	58.0	.11	.021	.38	.032
				50400	37330	24.75	56.1	.12	.025	.40	.028
			Bottom,	52730	36810	28.50	58.0	.13	.022	.38	.031
			Average,	52256	36916	26.40	58.9	.12	.024	.37	.033
		3d ingot.	Top,	52610	36970	31.25	60.4	.13	.034	.38	.040
				51540	35700	27.00	61.5	.12	.030	.37	.033
				52760	36940	33.00	65.0	.11	.026	.37	.033
				52550	37040	32.00	62.3	.11	.028	.36	.028
			Bottom,	51480	40480	28.75	56.0	.11	.020	.39	.028
			Average,	52188	37426	30.40	61.0	.12	.028	.37	.032
8234. 50-ton heat.	All $\frac{5}{16}$ inch.	1st ingot.	Top,	56080	35890	30.00	60.0	.19	.025	.48	.030
				55580	34920	28.00	59.0	.14	.019	.46	.024
				54820	34450	31.25	62.0	.13	.019	.46	.023
				54280	35320	31.25	63.0	.14	.023	.46	.025
			Bottom,	54360	34400	30.50	62.2	.17	.022	.47	.021
			Average,	55024	34996	30.20	61.2	.15	.022	.47	.025
		2d ingot.	Top,	55680	35380	31.50	59.2	.11	.024	.49	.027
				55210	34580	29.50	62.3	.12	.024	.48	.027
				54120	35950	31.25	61.2	.14	.021	.47	.026
				53200	34460	31.25	62.7	.12	.020	.46	.020
			Bottom,	54180	34700	31.75	60.9	.13	.021	.49	.021
			Average,	54478	35014	31.05	61.3	.12	.022	.48	.024
		3d ingot.	Top,	54000	35440	31.50	62.8	.14	.020	.46	.021
				55120	36310	29.50	63.8	.13	.025	.48	.027
				54180	35060	30.75	62.9	.17	.024	.45	.028
				53940	34460	30.00	65.4	.14	.019	.46	.022
			Bottom,	53400	33590	31.25	63.6	.15	.019	.46	.020
			Average,	54128	34972	30.60	63.7	.15	.021	.46	.024
		4th ingot.	Top,	55120	34300	30.50	62.6	.16	.021	.47	.027
				54280	34940	29.50	61.9	.15	.024	.47	.025
				53980	35230	28.00	63.3	.13	.022	.54	.041
				52720	33400	32.50	63.8	.14	.021	.46	.024
			Bottom,	54720	34340	31.75	63.2	.14	.023	.46	.025
			Average,	54164	34442	30.45	63.0	.14	.022	.48	.028
		5th ingot.	Top,	53970	35710	30.25	65.3	.16	.023	.48	.024
				54640	34410	33.00	63.9	.16	.021	.47	.024
			Bottom,	53590	33210	32.00	64.9	.12	.019	.46	.021
			Average.	54067	34443	31.75	64.7	.15	.021	.47	.023
		6th ingot.	Top,	53550	35420	31.75	62.6	.15	.022	.48	.023
				54550	36180	32.00	64.6	.12	.021	.49	.026
			Bottom,	55560	37360	28.25	60.0	.15	.024	.49	.022
			Average,	54553	36320	30.67	62.4	.14	.022	.49	.024

TABLE XIII-G—Continued.

Heat No.	Thick. of plate.		Part of ingot from which slab was cut.	Ult. strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 in.; per cent.	Reduction of area; per ct.	Chemical composition; per cent.			
								C.	P.	Mn.	S.
8235. 50-ton heat.	All 1/4 inch.	1st ingot.	Top,	49880	29740	31.75	58.5	.11	.017	.32	.040
				49150	29680	33.00	63.5	.10	.017	.35	.041
				48190	30030	33.00	57.1	.11	.016	.26	.033
			Bottom,	48190	30270	30.25	60.8	.11	.016	.35	.043
			Average,	48853	29930	32.00	60.0	.11	.017	.32	.039
		2d ingot.	Top,	50480	28570	30.75	61.0	.13	.019	.33	.043
				49030	31880	33.75	62.6	.12	.018	.33	.038
				47740	29930	33.25	63.9	.10	.017	.33	.035
			Bottom,	48310	30430	33.00	64.7	.11	.019	.31	.036
			Average,	48890	30203	32.69	63.1	.12	.018	.33	.038
		3d ingot.	Top,	49630	30410	30.00	64.0	.11	.017	.36	.024
			Bottom,	48910	30510	30.50	63.0	.10	.017	.35	.033
			Average,	49270	30460	30.25	63.5	.10	.017	.36	.029
		4th ingot.	Top,	48440	30460	32.00	65.9	.10	.019	.32	.036
				47600	30530	34.00	57.2	.11	.017	.35	.036
			Bottom,	47260	29850	31.25	58.0	.13	.016	.35	.034
			Average,	47767	30280	32.42	60.4	.11	.017	.34	.035
8236. 50-ton heat.	All 5/16 inch.	1st ingot.	Top,	50660	32710	35.00	64.7	.13	.017	.45	.022
				50860	30480	33.25	63.8	.13	.021	.44	.028
			Bottom,	53860	33710	29.25	58.6	.11	.025	.46	.037
			Average,	51793	32300	32.50	62.4	.12	.021	.45	.029
		2d ingot.	Top,	54080	33970	30.00	59.4	.15	.024	.46	.031
				52680	34100	31.25	63.9	.15	.022	.46	.029
				51520	32140	33.00	61.0	.12	.018	.44	.026
				50750	32840	33.25	64.2	.14	.020	.44	.023
			Bottom,	50280	31760	31.75	65.2	.13	.013	.43	.022
			Average,	51862	32962	31.85	62.7	.14	.019	.45	.026
		3d ingot.	Top,	53440	32440	32.50	60.7	.11	.024	.42	.030
				51620	33400	32.75	65.1	.13	.019	.42	.029
				50660	32650	31.25	61.9	.14	.021	.42	.027
			Bottom,	49260	31460	31.00	65.0	.15	.020	.41	.026
			Average,	51245	32488	31.88	63.2	.13	.021	.42	.028
		4th ingot.	Top,	52060	32460	31.75	64.2	.15	.028	.44	.030
				54260	34450	30.00	59.4	.17	.026	.44	.028
				52880	33450	29.50	62.8	.14	.024	.45	.030
			Bottom,	50890	32090	33.75	61.4	.10	.018	.42	.029
			Average,	52523	33113	31.25	62.0	.14	.024	.44	.029

ingot from top to bottom, and it will be seen that, as a rule, the plates from the top give a slightly higher strength than those from the bottom, but that the variations are unimportant, not being as great as will often be found in different parts of a single plate rolled from an ordinary plate ingot.

The carbon determinations in Table XIII-G are inaccurate, since they were made by the color method. The work was performed by men who are regularly engaged in doing nothing else, and without any attempt at extra care, but in order to see whether there really were any such differences in composition as the records would indicate, the samples showing the widest variations in three heats were reworked twice by color and once by combustion; the results are given in Table XIII-H, and show that the variations in any one heat are in the third place from the decimal point, which is close to the limit of experimental error.

Table XIII-H.

Showing that Variations in the Carbon Content in the Test-Pieces Given in Table XIII-G are Due to Analytical Errors.

Group A is made up of pieces showing the highest carbons in the heat, and Group B of those showing the lowest.

Heat No.	Group.	Composition; per cent.					
		Original as given in Table XIII-G.			Reworked.		
		Carbon by color.	P.	Mn.	Duplicate determinations by color.		Average of group by combustion.
5633	A	.15	.018	.32	.13	.14	.118
		.16	.015	.32	.13	.13	
	B	.11	.015	.31	.13	.14	.124
8234	A	.19	.025	.48	.18	.19	.165
		.17	.022	.47	.17	.18	
		.17	.024	.45	.15	.16	
	B	.11	.024	.49	.17	.17	.158
		.12	.024	.48	.15	.16	
		.12	.020	.46	.16	.17	
8236	A	.15	.028	.44	.14	.14	.150
		.17	.026	.44	.14	.15	
	B	.11	.024	.42	.13	.13	.149
		.10	.018	.42	.14	.14	

Sec. XIIIe.—*Homogeneity of acid open-hearth rivet and angle steel.*—A very good opportunity of investigating the homogeneity of a heat of steel occurs in the manufacture of rivet rods and angles, where tests may be conveniently taken from many different members. In the case of rivet rods, the test-pieces will represent the entire cross section of the ingot, and thus include the segregated portions. Table XIII-I gives the records obtained from several tests taken at random from the piles of rivet rods from five different heats, without any knowledge as to what part of the heat or what part of the ingot the tests came from.

The data on the natural bars are arranged in the order of tensile strength, while in parallel columns are given the results obtained by annealing the same bar. Although all the pieces of one heat were annealed at the same time, and with the utmost care to have all conditions uniform, it will be seen that the variations in the strength of the treated bar are entirely independent of the variations in the strength of the natural bar. This would indicate that the differences are due to irregularities in rolling and to determinative errors rather than to any inherent variations in the character of the metal.

TABLE XIII-I.

Tests on Rivet Rounds taken from Different Parts of the Same Heats.

All steels were made by The Pennsylvania Steel Co.

Heat No.	Kind of steel.	Weight of charge.	Diameter of bar.	Composition; per cent.	Ultimate strength; pounds per square inch.		Elastic limit; pounds per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
					Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.
10167.	Acid open-hearth.	110,000 pounds.	¾ inch.	C=.11; P=.053; S=.022; Mn=.34; Cu=und.	61260	55640	43960	34420	31.25	30.00	60.30	66.24
					60950	54760	42430	34840	32.00	29.50	62.73	65.91
					60800	52700	42790	33800	32.00	31.50	65.25	68.88
					60720	55130	43600	34700	31.25	32.50	66.76	67.87
					60210	54600	41160	34040	30.50	30.75	62.60	65.68
					60010	54360	41720	34040	30.50	32.50	66.76	67.74
					59970	54820	40770	33840	30.50	32.00	63.97	64.92
					59710	54340	40900	34320	32.50	32.50	63.43	63.78
					59620	54040	40920	34120	33.00	30.00	57.70	66.39
					59300	54600	40320	34030	34.50	33.00	65.96	68.05
	Average,				60260	54500	41860	34220	31.80	31.42	63.55	66.54
10163.	Acid open-hearth.	110,000 pounds.	⅞ inch.	C=.10; P=.011; S=.107; Mn=.40; Cu=.17.	56040	49990	37710	30200	33.25	34.75	65.73	66.70
					56000	50520	37800	30700	35.00	34.25	64.26	69.18
					55520	50520	37890	31750	31.50	35.75	61.86	66.94
					55420	51000	37360	31165	31.75	34.50	62.18	67.97
					55080	49460	36130	30910	33.00	34.75	56.03	68.70
					55040	51170	37980	31475	34.75	34.50	65.48	69.50
					54980	50400	37710	30665	33.00	35.50	59.64	69.68
					54950	50640	37800	31345	31.75	35.00	67.02	69.28
					54860	50520	37980	31970	33.00	35.00	64.09	68.04
					54720	50940	36830	31900	33.75	35.75	55.25	67.85
	Average,				55260	50520	37520	31210	33.07	34.97	62.15	68.38
10156.	Acid open-hearth.	110,000 pounds.	⅞ inch.	C=.09; P=.012; S=.021; Mn=.35; Cu=.12.	54000	48870	36230	30990	33.75	33.75	62.30	70.59
					53500	49460	35960	31220	34.50	36.25	63.32	68.27
					53400	48520	35710	31520	33.50	35.50	64.05	69.28
					52690	48290	35880	31190	33.75	32.50	66.49	68.77
					53300	48460	36060	31370	33.75	34.25	61.57	68.14
					52620	49760	35080	32710	33.75	36.25	68.27	67.52
					52620	48640	35080	30490	33.75	36.25	65.29	69.43
					52620	48520	35950	30590	31.25	35.00	62.04	69.49
					51910	49230	36230	32580	32.25	34.50	58.63	67.98
					51900	48410	34840	30350	33.75	83.75	63.72	66.95
	Average,				52860	48820	35700	31300	33.40	34.80	63.57	68.64

TABLE XIII-I—Continued.

Heat No.	Kind of steel.	Weight of charge.	Diameter of bar.	Composition; per cent.	Ultimate strength; pounds per square inch.		Elastic limit; pounds per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
					Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.
10168.	Acid open-hearth.	110,000 pounds.	¾ inch.	C=.12; P=.013; S=.024; Mn=.29; Cu=.27.	55480	49460	37600	29870	32.50	28.75	67.45	65.30
					55480	49940	36670	30350	32.50	31.25	68.22	65.30
					55430	49460	38400	30110	33.25	31.75	68.40	67.70
					55400	49700	37250	31300	30.00	35.00	64.67	69.22
					55160	49700	37950	32730	30.00	32.50	64.97	69.22
					54770	50720	37600	31760	32.50	30.00	69.68	64.62
					54750	50420	38400	32740	33.75	33.75	63.15	61.12
					54690	50010	39120	32470	32.75	32.50	67.35	67.96
					54520	50880	38640	32220	33.00	31.25	67.17	67.25
					54220	49770	38900	32230	33.75	33.75	66.57	69.47
			Av'r'ge		54990	50006	38053	31578	32.40	32.05	66.76	66.72
			⅞ inch.	C=.12; P=.013; S=.024; Mn=.29; Cu=.27.	55000	50230	37710	31950	31.75	33.75	66.31	70.77
					54780	49170	37100	30310	33.75	36.00	62.83	68.77
					54700	50880	36750	31620	32.50	34.00	60.11	66.70
					54180	48820	37450	30840	31.75	35.00	62.30	68.77
					54170	48290	36580	30840	31.25	34.00	67.83	68.77
					53880	48930	36320	30730	31.00	36.00	60.20	68.43
					53770	50520	35610	31670	32.50	34.00	60.02	65.08
					53770	49060	35960	31120	32.75	35.50	65.73	69.76
					52860	50160	35700	31920	33.25	35.50	61.39	69.57
					52600	50640	35360	32400	33.00	35.00	68.49	68.62
	Average,				53970	49670	36450	31340	32.35	34.87	63.52	68.52
1820.	Basic open-hearth.	40,000 pounds.	⅞ inch.	C=.11; P=.02; S=.025; Mn=.31.	48340	. . . . .	33065	. . . . .	34.50	. . . .	71.87	. . . .
					47380	. . . . .	31530	. . . . .	35.00	. . . .	72.05	. . . .
					48450	. . . . .	33650	. . . . .	35.00	. . . .	72.05	. . . .
					48230	. . . . .	31600	. . . . .	37.00	. . . .	74.14	. . . .
					49175	. . . . .	33340	. . . . .	36.25	. . . .	70.09	. . . .
					48560	. . . . .	32760	. . . . .	33.75	. . . .	72.95	. . . .
					47730	. . . . .	33260	. . . . .	35.00	. . . .	74.49	. . . .
					48785	. . . . .	32130	. . . . .	34.00	. . . .	71.80	. . . .
					48640	. . . . .	32935	. . . . .	34.25	. . . .	71.92	. . . .
					49440	. . . . .	33270	. . . . .	34.00	. . . .	71.48	. . . .
					47835	. . . . .	32900	. . . . .	34.00	. . . .	72.72	. . . .
					48050	. . . . .	31920	. . . . .	33.75	. . . .	71.42	. . . .
					48360	. . . . .	32185	. . . . .	36.25	. . . .	74.28	. . . .
					48400	. . . . .	33880	. . . . .	33.75	. . . .	73.64	. . . .
	Average,				48384	. . . . .	32745	. . . . .	34.75	. . . .	72.49	. . . .

In further proof of this, drillings were taken from the three annealed bars of heat 10,168, which showed the highest tensile strength, and from the three which were the weakest. The results of analysis are given in Table XIII-J.

The ingots from which these rivet rods were made measured 16″x20″ in cross section and weighed about two tons each. In the case of angles it is the practice at The Pennsylvania Steel Works to roll a larger ingot than is used elsewhere for the same purpose, the cross section being 24″x26″, and the weight about 5 tons. In order to test the uniformity of the material, the blooms from several such ingots were stamped so as to denote from what part of the ingot each one came, and drillings were taken from the corresponding finished angles.

TABLE XIII-J.

Composition of Rivet Rods from Heat 10,168, which showed the Greatest Differences in the Tensile Strength of the Annealed Bars.

Nature of Sample.	Ultimate strength; pounds per sq. inch.		Composition; per cent.			
	Natural.	Annealed.	C.	P.	S.	Mn.
Preliminary test	52280	. . . . . .	.12	.013	.024	.29
Average of strongest three bars of ⅞ inch diameter . . .	53690	50680	.12	.013	.019	.30
Average of weakest three bars of ⅞ inch diameter . . .	54077	48680	.12	.013	.024	.30

The results of analysis are given in Table XIII-K, and they show that each ingot was practically uniform throughout. The drillings were taken so as to include the center of the bar, which is the most impure portion. In each case the first bloom in the list is the top of the ingot, and the last is the bottom; the varying number of blooms in the ingots arises from the different weight of the angles to be made.

SEC. XIIIf.—*Homogeneity of high-carbon steels.*—It would naturally be expected that segregation would be most marked in ingots of high-carbon, because such metal remains liquid for a long time. It is found, however, that even under these conditions separation of the impurities does not always occur. This will be shown by Tables XIII-L and XIII-M, which give the results of certain investigations by The Pennsylvania Steel Company. The data on carbon in Table XIII-L are of little importance, for a color determination is well-nigh worthless on such high steels.

The determinations of carbon in Table XIII-M are made by combustion and are accurate, and they show a considerable variation in the distribution of this element; this might be expected when such a large proportion is present, and its hold upon the iron correspondingly less firm. The sulphur and phosphorus are very regular, the variations in the purer metal being almost within the limits of error. In the ingot of medium phosphorus, the percentage of variation is no more than in the others, but the actual range is greater. Although this would follow naturally, it is possible to show, by an incident which happened under my own observation, that concentration does not always occur, even in the case of impure steels.

TABLE XIII-K.

Chemical Composition of Angles, rolled from 26″x24″ Ingots of Acid Open-Hearth Steel, made by The Pennsylvania Steel Company.

NOTE.—The angle from the top of the ingot is marked No. 1, the next No. 2, and so on consecutively to the bottom.

Heat number.	No. of ingot.	No. of angle.	Composition; per cent.			No. of ingot.	No. of angle.	Composition; per cent.			No. of ingot.	No. of angle.	Composition; per cent.			No. of ingot.	No. of angle.	Composition; per cent.		
			S.	P.	Mn.			S.	P.	Mn.			S.	P.	Mn.			S.	P.	Mn.
11391	A	1	.043	.063	.41	B	1	.033	.069	.41	C	1	.045	.065	.40	D	1	.044	.060	.41
		2	.030	.066	.39		2	.039	.068	.41		2	.041	.065	.39		2	.033	.064	.41
		3	.043	.063	.40		3	.036	.063	.42		3	.042	.058	.40		3	.038	.058	.40
		4	.041	.061	.40		4	.045	.068	.41		4	.038	.058	.43		4	.037	.062	.40
		5	.042	.031	.42		5	.031	.051	.42		5	.039	.057	.40		5	.040	.060	.42
		6	.036	.061	.39		6	.035	.065	.42		6	.036	.060	.39		6	.033	.062	.41
		7	.033	.060	.40		7	.033	.060	.42		...	...	...	...		7	.033	.058	.41
		8	.033	.056	.41		...	...	...	...		...	...	...	...		...	...	...	...
	E	1	.032	.049	.41	F	1	.054	.076	.40	G	1	.039	.081	.39	H	1	.039	.068	.40
		2	.039	.062	.40		2	.041	.062	.41		2	.039	.067	.39		2	.039	.064	.35
		3	.039	.063	.40		3	.039	.059	.37		3	.039	.060	.40		3	.036	.059	.38
		4	.039	.062	.41		4	.041	.058	.41		4	.037	.061	.38		4	.034	.057	.39
		5	.039	.062	.41		5	.039	.058	.42		5	.036	.060	.38		5	.034	.057	.38
		6	.041	.054	.41		...	...	...	...		6	.033	.056	.38		6	.037	.064	.39
		7	.037	.060	.42		...	...	...	...		7	.033	.055	.41		...	...	...	...
10867	A	1	.052	.080	...	B	1	.034	.081	...	C	1	.051	.074	...		...	...	...	...
		2	.049	.064	...		2	.041	.073	...		2	.048	.067	...		...	...	...	...
		3	.044	.076	...		3	.040	.071	...		3	.040	.061	...		...	...	...	...
		4	.052	.059	...		4	.041	.070	...		4	.040	.065	...		...	...	...	...
		5	.040	.069	...		5	.040	.069	...		5	.040	.061	...		...	...	...	...
		6	.025	.070	...		6	.042	.069	...		6	.033	.068	...		...	...	...	...
		7	.033	.068	...		7	.040	.067	...		7	.040	.069	...		...	...	...	...
		8	.042	.068	...		8	.042	.063	...		8	.032	.067	...		...	...	...	...
		9	.038	.067	...		9	.036	.062	...		9	.036	.068	...		...	...	...	...
		10	.039	.066	...		10	.034	.063	...		...	...	...	...		...	...	...	...
		11	...	...	...		...	...	...	...		...	...	...	...		...	...	...	...

A 50-ton acid open-hearth charge had been made containing .46 per cent. of carbon, together with unusually high manganese, phosphorus, and silicon. The ingots had a cross section of 16″x20″, and weighed about 4000 pounds each. In loading them, one fell over and "bled" at the top. The amount of liquid metal thus lost did not exceed 25 pounds, although the cavity was completely emptied, so that if segregation existed to any considerable extent it should appear in this metal which remained liquid to the last. Table XIII-N will, however, show that very little segregation had taken place.

TABLE XIII-L.

Distribution of Elements in a High-Carbon, Low-Phosphorus Open-Hearth Ingot, 14 inches square, 63 inches long.

NOTE.—Made by The Pennsylvania Steel Company. Carbon was determined by color, and is, therefore, only approximate.

Part of the ingot from which test was taken.	Depth from which drillings were taken; in inches.	Composition; per cent.					
		C.	P.	Mn.	Average.		
					C.	P.	Mn.
Four inches from bottom,	2	.79	.013	.20	.77	.013	.20
	4	.78	.015	.20			
	6	.79	.013	.19			
	7	.72	.012	.19			
Fifteen inches from bottom,	2	.77	.011	.20	.81	.012	.20
	4	.87	.015	.20			
	6	.84	.011	.20			
	7	.78	.011	.19			
Twenty-six inches from bottom,	2	.80	.012	.18	.84	.012	.20
	4	.89	.014	.21			
	6	.85	.014	.21			
	7	.81	.009	.20			
Thirty-seven inches from bottom,	2	.77	.011	.20	.85	.013	.20
	4	.90	.014	.21			
	6	.89	.015	.20			
	7	.83	.012	.20			
Forty-eight inches from bottom; all above this would be cut off as scrap when the ingot is rolled,	2	.79	.011	.21	.88	.014	.20
	4	.91	.014	.20			
	6	.89	.016	.19			
	7	.94	.014	.21			
Four inches from top,	2	.74	.010	.21	.91	.016	.21
	4	.90	.016	.21			
	6	.95	.017	.21			
	7	1.06	.023	.21			

SEC. XIIIg.—*Homogeneity of acid open-hearth nickel steel.*—It is the current impression among manufacturers of nickel steel that the presence of this element prevents segregation. In order to have some evidence upon this point, an investigation was conducted on an ingot of nickel steel made by The Pennsylvania Steel Company. The cross section of the ingot was 18"x20", and the weight about 5500 pounds. This was rolled into a piece 16 inches wide, 5 inches thick, and 20 feet long, and cut into five slabs.

The top slab was rolled into a three-eighth-inch universal plate, the second slab into a three-eighth-inch sheared plate, the third slab into a half-inch universal plate, the fourth slab into a half-inch sheared plate, and the fifth slab was hammered into a bloom and then rolled into 6″x4″ angles.

TABLE XIII-M.

Distribution of Elements in 7-inch Square Blooms Rolled from High-Carbon, Open-Hearth Ingots, 14 inches Square.

A slice was cut crosswise from the rolled bloom at different places and drillings taken from the *center* of this slice, corresponding to the center of the ingot.

Kind of ingot.	Place from which slice was taken.	Composition; per cent.				
		C by comb.	P.	Mn	S.	Si.
Low-phosphorus ingot.	Ladle test	.984	.013	.09	.022	.12
	Top of ingot after cutting off 20 per cent. as scrap	.941	.015	.11	.012	.09
	One-fourth way down the ingot	.990	.019	.11	.010	.10
	One-half way down the ingot	.991	.017	.11	.012	.09
	Three-quarters way down the ingot	.982	.020	.11	.010	.11
	Bottom of ingot	1.012	.016	.11	.010	.11
Medium-phosphorus ingot.	Ladle test	1.440	.050	.28	.016	.12
	Top of ingot after cutting off 20 per cent. as scrap	1.205	.064	.28	.015	.16
	One-fourth way down the ingot	1.430	.059	.27	.015	.12
	One-half way down the ingot	1.443	.051	.27	.013	.12
	Three-quarters way down the ingot	1.400	.053	.27	.014	.13
	Bottom of ingot	1.459	.055	.27	.012	.12
Low-phosphorus ingot.	Ladle test	.913	.024	.13	.019	. .
	Top of ingot after cutting off 20 per cent. as scrap	.925	.021	.13	.018	. .
	One-fourth way down the ingot	.965	.022	.14	.018	. .
	One-half way down the ingot	.948	.021	.13	.020	. .
	Three-quarters way down the ingot	.956	.025	.13	.021	. .
	Bottom of ingot	.943	.021	.13	.021	. .

TABLE XIII-N.

Composition of the Liquid Interior of an Ingot as Compared with the Ladle Test of the Same Charge.

Origin of sample.	Composition; per cent.				
	Carbon by combustion	P.	S.	Mn.	Si.
Metal from interior	.480	.095	.047	0.95	und.
Ladle test	.461	.091	.034	1.13	.12

Each end of each slab was marked so as to note whether it was toward the top or bottom of the ingot, and the location of each test-piece in each plate was kept of record. Table XIII-O gives the physical and chemical results obtained from the different strips, while the diagram immediately below the table represents the entire length of the original piece produced by rolling the 18″x20″ ingot to a section of 16″x5″. The numbers on this diagram correspond to the numbers of the test-pieces in the table, and serve to mark the exact place in the ingot from which the corresponding test-piece was derived.

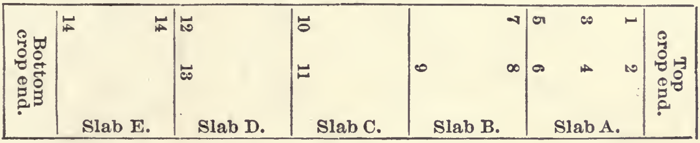
TABLE XIII-O.

Homogeneity of Acid Open-Hearth Nickel Steel.

Size of ingot, 18″x20″; made by The Pennsylvania Steel Company. Composition of preliminary test, per cent.: C, .24; Mn, .78; P, .032; S, .027.

Slab mark.	Shape into which slab was rolled.	No. of test.	Composition; per cent.				Ultimate strength; pounds per square inch.	Elastic limit; lbs. per square inch.	Elongation in 8 inches; per cent.	Elongation in 2 inches; per cent.	Reduction of area; per cent.
			Ni.	P.	Mn.	S.					
A	⅜-inch universal mill plate.	1	3.22	.038	0.78	.036	86480	59000	19.25	37.00	47.8
		2	3.21	.040	0.80	.046	88500	59500	20.50	36.00	39.1
		3	3.31	.035	0.78	.034	85140	59240	21.75	39.00	54.2
		4	3.24	.039	0.78	.036	88700	58100	19.75	34.50	38.6
		5	3.22	.031	0.77	.028	84080	57320	21.25	40.00	53.1
		6	3.29	.037	0.77	.026	85400	59410	19.75	38.00	51.5
B	⅜-inch sheared plate.	7	3.27	.035	0.77	.034	84440	58800	19.50	37.00	48.8
		8	3.29	.039	0.77	.037	86680	59640	17.00	31.50	42.8
		9	3.27	.037	0.78	.038	86520	59560	20.50	37.00	52.6
C	½-inch universal mill plate.	10	3.22	.037	0.77	.032	86200	58260	21.00	40.00	54.1
		11	3.22	.037	0.78	.032	85660	56760	22.00	42.00	53.1
D	½-inch sheared plate.	12	3.21	.035	0.77	.034	85180	56800	19.00	34.50	50.2
		13	3.21	.035	0.78	.033	84020	57600	20.50	39.00	52.2
E	Angles.	14	3.25	.038	0.77	.033	86960	58550	21.75	39.67	50.5

NOTE.—The following diagram shows the parts of the ingot which correspond to the places in the plates from which the tests, given in the third column of above table, were taken.



It will be seen that there are evidences of segregation, both in a slightly higher tensile strength and in higher phosphorus and sulphur, in the center of the ingot near the top, but the differences are unimportant, and in view of the fact that the carbon in the steel was .24 per cent., there seems to be good ground for the assumption that nickel prevents the separation of the metalloids. It has not prevented it altogether, however, and it is not probable that any other agent will ever be found competent for this task.

TABLE XIII-P.

Segregation in Swedish Ingots.

Calculated from Wahlberg: Journal I. and S. I.. Vol. II, 1901. Left-hand figures in each rectangle = surface at top and bottom. Right-hand figures = centre of ingot at top and bottom. Each figure is average of determinations by three chemists. Plain figures = carbon; parentheses in italics = phosphorus.

A	Surface.	Center.
Top.	096 (*.028*)	.159 (*.091*)
Bottom.	.095 (*.031*)	.128 (*.056*)

E	Surface.	Center.
Top.	.470 (*.024*)	.475 (*.029*)
Bottom.	.483 (*.025*)	.469 (*.023*)

I	Surface.	Center.
Top.	.929 (*.035*)	1.032 (*.055*)
Bottom.	.975 (*.043*)	.932 (*.039*)

B	Surface.	Center.
Top.	.128 (*.012*)	.129 (*.015*)
Bottom.	.106 (*.013*)	.115 (*.013*)

F	Surface.	Center.
Top.	.508 (*.033*)	.590 (*.063*)
Bottom.	.495 (*.034*)	.486 (*.035*)

J	Surface.	Center.
Top.	1.032 (*.025*)	.906 (*.021*)
Bottom.	.982 (*.025*)	1.024 (*.027*)

C	Surface.	Center.
Top.	.125 (*.020*)	.207 (*.056*)
Bottom.	.117 (*.019*)	.140 (*.034*)

G	Surface.	Center.
Top.	.591 (*.026*)	.594 (*.031*)
Bottom.	.549 (*.026*)	.543 (*.025*)

K	Surface.	Center.
Top.	1.055 (*.025*)	1.202 (*.040*)
Bottom.	1.102 (*.026*)	1.099 (*.026*)

D	Surface.	Center.
Top	.220 (*.022*)	.270 (*.042*)
Bottom.	.192 (*023*)	.218 (*.030*)

H	Surface.	Center.
Top.	.612 (*.030*)	.675 (*.034*)
Bottom.	.625 (*.033*)	.631 (*.034*)

L	Surface.	Center.
Top.	1.234 (*.028*)	1.262 (*.033*)
Bottom.	1.240 (*.031*)	1.217 (*.031*)

SEC. XIIIh.—*Investigations on Swedish steel.*—The experiments related in this chapter were for the most part made at Steelton; manufacturers, as a rule, do not want to discuss segregation at all, and published records are rare. Very recently, however, a careful account has been written by Wahlberg* on certain investigations on Swedish steels. He gives the determinations by three chemists

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* *Journal I. and S. I.*, Vol. II, 1901.

of the carbon and phosphorus in several different steels and Table XIII-P shows the averages made from his tables. Inspection will show that B, E, G, H, J and L, which is to say one-half of all the ingots, showed practically no segregation of either carbon or phosphorus. F, I and K showed segregation in the center of the top of both carbon and phosphorus, but none elsewhere. C and D showed segregation in the top and a slight amount in the centre of the bottom, while A showed quite marked segregation in the top and a very considerable amount in the bottom of both carbon and phosphorus. It will be evident, however, that by cutting off the top of the ingot the remainder of the steel will be practically uniform, for, as before pointed out, the central axis constitutes but a small portion of the finished material.

The burden of the testimony given in this chapter is to the effect that segregation is an ever present factor; that the extent of the concentration bears a certain relation to the proportion of impurities that are present; that manganese, copper and nickel do not segregate to any extent, but that certain portions of the finished material will contain a higher percentage of carbon, phosphorus and sulphur than will be found in the tests cut from the edge of plates and bars, or than will be shown by an analysis of the preliminary test. It is also indicated that a degree of uniformity, sufficient for practical needs, may be expected if the initial metal is low in phosphorus and sulphur.

CHAPTER XIV.

INFLUENCE OF HOT WORKING ON STEEL.

SECTION XIVa.—*Effect of thickness upon the physical properties.*—One of the fundamental difficulties in writing specifications is to decide the nature of the test-piece to be required, inasmuch as the strength and ductility will vary in pieces of different thickness, while the results will not be alike in tests cut from different structural shapes, like plates, angles and rounds, even though they be rolled from the same steel. From one point of view each piece of metal throughout a bridge should be of exactly the same strength per unit of section without regard to its thickness; but in taking this as a basis a serious trouble is encountered. Suppose, for instance, that a metal is required running between 56,000 and 64,000 pounds per square inch, and a charge is made which in three-eighth-inch plate gives 57,000 pounds. If this steel be rolled into seven-eighth-inch angles, or into one-inch plate, or into two-inch rounds, it is quite probable that these will run below the allowable minimum. On the other hand, if the steel gives 62,000 pounds in a preliminary test, the larger sections will give proper results, while one-quarter-inch plate will be too high in ultimate strength.

Where a structure is to be made of large quantities of very large or very small sections, it is well to specify that the test shall be made on the special thicknesses needed, but in ordinary cases it seems absurd to the practical mind that a heat of steel can be perfectly suitable for one size and unsuitable for another. It was the custom in the past for inspectors to recognize the situation and make tests from the usual sizes, with a full knowledge that thicker and thinner members would give different results, but in later practice there is a growing tendency to test each separate thickness, a change which has been the cause of great expense to the manufacturer. Provisions to cover this point should be incorporated into contracts and a certain definite allowance made for variations in the dimensions of the finished material. On the other hand the requirements should be worded so that manufacturers would be obliged to put sufficient work on large members to render them of proper structure.

There is often a confusion of terms in considering the effect of work as represented by a large percentage of reduction from the ingot, and the effect of finishing at a low temperature. This is found most often in the case of plates, for it has been quite a general practice to roll these directly from the ingot in one heat. In order that a piece shall be finished hot enough under this practice, there has been a standing temptation to use a thin ingot; but, on the other hand, it has been almost universally shown that the best results are obtained when a large amount of work is put upon the piece during rolling.

SEC. XIVb.—*Discussion of Riley's investigations on the effect of work.*—The truth of this last statement was disputed by Riley,* who tabulated the results of testing different thicknesses of plate when rolled from ingots of varying section. In all cases the ingot was either hammered or cogged to a slab and this was reheated before finishing into a plate. His analysis of the records consisted in picking out individual cases and showing that the small ingots gave some results which were equal to those from the large ones, but this method of comparison must be recognized as entirely unworthy of the subject. It is true that the number of tests is very small, and it would not be surprising if the accidental variations in the double working should produce anomalous results; but even taking these very data and making comparisons by the proper system of averages, it will be found that they tell a story exactly opposite from the conclusions formulated by Mr. Riley. In Tables XIV-A and XIV-B such figures are presented.

In the comparison of the different thicknesses in Table XIV-A the thinner plates give much better results, the one-half-inch plate showing an increased ductility in spite of its greater strength. The one-quarter-inch plates are somewhat lower in elongation and two and one-half per cent. better in reduction of area than the one inch plates, but they possess 7600 pounds more strength, so that less ductility should be expected. This statement is open to criticism, as no account is taken of the effect of variation in the

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* *Some Investigations as to the Effects of Different Methods of Treatment of Mild Steel in the Manufacture of Plates. Journal I. and S. I.*, Vol. I, 1887, 121.

dimensions of the test-piece, but Table XIV-B, which is free from this error, proves that the plates made from the large sizes have a higher tensile strength and greater ductility.

Table XIV-A.

Average Physical Results on Different Thicknesses of Steel Plates Without Regard to Size of Ingots; there being an Equal Number of Plates of each Thickness Rolled from Each Sized Ingot.*

Thickness of plate.	Ultimate strength; lbs. per square in.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Annealed, ultimate strength; pounds per square inch.
One inch . . .	62037	24.40	40.20	59416
One-half inch .	64534	24.71	44.85	61018
One-quarter in.	69642	22.35	42.68	62989

Table XIV-B.

Average Physical Results on Plates from Different-Sized Ingots Without Regard to Thickness of Plate; there being the same Number of each Thickness Rolled from a Given Size.*

Size of ingot; in inches.	Thickness of slab in inches.	Ultimate strength; lbs. per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Annealed ultimate strength; pounds per square inch.
24x15	8	66155	24.14	45.79	62197
14x14	8	65296	23.91	44.13	62571
18x12	8	65128	23.77	41.38	60461
18x12	4	65520	23.68	40.00	60461
12x 6	4	64923	23.68	41.58	60013

Thus these experiments which were heralded as upsetting current beliefs are found to vindicate them; they do prove that in some cases very good results may be obtained by skillful manipulation under a bad system; but manufacturers have long since learned that a large amount of reduction is essential to secure reliable results in regular practice, and no short series of tests can upset this well-established fact.

Sec. XIVc.—*Amount of work necessary.*—Up to within a comparatively recent period it was a common practice in America to roll plates directly from the ingot in one heat. This was unsatisfactory for more than one reason. First, the rolling of thin plates involved either the making of small ingots, which was objectionable and costly, or it involved rolling them from a large ingot, which

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* From data in *Journal I. and S. I.*, Vol. I., 1887, p. 121, *et seq.*

was very severe on the machinery; second, when the ingot was rolled into one single plate the segregated interior of the mass constituted a very considerable proportion of the finished piece, and it was generally out of the question to cut this part off, as by so doing a piece would be wasted which would be a very large proportion of the whole and which generally would be unsuited for other purposes on account of its dimensions.

Third, it is not possible to make every heat of steel just the exact composition and physical qualities desired, and if the steel be cast in ingots of a size suited for the making of certain plates, and if, on account of such variations in chemical or physical quality, they are not suited to the purpose for which they are made, they may be unsuited for any other purpose. On the other hand, when large ingots are cast and bloomed in a large mill and cut up into slabs, it is possible to know before the steel is rolled just what are the chemical and physical qualities of the metal, and the slabs may be made to suit the orders on hand. Moreover, the upper part of the ingot may be put into the less important work, while the bottom portion may be used for fire box plates and for other purposes calling for the best material. For these reasons the use of a slabbing mill has come into quite general use.

The Pennsylvania Steel Company was the first works in this country to introduce this practice; the Carnegie Steel Company followed with a much larger mill; The Pennsylvania Steel Company then built one of a large size handling an ingot 36 inches by 48 inches, and the Illinois Steel Company and the Lukens Iron and Steel Company have lately followed the example.

It is difficult to say just what should be the size of the slab for a given plate. Theoretically it would seem immaterial whether a 15-inch ingot is cogged to 8 inches and rolled to one-half inch, or whether it is cogged to 4 inches and rolled to the same thickness. The experiments of Mr. Riley point the same way, but they are far from being comprehensive. If a slab 4 inches thick is not heated to a full heat the plate may be finished at the same temperature as one of the same gauge rolled from a hotter slab of twice the thickness, but in regular practice the thin slabs are sometimes heated hotter than the thick ones, and consequently will be finished at a higher temperature. If carried too far this produces a coarser structure and an inferior metal, so that it is best to proportion the thickness of the slab to the thickness of the plate. The exact relation is of little importance as long as the reduction is sufficient, for in this matter the old adage is strictly applicable: "Enough is as good as a feast." This will be shown by Tables XIV-C and XIV-D, which investigate the effect of work on billets made from ingots 16 inches square and which thus had an all-sufficient reduction to begin with.

TABLE XIV-C.

Influence of Thickness of Test-Piece on the Physical Properties when the Percentage of Reduction in Rolling is Constant for all Thicknesses; the Finished Bars in each Case having a Sectional Area of about 8 Per Cent. of the Billet.

Heat number.	Size of billet; in inches.	Size of bar; in inches.	Ultimate strength; lbs. per sq. inch.		Elastic limit; pounds per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
			Finished at usual temperature.	Finished at dull red heat.	Finished at usual temperature.	Finished at dull red heat.	Finished at usual temperature.	Finished at dull red heat.	Finished at usual temperature.	Finished at dull red heat.
4605	4x4	2x⅝	51640	51280	33440	35380	37.50	29.50	60.1	50.9
	3⅝x3⅝	2x½	51120	52340	32650	35410	32.50	33.75	56.4	55.6
	3x3	2x⅜	50850	51970	35700	37860	32.50	30.00	60.8	58.9
	2½x2½	2x¼	53320	53200	37360	41400	31.25	31.50	61.0	66.2
	2x1⅝	2x⅛	....	58850	....	50620	....	19.75	...	58.4
9227	4x4	2x⅝	59540	60160	37050	39840	35.00	31.00	60.0	57.4
	3⅝x3⅝	2x½	59730	60490	38100	40490	29.75	32.50	56.4	55.1
	3x3	2x⅜	60950	61390	42110	42090	30.00	30.50	60.0	55.9
	2½x2½	2x¼	62350	62700	43070	46630	27.50	28.75	60.7	63.3
	2x1⅝	2x⅛	65130	67470	52180	57830	26.25	23.75	58.9	67.5
1509	4x4	2x⅝	67860	68140	42850	44050	25.00	24.25	40.8	43.9
	3⅝x3⅝	2x½	67550	68040	43190	45560	26.25	28.25	46.1	46.6
	3x3	2x⅜	67470	68300	44090	46610	26.25	23.25	53.2	50.3
1440	4x4	2x⅝	72840	73260	47080	49160	25.00	24.00	40.7	40.8
	3⅝x3⅝	2x½	71230	73510	46010	50830	26.25	25.00	40.5	43.5
	3x3	2x⅜	72950	73710	48760	50540	26.25	22.00	52.1	43.1
	2½x2½	2x¼	73620	75650	51550	58280	26.25	26.75	45.9	52.1
	2x1⅝	2x⅛	78560	79260	58140	63820	22.75	25.25	52.0	50.4

It will be found from a detailed comparison of these tables that there is little difference between the bars of the same thickness, even though rolled from different-sized billets. There is a gain in ultimate strength as the thickness decreases, this being most marked in the cold-finished bars, but the differences are not very marked except in the case of the one-eighth-inch. The elastic limit follows the same law, but it is raised more than the ultimate as the bar gets thinner. The elongation varies irregularly, but, as a rule, it remains unaffected except in the one-eighth-inch, where it is low-

TABLE XIV-D.

Influence of Thickness of Bar upon the Physical Properties when all Pieces are Rolled from Billets Three Inches Square.

Heat number.	Size of bar; in inches.	Ultimate strength; lbs. per square inch.		Elastic limit; pounds per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
		Finished at usual temperature.	Finished at dull red heat.	Finished at usual temperature.	Finished at dull red heat.	Finished at usual temperature.	Finished at dull red heat.	Finished at usual temperature.	Finished at dull red heat.
4605	2x⅝	51370	50960	32860	33760	34.50	32.75	59.6	56.7
	2x½	51070	52430	33200	36050	31.50	30.00	59.2	57.2
	2x⅜	50850	51970	35700	37860	32.50	30.00	60.8	58.9
	2x¼	52960	52280	36220	40040	31.25	32.50	63.2	68.3
	2x⅛	55560	55000	47380	42500	30.00	29.00	53.2	60.4
9227	2x⅝	59690	60190	37000	40130	35.00	30.00	55.4	58.7
	2x½	60350	60510	38560	40470	29.50	32.50	58.8	61.7
	2x⅜	60950	61390	42110	42090	30.00	30.50	60.0	55.9
	2x¼	62230	63970	42600	49200	25.75	29.25	55.9	61.9
	2x⅛	66340	68130	49860	56180	27.50	24.00	56.6	65.7
1509	2x⅝	65600	67090	40980	45830	29.50	25.50	50.9	44.8
	2x½	67310	67660	43090	45170	26.25	25.50	47.1	46.2
	2x⅜	67470	68300	44090	46610	26.25	23.00	53.2	50.3
	2x¼	69210	70200	47950	53680	26.50	25.25	54.1	56.9
	2x⅛	72100	77460	54060	64430	27.75	15.25	55.0	48.2
1440	2x⅝	72440	74060	46440	49480	27.50	24.00	45.7	42.0
	2x½	72570	68150	46200	45990	27.25	28.50	47.3	53.4
	2x⅜	72950	73710	48760	50540	26.25	22.00	52.1	43.1
	2x¼	75620	71260	51160	54660	25.00	27.25	53.5	49.4
	2x⅛	77500	80240	60920	69360	26.00	18.50	46.8	53.6

TABLE XIV-E.

Effect of Hammering Rolled Acid Open-Hearth Steel.

NOTE.—Chemical composition in per cent.; C, .40; Mn, .86; P, .037; S, .046.

Mark on bar.	Size of billet in inches; being the measure of the side of the square.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 2 inches; per cent. in a section ¾ inch in diameter.	Reduction of area; per cent.	Elastic ratio; per cent.	Remarks.
A	6	54460	89240	29.00	41.2	61.0	Finished at dull yellow.
B	6	41500	88660	28.00	42.2	46.8	Annealed at bright yellow.
C	5	50800	89070	26.50	38.0	57.0	Finished at dull yellow.
D	4	55240	87300	25.50	37.0	63.3	Finished at dull yellow.
E	3	51170	86450	27.50	39.3	59.2	Finished at dull yellow.
F	2	51830	89280	28.00	41.8	58.1	Finished at dull yellow.
G	2	57140	92400	28.00	42.0	61.8	Finished at cherry red.
H	4	45620	89900	27.00	38.9	50.8	Finished at dull yellow.
I	3	47830	88800	25.00	34.3	53.9	Finished at dull yellow.
K	2	51000	88760	27.50	42.7	57.5	Finished at dull yellow
L	5	54020	86400	7.50	5.8	62.5	Annealed at white heat.
M	2	54700	93360	24.50	34.8	58.6	Finished at cherry red.

ered to some extent. The reduction of area is also irregular, but it seems to be independent of the thickness even in the thinnest plate. The conclusion seems justifiable that if the billets have already received sufficient work, the good condition caused thereby is not destroyed by reheating, since bars rolled from them reach their standard level of quality with only a reasonable degree of reduction, as proven by the fact that further work gives no decided improvement. But it is also certain, as shown by all experience, that no harm can be done by increased work, and that there is a slight gain in the long run provided the finishing temperature remains constant.

SEC. XIVd.—*Experiments on forgings.*—The persistency of a proper structure even through subsequent heating may be seen in Table XIV-E, which gives the results obtained from a series of forged billets. The original bloom was 6 inches square, being rolled from an ingot 18″x20″. From this bloom several short pieces were cut and treated in different ways:

A was not reheated, but a test-piece was cut from it as a standard of comparison,

B was heated to a full working heat and cooled without hammering.

C was hammered to 5 inches square in one heat.

D was hammered to 4 inches square in one heat.

E was hammered to 3 inches square in one heat.

F was hammered to 2 inches square in one heat.

G was hammered to 2 inches square in one heat from the annealed bar *B* and was finished at a cherry red heat.

H was hammered to 5 inches square, then reheated and hammered to 4 inches.

I was hammered to 4 inches square, then reheated and hammered to 3 inches.

K was hammered to 3 inches square, then reheated and hammered to 2 inches.

L was hammered to 5 inches square, then overheated and cooled without hammering.

M was made by reheating the burned piece *L* and hammering to 2 inches square in one heat, being finished at a cherry red heat.

All the pieces were worked under a 4-ton double-acting hammer, and the test-bars were cut from the corner of the billet and pulled in a length of 2 inches.

It is quite evident that the pieces which were heated twice, and which received only one inch of reduction after the second heating, must have been finished hotter, as well as have received less work after a full heat, but in spite of these differences in amount of work and temperature it is clear that the bars are practically uniform in strength and ductility, showing that the steel was in thoroughly good condition originally, and that proper heating did no harm when followed by a fair amount of work.

The ultimate strength is fairly uniform save in the case of the two bars which were finished at a cherry red heat. The elastic ratio varies in much greater measure, but the results are not regular since, in some cases, as in *K*, a high ratio accompanies heavy reduction under the hammer, while in others, as in *D*, it appears in bars which have received very little work.

TABLE XIV-F.

Comparative Physical Properties of Test-Pieces of Bessemer Steel Cut from Thick and Thin Angles of Large and Small Sizes.

Each figure is an average of 50 bars.

Thickness of angle: inches.	Elastic limit: lbs. per sq. in.		Ult. strength: lbs. per sq. in.		Elastic ratio; per cent.		Elongation in 8 in.; per cent.		Reduction of area; per cent.	
	Large sizes.	Small sizes.	Large sizes.	Small sizes.	Large sizes.	Small sizes.	Large sizes.	Small sizes.	Large sizes.	Small sizes.
$\frac{5}{16}$	. . . .	44158	. . . .	61252	. . . .	72.09	. . . .	27.55	. . . .	56.79
$\frac{3}{8}$	43002	43090	60097	60629	71.55	71.07	28.13	28.55	58.23	54.80
$\frac{7}{16}$	43637	43128	60019	60239	72.70	71.59	28.16	28.52	57.59	57.53
$\frac{1}{2}$	41671	41634	60120	59151	69.31	70.38	28.58	29.24	55.17	56.96
$\frac{9}{16}$	41080	41836	59467	59750	69.08	70.02	28.65	28.74	55.30	57.59
$\frac{5}{8}$	40391	40944	59360	59084	68.04	69.30	29.03	29.38	53.43	56.07
$\frac{3}{4}$	38867	. . . .	58267	. . . .	66.70	. . . .	28.87	. . . .	51.63	. . . .

The original bar *A* shows a high ratio, but this was finished at a low heat. In the annealed bar *B* the ratio drops very much, but the "burned" bloom *L* shows almost as high an elastic strength as the original steel. In the bar *M*, which should be compared with the bar *G*, it is shown that reheating and hammering will do very much toward restoring a piece of burned steel to its original condition, although it is doubtful whether it ever can make of it a thoroughly reliable material.

SEC. XIVe.—*Tests on Pennsylvania Steel Company angles of different thicknesses.*—The fact that there is very little difference between thick and thin pieces, provided the work has been sufficient in both cases, is shown by Table XIV-F. This was constructed by taking at random from the records of The Pennsylvania Steel Company the tests on fifty bars of small angles and fifty bars of large angles of each different thickness, of common Bessemer steel, running from .07 to .10 per cent. of phosphorus.

For making the 6″x6″ angles, a bloom 8″x9½″ was rolled from a 16″x20″ ingot, but all other sizes were made from a 7½-inch square bloom which was cogged from a 16″x16″ ingot. The term "small" angles includes 4½″x3″, 4″x4″, and all smaller sizes down to and including 3″x3″; while the "large" embraces from 5″x3″ to 6″x6″, inclusive. The finished area of the smaller bars is such a small part of the original bloom that the reduction may be considered uniform for them all, thus giving a fairly valid basis of comparison for the different thicknesses, while the columns "large" and "small" should show the effect of a varying amount of work on a piece of given thickness.

Table XIV-G.

Comparison of Ultimate Strength of Bars Rolled from Test Ingots Six Inches Square, and Test-Pieces Cut from Angles of Different Thicknesses Rolled from the same Heats.

Thickness of angle; in inches.	Number of heats represented.	Elastic limit; lbs. per square inch.			Ultimate strength; lbs. per square inch.			Elastic ratio; per cent.	
		Bar from test ingot.	Bar from angle.	Loss of strength in angle.	Bar from test ingot.	Bar from angle.	Loss of strength in angle.	Bar from test ingot.	Bar from angle.
5/16 and 3/8	39	42270	41300	970	60200	60190	10	70.23	68.62
7/16 and 1/2	46	43070	40170	2900	61360	60660	700	70.19	66.22
9/16 and 5/8	37	42990	39710	3280	62930	61520	1410	68.31	64.55

It will be noted that the small-sized angles give slightly better results on elongation, but the difference is trifling, while in neither the elastic ratio nor the reduction of area is there any marked superiority. The results indicate that when the amount of work is large, the exact percentage is of little consequence.

The ultimate strength decreases in the thicker angles, but it is not proven that the variation is due entirely to the thickness, for it may be that the heats which were rolled into thick sizes did happen to be of lower strength, but as all the heats were made in the same way, and as both large and small sizes follow the same law, and as each group includes fifty bars, it seems probable that the gradation represents in some measure the effect of different amounts of work on the material.

TABLE XIV-H.

Comparative Physical Properties of Various Steels, Made by The Pennsylvania Steel Company, when Rolled into Angles of Different Thicknesses.

No. of group.	Kind of steel.	Limits of phosphorus; per cent.	Limits of ultimate strength in group; lbs. per sq. inch.	Thickness of angle; inches.	Number of heats in average.	Average elastic limit; lbs. per sq. inch.	Average ultimate strength; lbs. per sq. in	Average elastic ratio; per cent.	Average elongation in 8 in.; per cent.	Average reduction of area; per cent.
I	Basic open-hearth.	below .04	47000 to 55000	$\frac{5}{16}$ to $\frac{3}{8}$	32	36284	52533	69.07	32.18	63.7
				$\frac{7}{16}$ to $\frac{1}{2}$	20	34891	53171	65.62	32.33	62.3
				$\frac{9}{16}$ to $\frac{5}{8}$	14	34026	51903	65.56	32.87	63.4
				$\frac{11}{16}$ to $\frac{7}{8}$	7	32356	51923	62.31	33.86	63.0
II	Basic open-hearth.	below .04	55000 to 63000	$\frac{5}{16}$ to $\frac{3}{8}$	64	39692	58865	67.43	30.52	58.8
				$\frac{7}{16}$ to $\frac{1}{2}$	39	37827	58538	64.62	30.06	56.8
				$\frac{9}{16}$ to $\frac{5}{8}$	17	37487	59235	63.28	29.28	52.6
				$\frac{11}{16}$ to $\frac{7}{8}$	10	36035	59125	60.95	30.58	55.3
III	Acid open-hearth.	.05 to .07	56000 to 64000	$\frac{5}{16}$ to $\frac{3}{8}$	212	40891	60845	67.21	29.35	57.4
				$\frac{7}{16}$ to $\frac{1}{2}$	126	39415	60695	64.94	29.23	55.6
				$\frac{9}{16}$ to $\frac{5}{8}$	81	38645	60558	63.81	28.95	53.8
				$\frac{11}{16}$ to $\frac{3}{4}$	121	37478	59906	62.56	29.32	51.3
				$\frac{13}{16}$ to $\frac{7}{8}$	3	37793	61943	61.01	28.58	48.7
IV	Acid open-hearth.	.07 to .10	56000 to 64000	$\frac{5}{16}$ to $\frac{3}{8}$	50	41143	60064	68.50	28.82	58.4
				$\frac{7}{16}$ to $\frac{1}{2}$	50	40170	60583	66.30	29.05	56.3
				$\frac{9}{16}$ to $\frac{5}{8}$	50	39656	61049	64.96	28.98	54.8
				$\frac{11}{16}$ to $\frac{3}{4}$	50	38338	59763	64.15	29.60	55.3
				$\frac{13}{16}$ to $\frac{7}{8}$	50	37969	61129	62.11	28.85	50.8
V	Acid Bessemer.	.07 to .10	56000 to 64000	$\frac{5}{16}$ to $\frac{3}{8}$	150	43417	60659	71.58	28.07	56.6
				$\frac{7}{16}$ to $\frac{1}{2}$	200	42518	59882	71.00	28.63	56.8
				$\frac{9}{16}$ to $\frac{5}{8}$	200	41063	59415	69.11	28.95	55.6
				$\frac{11}{16}$ to $\frac{3}{4}$	200	38867	58267	66.70	28.37	51.6
VI	Acid open-hearth.	.05 to .07	64000 to 72000	$\frac{5}{16}$ to $\frac{3}{8}$	40	43713	65656	66.58	27.90	55.0
				$\frac{7}{16}$ to $\frac{1}{2}$	29	42191	65631	64.28	27.83	53.7
VII	Acid open-hearth.	.07 to .10	64000 to 72000	$\frac{5}{16}$ to $\frac{3}{8}$	25	44486	66365	67.03	27.19	55.4
				$\frac{7}{16}$ to $\frac{1}{2}$	39	42817	65777	65.09	27.49	53.2
VIII	Acid Bessemer.	.07 to .10	64000 to 72000	$\frac{5}{16}$ to $\frac{3}{8}$	53	46422	66277	70.04	26.42	50.4
				$\frac{7}{16}$ to $\frac{1}{2}$	23	45280	65940	68.66	27.20	51.5

SEC. XIVf.—*Comparison of the strength of angles with that of the preliminary test-piece.*—That the thin angles will give a higher strength is proven quite conclusively by Table XIV-G, which gives in parallel columns the tests on the finished angles from acid open-hearth heats, and the results obtained from bars rolled from 6-inch square ingots of the same charges. It matters not whether this preliminary test really represents the true value of the steel, for it may reasonably be assumed that it will give a regular basis of comparison, so that the differences between the results on this standard and on the various thicknesses will be the measure of the effect of rolling.

It is shown that for an increase of one-eighth of an inch in thickness there is a diminution in strength of 700 pounds per square inch. It is, perhaps, as close an agreement as could be expected when we find that in Table XIV-F the difference on the large sizes between the three-eighth-inch and three-quarter-inch angles was 1830 pounds per square inch, or 610 pounds to every one-eighth in thickness, while on the smaller sizes it is 2168 pounds from five-sixteenth-inch to five-eighth-inch, or 434 pounds to every eighth, being an average of 522 pounds for both large and small sizes.

Sec. XIVg.—*Physical properties of Pennsylvania Steel Company steels of various compositions, when rolled into angles of different thicknesses.*—The subject is more fully investigated in Table XIV-H, which gives the average results from angle bars of several different kinds of steel. The accidental variations in the metals make it impossible to compare the influence of the thickness upon the ultimate strength, but the column showing the elastic ratio proves that a lower elastic limit follows an increase in thickness. The elongation remains the same for all thicknesses. The reduction of area varies somewhat, but in the groups where a large number of tests make the figures of much value there is a decrease in the heavier bars.

The variation in strength of the different thicknesses is due in part to the fact that the thin pieces are finished at a lower temperature. The effect of such working is investigated in Tables XIV-C and XIV-D, where pieces of the same billets were heated differently before rolling and were, therefore, finished under unlike conditions. In the bars finished at the lower temperature the elastic limit was raised very considerably, but the ultimate strength and the ductility did not vary much from the hot-rolled bars. This conclusion has nothing to do with the fact so well known to all manufacturers that if a bar or plate is finished so cool that it looks dark in the sunlight it will give a much higher tensile strength; the bars referred to in the table were all finished somewhat hotter than this, and the small variation in temperature seems to have little effect. These conclusions will be corroborated by Table XIV-I, which records certain tests on acid open-hearth steel.

SEC. XIVh.—*Comparative physical properties of hand and guide rounds.*—The fact that the elongation is as high on thick as on thin angles is contrary to a prevailing opinion concerning the effect of surface work upon rolled steel. Further information is given in

TABLE XIV-I.

Effect of Finishing 2x3/8-inch Flats of Acid Open-Hearth Steel at Different Temperatures.

(A = finished at usual temperature. B = finished at a low red heat.)

Group.	Ult. strength; per sq. in.	Heat No.	Composition; per cent.			Ultimate strength; pounds per square inch.		Elastic limit; pounds per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
			C.	P.	Mn.	A.	B.	A.	B.	A.	B.	A.	B.
I.	56000 to 60000 lbs.	10063	.11	.037	.49	57520	59160	39150	41490	30.50	33.25	63.0	60.9
		10058	.12	.037	.55	57810	61270	39250	44860	32.75	31.75	64.8	58.6
		10055	.12	.030	.65	59060	59140	40800	42760	28.00	30.50	57.9	59.3
		Av.	.12	.035	.56	58130	59857	39733	43037	30.42	31.83	61.9	59.6
II.	60000 to 64000 lbs.	10065	.11	.056	.48	60840	63160	41540	44230	29.25	29.00	61.8	56.5
		10064	.11	.062	.48	60900	63500	41500	45890	30.25	30.50	60.6	56.3
		10071	.13	.065	.48	62230	63820	42290	46730	32.00	30.00	58.9	60.2
		10066	.12	.074	.50	62840	63860	42610	44000	29.25	30.75	61.5	57.3
		Av.	.12	.064	.48	61703	63585	41985	45213	30.19	30.06	60.7	57.6
III.	72000 to 80000 lbs.	10041	.23	.047	.77	72780	74500	47010	49090	25.50	28.75	59.5	57.1
		10045	.23	.052	.86	73060	75910	48660	54240	25.75	28.00	57.8	51.0
		10043	.21	.049	.75	73340	75840	48580	49900	24.00	28.25	55.3	54.6
		10061	.25	.062	.68	75300	77280	49400	51600	25.50	28.50	50.7	54.8
		10034	.25	.059	.78	76860	79430	49340	54920	22.50	27.50	54.4	51.2
		10047	.25	.045	.80	77340	80260	49460	54800	23.75	26.75	52.3	52.4
		10068	.26	.062	.79	78280	80880	50860	57220	26.00	27.50	48.6	47.4
		10042	.26	.042	.76	78540	80560	49930	54900	24.25	24.00	53.8	49.3
		Av.	.24	.052	.77	75688	78083	49155	53334	24.66	27.41	54.1	52.2

TABLE XIV-J.

Comparative Physical Properties of Hand Rounds and Guide Rounds from the Same Acid Open-Hearth Heats.

Group.	Limits of ult. strength in group; pounds per sq. inch	Number of heats in group.	Average manganese; per cent.	Ultimate strength; lbs. per sq. inch.		Elastic limit; lbs. per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
				Hand.	Guide.	Hand.	Guide.	Hand.	Guide.	Hand.	Guide.
I	56000 to 64000	3	.41	59830	59192	42548	38848	28.23	29.35	55.90	61.85
II	70000 to 75000	5	.76	72464	69750	48024	45601	22.77	24.73	40.77	48.98
III	75000 to 80000	5	.81	78805	77790	51943	51933	23.55	24.92	46.09	53.30
IV	80000 to 86000	6	.79	83813	82524	52986	52863	22.74	24.51	45.69	55.57
Av. of all heats,		19	.73	75722	74232	49758	48495	23.83	25.44	46.11	54.23

Table XIV-J, which shows the comparative results on hand and guide rounds from the same heats.

A guide round is made in one pass from an ellipse, while a hand round is put through the same pass several times, being turned one-quarter way each time in order to obtain a true circular section. This has the effect of finishing the bar somewhat cooler than a guide round, and thus naturally gives a higher ultimate strength, while it also works the skin of the piece during the finishing process without any great reduction in diameter. It will be seen that nothing is gained by this operation, for, although the guide rounds are slightly reduced in strength, they are considerably better in elongation and reduction of area.

Table XIV-K.

Changes in the Physical Properties of Steel by Variations in the Details of Plate-Rolling; Classified According to Strength of Preliminary Test.

Limits of ult. strength of preliminary test; lbs. per square inch.		Thickness of plate; in inches.	Number of heats tested.	Increase in ultimate strength from preliminary test to plate; pounds per square inch.	Ultimate strength; lbs. per sq. in.			Elastic limit of plate; lbs. per square inch.	Elastic ratio of plate; per cent.	Elongation of plate in 8 inches; per cent.	Reduction of area of plate; per cent.
					Finished plate.	Preliminary test bar.	Average increase from preliminary test to plate.				
Basic open-hearth steel.	44000 to 52000	5/16	12	more than 7500	60040	49479	10561	44659	74.4	25.94	52.9
			18	less than 7500	56475	51177	5298	42570	75.4	26.31	52.3
		3/8	13	more than 5500	57807	50020	7787	40407	69.9	26.94	57.4
			19	less than 5500	54799	51033	3766	39675	72.4	28.78	61.1
	52000 to 58000	5/16	94	more than 4000	59582	54096	5486	44653	74.9	26.44	59.6
			68	less than 4000	58323	55741	2582	43028	73.8	27.10	55.3
		3/8	69	more than 3000	58705	54013	4692	40420	68.9	28.50	56.9
			60	less than 3000	57021	55328	1693	40266	70.6	28.37	57.8
		7/16	10	more than 3000	59414	53557	5857	38222	64.3	28.09	59.9
			16	less than 3000	56501	54786	1715	36525	64.6	30.58	58.5
		1/2	7	more than 3000	59135	53934	5201	38078	64.4	27.90	57.9
			10	less than 3000	56977	55840	1137	36770	64.5	27.13	52.5
Acid open-hearth steel.	58000 to 64000	3/8	8	more than 2000	62228	59506	2722	42687	68.6	25.69	51.0
			4	less than 2000	61425	60550	875	42325	68.9	25.41	51.0
		7/16	11	more than 1000	61827	59706	2121	42027	68.0	25.12	53.2
			9	less than 1000	59022	59320	....	39875	67.6	24.46	55.5
		1/2	19	more than 1000	61174	59573	1601	40157	65.7	24.19	50.2
			14	less than 1000	60293	60408	....	39693	65.8	24.69	48.7

Sec. XIVi.—*Changes in the physical properties of steel by vari-*

ations in the details of plate-rolling.—It has been already stated that it is the practice at The Pennsylvania Steel Works to roll a preliminary test-bar from each open-hearth heat for physical testing, and that the ultimate strength of this bar corresponds closely with that of angles rolled from the same charge. In the case of plates, on the contrary, there is often a considerable variation, and Table XIV-K investigates the effect of such differences upon the physical qualities.

TABLE XIV-L.

Changes in the Physical Properties of Steel by Variations in the Details of Plate-Rolling; Classified According to Strength of Finished Plate.

	Limits of ult. strength of finished plate; pounds per square inch.	Thickness of plate in inches.	Number of heats tested.	Increase in ultimate strength from preliminary test to plate; pounds per square inch.	Ultimate strength; pounds per square inch.			Elastic limit of plate; pounds per square inch.	Elastic ratio of plate; per cent.	Elongation of plate in 8 inches; per cent.	Reduction of area of plate; per cent.
					Finished plate.	Preliminary test bar.	Av. increase from preliminary test to plate.				
Basic open-hearth steel.	50000 to 58000	$\frac{5}{16}$	35	more than 4000	56971	51963	5008	43106	75.6	26.66	57.8
			30	less than 4000	56652	54680	1972	41345	73.0	27.35	55.2
		$\frac{3}{8}$	42	more than 3000	56370	52161	4209	40387	71.6	28.28	58.5
			49	less than 3000	55958	54441	1517	39759	71.0	28.66	58.2
		$\frac{7}{16}$	7	more than 1700	55963	53391	2572	37613	67.2	30.27	58.6
			6	less than 1700	53981	53213	768	34802	64.5	31.43	59.6
		$\frac{1}{2}$	3	more than 1100	56633	54076	2557	36366	64.2	27.91	54.7
			4	less than 1100	55292	54843	449	36150	65.4	28.50	53.7
	58000 to 64000	$\frac{5}{16}$	39	more than 4000	60130	54234	5896	44572	74.1	26.63	58.7
			38	less than 4000	59344	56401	2943	44054	74.2	26.92	56.2
		$\frac{3}{8}$	15	more than 3000	59750	53676	6074	40928	68.5	27.87	57.6
			15	less than 3000	58920	56969	1951	40855	69.3	28.07	58.7
Acid open-hearth steel.	56000 to 64000	$\frac{3}{8}$	6	more than 2550	62841	59151	3690	43933	69.9	25.92	50.5
			6	less than 2550	61080	60557	523	41200	67.4	25.04	52.0
		$\frac{7}{16}$	9	more than 1400	61833	59647	2186	42512	68.7	25.28	54.9
			11	less than 1400	59527	59439	88	40230	67.6	24.45	53.8
		$\frac{1}{2}$	17	more than 1700	61241	59442	1799	40110	65.5	24.38	50.7
			16	less than 1700	60331	60442	....	39800	66.0	24.43	48.6

It is assumed that the preliminary test-piece is the standard, and whatever difference from this is shown in the plate is due to the conditions of rolling. On this basis it is possible to compare those plates which show a great with those which show a less variation from the standard, and note the corresponding ductility. In the first division, for example, it was found that the average increase in strength from the preliminary bar to the finished plate was 7500 pounds per square inch. Consequently this figure was taken as a dividing line, and a comparison was made of the heats showing more than this difference with those showing less. The same rule was followed in all the other divisions.

Table XIV-L gives a different view of the same data, the groups being divided on the less logical but more practical basis of the strength of the finished plate. It will be seen that the elongation for a given tensile strength is not seriously affected by the variations in rolling, but that the hotter finished plates are somewhat better. The elastic ratio exhibits much less variation than would be expected; and this might throw some doubt on the results, but all the different groups teach the same lesson, and in some of them the number of heats is so large as to give great weight to the conclusion. The plates were all rolled from slabs, which in turn had been rolled from large ingots, so that there was ample work on all thicknesses.

TABLE XIV-M.

Comparative Physical Properties of Angles and Sheared Plates, both being made from Pennsylvania Steel Company Steel.

	Thickness of bar; in inches.	Kind of piece.	No. of heats in average.	Ult. strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elastic ratio; per cent.	Elongation in 8 inches; per cent.	Reduction of area; per ct.
Basic open-hearth soft steel, below .04 per cent. in phosphorus.	$\frac{5}{16}$ to $\frac{3}{8}$	Angles	32	52533	36284	69.07	32.18	63.7
		Plates	107	54998	38017	69.12	29.28	58.6
	$\frac{7}{16}$ to $\frac{1}{2}$	Angles	20	53171	34891	65.62	32.33	62.3
		Plates	102	55017	34947	63.52	29.03	61.5
Basic open-hearth medium steel, below .04 per cent. in phosphorus.	$\frac{5}{16}$ to $\frac{3}{8}$	Angles	64	58865	39692	67.43	30.52	58.8
		Plates	265	58271	40349	69.24	28.27	58.1
Acid open-hearth soft steel, below .08 per cent. in phosphorus.	$\frac{5}{16}$ to $\frac{3}{8}$	Angles	212	60845	40891	67.21	29.35	57.4
		Plates	190	60217	43278	71.87	25.98	57.4
	$\frac{7}{16}$ to $\frac{1}{2}$	Angles	126	60695	39415	64.94	29.23	55.6
		Plates	59	60768	39061	64.28	25.87	55.1
	$\frac{9}{16}$ to $\frac{5}{8}$	Angles	81	60558	38645	63.81	28.95	53.8
		Plates	13	60666	37932	62.53	24.67	52.7

SEC. XIVj.—*Comparative physical properties of plates and* *angles.*—It is very difficult to make a comparison of two different structural shapes, since it does not often happen that the same heat is rolled into more than one kind of section, but an attempt is made to do this in Table XIV-M. The prime requisite is that the steel in both cases shall be of the same manufacture, and this specification is satisfied in the present instance. The figures for the angles are found by combining certain groups in Table XIV-H, which was compiled from the records of The Pennsylvania Steel Company, while the plates represent the average obtained from The Paxton Rolling Mill, which was running on slabs from the same works.

The one predominant feature is the lower elongation in the plates. This may be explained by the fact that the metal receives a less thorough compression in the plate train than it does in the rolling of angles, in which latter case it undergoes a certain amount of lateral thrust.

SEC. XIVk.—*Effect of thickness on the physical properties of plates.*—The effects caused by variations in rolling temperature appear in their most marked degree in the comparison of plates of different gauges. It is not customary to test the same heat in several sizes, but by long experience the manufacturer is able to judge the relative properties of each thickness. The heads of two widely-known plate mills have given me as their estimate that, taking one-half inch as a basis, there will be the following changes in the physical properties for every increase of one-quarter inch in thickness:

(1) A decrease in ultimate strength of 1000 pounds per square inch.

(2) A decrease in elongation of one per cent. when measured in an 8-inch parallel section.

(3) A decrease in reduction of area of two per cent.

W. R. Webster* gives the same data on ultimate strength, but does not mention the relation of section to elongation.

It is, therefore, plain that in the writing of specifications some allowance must be made for these conditions, since a requirement which is perfectly proper for a three-eighth-inch plate will be unreasonable for a 1½-inch. Moreover, the effect is cumulative, since a harder steel must be used in making the thick plate and

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* *Observations on the Relations between the Chemical Constitution and Ultimate Strength of Steel. Journal I. and S. I.,* Vol. I, 1894, p. 329.

this will tend to lessen the ductility rather than make up for the reduction caused by the larger section. In plates below three-eighths inch in thickness it is also necessary to make allowances, since it is almost impossible to finish them at a high temperature, and the test will give a high ultimate strength and a low ductility.

These conditions have now been officially recognized by the United States Government, for the rules of the Board of Supervising Inspectors, issued January, 1899, contain the following clause:

"The sample must show, when tested, an elongation of at least 25 per cent. in a length of two inches for thicknesses up to one-quarter inch, inclusive; and in a length of four inches, for over one-quarter to seven-sixteenths, inclusive; and in a length of six inches, for all thicknesses over seven-sixteenths inch and under 1¾ inches."

It is to be hoped that constructive engineers will follow this example in recognizing the influence of causes over which the manufacturer has no control.

CHAPTER XV.

HEAT TREATMENT.

Within the last few years there have been radical advances in our knowledge of the structure of steel and the influence exerted by what has come to be known as "heat treatment." The main principles of this branch of metallurgy have been understood for quite a long time, but they were applied only in exceptional cases, such as the manufacture of guns and armor plate. To-day progressive manufacturers are using the results of research in improving the quality of their ordinary forgings and castings, and it is therefore necessary to consider at some length the general underlying principles of the science of micro-metallography. This has been done in the latter half of this chapter, the article being written by my brother, J. W. Campbell, who has charge of the special steels at Steelton.

The introduction of accurate determinations of temperatures and a better knowledge of the proper heat to use, has to a certain extent diminished the value of the experiments and investigations published in the first edition of this book, but I believe they may be worth recording again, as it is quite certain that many non-progressive works will follow the common and ancient methods of annealing both at the forge of the smith and on a larger scale in the treatment of eye bars and similar material. In the following sections the word "annealing" is used unless otherwise stated to signify that the piece was heated in a muffle heated by a soft coal fire, the bar being withdrawn when it had reached a dull yellow heat. The experiments were carefully performed and it is believed that the practice was fairly uniform.

Section XVa.—*Effect of annealing on the physical properties of rolled bars.*—It is a well known fact that annealing tends to remove the strains which are created by cold rolling and distortion, but it is not generally understood how profound are the changes produced. Table XV-A will show the results obtained on rounds and flats by comparing the natural bar with the annealed specimen

TABLE XV-A.

Effect of Annealing on Rounds and Flats of Bessemer and Acid Open-Hearth Steel.

A 4"x4" billet from each heat was rolled into a 2"x⅜" flat and another into a ¾ round.

	Limits of ultimate strength; pounds per square inch.	Kind of steel.	Number of heats in average.	Condition of bar.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
¾-inch rounds.	56000 to 60000	Bess.	11	Natural	58869	42318	27.75	58.83	71.88
				Annealed	55703	37828	29.14	66.55	67.91
		O. H.	4	Natural	58568	40300	29.69	60.78	68.81
				Annealed	54098	31823	28.75	62.65	58.82
	60000 to 64000	Bess.	6	Natural	62087	45323	27.04	55.31	73.00
				Annealed	59372	40570	30.13	65.50	68.33
		O. H.	7	Natural	62187	42606	28.04	62.16	68.51
				Annealed	58364	35120	28.61	63.47	60.17
	64000 to 68000	Bess.	9	Natural	66241	47568	26.08	50.07	71.81
				Annealed	61694	42228	28.25	62.91	68.45
	68000 to 72000	Bess.	3	Natural	70457	50263	24.75	48.30	71.34
				Annealed	65903	44660	26.08	63.23	67.76
		O. H.	2	Natural	70530	49000	26.88	61.10	69.47
				Annealed	65500	37685	23.38	55.30	57.53
	72000 to 80000	Bess.	4	Natural	77440	53760	24.06	42.35	69.42
				Annealed	71548	47643	25.81	57.53	66.59
		O. H.	12	Natural	76616	51108	24.52	53.73	66.71
				Annealed	69402	40505	23.04	56.54	58.36
2x⅜-inch flats.	56000 to 60000	Bess.	11	Natural	58458	41698	31.45	56.13	71.33
				Annealed	54194	35603	30.05	63.13	65.70
		O. H.	4	Natural	58130	40400	30.13	61.75	69.51
				Annealed	51418	30393	31.06	60.50	59.11
	60000 to 64000	Bess.	6	Natural	60825	43135	30.42	56.20	70.92
				Annealed	56192	37542	30.63	63.38	66.81
		O. H.	7	Natural	62089	42441	30.14	60.86	68.36
				Annealed	55021	31576	30.36	60.00	57.39
	64000 to 68000	Bess.	9	Natural	64621	45194	28.42	47.80	69.94
				Annealed	58838	38476	28.36	59.01	65.39
	68000 to 72000	Bess.	3	Natural	69773	49060	26.67	48.40	70.31
				Annealed	64160	43770	28.53	59.50	68.22
		O. H.	2	Natural	69420	45090	25.63	59.30	64.96
				Annealed	60850	34000	26.50	52.10	55.87
	72000 to 80000	Bess.	4	Natural	76900	52240	23.44	40.15	67.93
				Annealed	68780	43568	26.38	51.00	63.34
		O. H.	12	Natural	75865	49691	24.69	54.40	65.50
				Annealed	67618	39403	26.31	51.36	58.27

when all the pieces were rolled from billets of the same size and on the same mill.

The decrease in ultimate strength by annealing the Bessemer bars averaged 4175 pounds per square inch in the rounds and 5683 pounds in the flats; while the open-hearth was lowered 5134 pounds in the rounds and 7649 in the flats. In this important and fundamental quality the two kinds of steel are very similarly affected, but in other particulars there seems to be a radical difference which is difficult to explain.

TABLE XV-B.

Comparison of the Natural and Annealed Bessemer Steel Bars Given in Table XV-A, which show about the same Ultimate Strength.

	Group.	Limits of ultimate strength in group; pounds per square inch.	No. of heats in average.	Condition of bar.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
¾-inch rounds.	I	56000 to 60000	11	Natural	58869	42318	27.75	58.83	71.88
			17	Annealed	56998	38796	29.49	66.18	68.06
	II	60000 to 64000	6	Natural	62087	45323	27.04	55.31	73.00
			9	Annealed	61694	42228	28.25	62.91	68.45
	III	64000 to 68000	9	Natural	66241	47568	26.08	50.07	71.81
			3	Annealed	65903	44660	26.08	63.23	67.76
	IV	68000 to 72000	3	Natural	70457	50263	24.75	48.30	71.34
			4	Annealed	71548	47643	25.81	57.53	66.59
2x⅜-in. flats.	V	56000 to 60000	11	Natural	58458	41698	31.45	56.13	71.33
			15	Annealed	57780	38102	29.27	60.76	65.95
	VI	64000 to 68000	9	Natural	64621	45194	28.42	47.80	69.94
			3	Annealed	64160	43770	28.58	59.50	68.22
	VII	68000 to 72000	3	Natural	69773	49060	26.67	48.40	70.31
			4	Annealed	68780	43568	26.38	51.00	63.34

The elongation of the Bessemer steel is increased by annealing in every case except two, the average being 1.33 per cent., while the open-hearth metal shows a loss in three cases, with an average loss for all cases of 0.21 per cent. This is not very conclusive, but there is a more marked difference in the reduction of area, for in the Bessemer steel there is an increase in the annealed bar in every case varying from 7 to 15.18 per cent., while the open-hearth showed an increase in only three cases, the maximum being 2.81 per cent., and a decrease in five cases, the greatest loss being 7.20 per cent.

The elastic limit fell much more than the ultimate strength, and here again the Bessemer seems to be different from the open-hearth steel, for while the elastic ratio of the former is lowered from 2.1 to 4.7 per cent. by annealing, the latter loses from 7.2 to 11.9 per cent. It will not do to draw a general conclusion from these limited data on the nature of the two kinds of steel, but whether further experiment would or would not corroborate these results, it is quite certain that annealing under ordinary conditions, even though very carefully conducted, may produce grave differences in physical properties in steels of similar composition which have been rolled in the same manner and treated at the same time, even when the effect upon the ultimate strength has been the same.

Table XV-C.

Comparison of the Natural and Annealed Open-Hearth Steel Bars Given in Table XV-A, which show about the same Ultimate Strength.

	Group.	Limits of ultimate strength in group; pounds per square inch.	Number of heats in average.	Condition of bar.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
¾-inch rounds.	I	56000 to 60000	4	Natural	58568	40300	29.60	60.78	68.81
			7	Annealed	58364	35120	28.61	63.47	60.17
	II	68000 to 72000	2	Natural	70530	49000	26.88	61.10	69.47
			12	Annealed	69402	40505	23.04	56.54	58.36
2x⅜-inch flats.	III	55000 to 60000	4	Natural	58130	40400	30.13	61.75	69.51
			7	Annealed	55021	31576	30.36	60.00	57.39
	IV	60000 to 64000	7	Natural	62089	42441	30.14	60.86	68.36
			2	Annealed	60850	34000	26.50	52.10	55.87
	V	66000 to 70000	2	Natural	69420	45090	25.63	59.30	64.96
			12	Annealed	67618	39403	26.31	51.36	58.27

It would also appear that in the Bessemer steel the marked increase in ductility is purchased at a great sacrifice of strength, and the question arises whether the gain is not more than balanced by the loss, and whether an equal degree of toughness could not be secured by using a softer steel in its unannealed state. A comparison of the natural and annealed bars of corresponding tensile strength in Table XV-A will give the results shown in Tables XV-B and XV-C.

SEC. XVb.—*Effect of annealing on bars rolled at different temperatures.*—These results show that the annealed bar has a very much lower elastic limit than a natural bar of the same ultimate strength, and oftentimes has less ductility. The difference between the Bessemer and open-hearth steels cannot be due to irregular finishing, since all the bars were rolled at the same time, and further experiments given in Table XV-D indicate that the same law holds good whether the metal is finished hot or cold.

TABLE XV-D.

Effect of Annealing Acid Open-Hearth Rolled Steel Bars 2x⅜ inches.

Group.	No. of heats in group.	Limits of tensile strength; pounds per square in. and composition; per cent.	Temperature at which bars were finished.	Condition of bar.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
I	3	56000 to 60000 C, .12; P, .035; Mn, .56.	Usual	Nat.	58130	39733	30.42	61.90	68.4
				Ann.	52323	31677	30.75	60.63	60.5
			Dull red	Nat.	59857	43037	31.83	59.60	71.9
				Ann.	51557	33893	32.92	63.60	65.7
II	4	60000 to 64000 C, .12; P, .086; Mn, .48.	Usual	Nat.	61703	41985	30.19	60.70	68.0
				Ann.	54463	30953	30.38	59.35	56.8
			Dull red	Nat.	63585	45213	30.06	57.58	71.1
				Ann.	55058	36988	30.94	61.53	67.2
III	8	72000 to 80000 C, .24; P, .052; Mn, .77.	Usual	Nat.	75688	49155	24.66	54.05	64.9
				Ann.	66584	37934	26.06	50.74	57.0
			Dull red	Nat.	78083	53334	27.41	52.23	68.3
				Ann.	67058	40343	26.50	53.41	60.2

In the bars which are finished at the usual temperature there is a loss in strength due to annealing of from 6000 to 9000 pounds per square inch, and a lowering in the elastic limit of from 8000 to 11,000 pounds. In the colder finished bars the loss in strength is from 8000 to 11,000 pounds, and the elastic limit is lowered from 8000 to 13,000 pounds. Thus in both cases the elastic limit is affected much more than the ultimate strength, and the result is seen in a lower elastic ratio. The ductility does not seem to be materially improved in any instance.

The cold finishing raised the strength of the bars 1727 pounds per square inch in Group I, 1882 pounds in Group II, and 2395 pounds in Group III. Annealing lowered the strength of these cold-finished bars so that in Group I it was 766 pounds per square inch below the annealed hot-finished bar, while in Group II it was 595 pounds above it, and in Group III 474 pounds. The effect upon the elastic limit is not as thorough, and the influence of the cold finishing may be seen in the higher elastic ratio of the annealed cold-finished bar.

TABLE XV-E.

Effect of Annealing on Bars of Different Thickness, when the Percentage of Reduction in Rolling had been Constant for all Pieces.

Heat number.	Size of billet in inches.	Size of bar in inches.	Ultimate strength; lbs. per sq. inch.		Elastic limit; lbs. per sq. inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
			Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.
4605	4x4	2x⅝	51640	45870	33440	25680	37.50	37.50	60.1	64.8
	3⅝x3⅝	2x½	51120	45100	32650	26350	32.50	38.00	56.4	64.0
	3x3	2x⅜	50850	46350	35700	25980	32.50	39.50	60.8	67.0
	2½x2½	2x¼	53320	46010	37360	26680	31.25	34.00	61.0	64.3
	2x1⅝	2x⅛	. . . .	44960	. . . .	28570	. . . .	31.25	. . . .	67.2
9227	4x4	2x⅝	59540	53360	37050	29030	35.00	32.50	60.0	59.7
	3⅝x3⅝	2x½	59730	51360	38100	28410	29.75	32.75	56.4	60.1
	3x3	2x⅜	60950	52460	42110	29860	30.00	31.75	60.0	56.6
	2½x2½	2x¼	62350	51230	43070	28580	27.50	30.00	60.7	62.4
	2x1⅝	2x⅛	65130	54110	52180	31170	26.25	28.25	58.9	64.9
1509	4x4	2x⅝	67860	63560	42850	38750	25.00	26.50	40.8	57.3
	3⅝x3⅝	2x½	67550	62680	43190	38810	26.25	29.00	46.1	58.4
	3x3	2x⅜	67470	62660	44090	40430	26.25	29.25	53.2	56.1
1440	4x4	2x⅝	72840	68940	47080	43580	25.00	27.00	40.7	53.6
	3⅝x3⅝	2x½	71230	67060	46010	42020	26.25	29.00	40.5	53.4
	3x3	2x⅜	72950	67860	48760	43920	26.25	26.25	52.1	55.4
	2½x2½	2x¼	73620	69720	51550	48380	26.25	26.50	45.9	54.1
	2x1⅝	2x⅛	78560	74000	58140	53200	22.75	25.25	52.0	53.6

SEC. XVc.—*Effect of annealing on bars rolled under different conditions of work and temperature.*—All these results will be corroborated by Tables XV-E and XV-F, which show the effect of annealing on bars which have been finished under different conditions. In Table XV-E, where each bar was made from a billet of proportionate size, the pieces would be in the rolls about the same length of time, so that the only difference in character will be due to the more rapid loss in heat from a thin bar and from the more thorough compression. In Table XV-F, where all bars were rolled from the same-sized billet, these factors are supplemented by the extra cooling during the longer exposure in the rolls.

TABLE XV-F.

Effect of Annealing on Bars of Different Thickness, when All Pieces had been Rolled from Billets 3 inches Square.

Heat Number.	Size of Bar in inches.	Ult. strength; lbs. per sq. inch.		Elastic limit; lbs. per sq. inch.		Elongation in 8 in.; per cent.		Reduction of area; per ct.	
		Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.
4605	2x⅝	51370	45490	32860	25560	34.50	36.75	59.6	65.6
	2x½	51070	43280	33200	24110	31.50	38.00	59.2	64.2
	2x⅜	50850	46350	35700	25980	32.50	39.50	60.8	67.0
	2x¼	52960	44470	36220	. . . . .	31.25	38.50	63.2	69.6
	2x⅛	55560	45830	47380	27780	30.00	33.25	53.2	69.0
9227	2x⅝	59690	52880	37000	29030	35.00	32.00	55.4	56.4
	2x½	60350	52270	38560	28460	29.50	32.00	58.8	55.1
	2x⅜	60950	52460	42110	29860	30.00	31.75	60.0	56.6
	2x¼	62230	53500	42600	31000	25.75	30.75	55.9	58.4
	2x⅛	66340	54310	49860	30600	27.50	26.25	56.6	61.6
1509	2x⅝	65600	61480	40980	37840	29.50	29.00	50.9	57.1
	2x½	67310	64500	43090	41400	26.25	29.25	47.1	56.0
	2x⅜	67470	62660	44090	40430	26.25	29.25	53.2	56.1
	2x¼	69210	65240	47950	44510	26.50	30.50	54.1	52.6
	2x⅛	72100	66940	54060	49000	27.75	27.50	55.0	52.6
1440	2x⅝	72440	69730	46440	45250	27.50	24.25	45.7	56.3
	2x½	72570	67980	46200	42000	27.25	28.25	47.3	54.2
	2x⅜	72950	67860	48760	43920	26.25	26.25	52.1	55.4
	2x¼	75620	71560	51160	48250	25.00	26.50	53.5	59.0
	2x⅛	77500	70820	60920	56420	26.00	25.50	46.8	59.9

SEC. XVd.—*Effect of annealing on plates of the same charge which showed different physical properties.*—This matter of finishing temperature is of supreme importance in filling specifications on structural material, more especially in the rolling of thin plates, for it will often happen that different members of one heat will show wide variations in tensile strength when the metal itself is practically homogeneous. Table XV-G will illustrate this point by giving the records of test-pieces which gave the greatest variations in any one heat, and comparing the natural bar with a piece of the same strip when annealed.

It will be seen that annealing has almost wiped away the variations in each heat, and it is therefore quite certain that the differences lie in the rolling history. The true way of testing the

TABLE XV-G.

Showing that Rolled Plates of the same Acid Open-Hearth Heat, which show Wide Variations in their Physical Properties, are made alike by Annealing.

NOTE.—In each case, *A* is the test giving the highest tensile strength of any plate in the heat, and *B* is the one giving the lowest. Carbon was determined by color and is therefore not reliable.

Heat number.	Thickness of plates.	Condition of test bar.	Test mark.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.	Chemical composition; per cent.			
									C.	P.	Mn.	S.
5633	1/4	Natural	A	61000	53200	21.50	61.9	87.2	.16	.015	.32	.022
		Natural	B	56480	46300	25.25	60.0	82.0	.12	.015	.31	.019
		Annealed	A	47750	29980	34.50	67.0	62.8	. . .	. . .	. . .	. . .
		Annealed	B	46970	30690	35.00	64.5	65.3	. . .	. . .	. . .	. . .
5658	1/4	Natural	A	65370	52560	21.75	58.7	80.4	.14	.009	.45	.025
		Natural	B	60380	48800	21.50	61.1	80.8	.10	.012	.45	.020
		Annealed	A	52160	32450	32.00	57.0	62.2	. . .	. . .	. . .	. . .
		Annealed	B	50260	33340	32.50	62.6	66.3	. . .	. . .	. . .	. . .
8217	1/4	Natural	A	64620	53140	25.00	58.1	82.2	.16	.021	.44	.031
		Natural	B	59960	48490	21.50	45.5	80.9	.14	.016	.44	.025
		Annealed	A	52820	35450	27.00	62.2	67.1	. . .	. . .	. . .	. . .
		Annealed	B	50000	31840	31.50	56.4	63.7	. . .	. . .	. . .	. . .
8226	1/4	Natural	A	64260	54370	21.00	50.6	84.6	.12	.036	.34	.058
		Natural	B	57040	39990	28.75	56.6	70.1	.12	.034	.32	.047
		Annealed	A	54070	38520	27.50	64.4	71.2	. . .	. . .	. . .	. . .
		Annealed	B	53960	38520	29.50	63.3	71.4	. . .	. . .	. . .	. . .
8231	5/16	Natural	A	64480	50560	26.00	58.8	78.4	.13	.021	.55	.048
		Natural	B	61100	45030	26.00	48.0	73.7	.11	.018	.51	.044
		Annealed	A	53830	34870	31.25	61.9	64.8	. . .	. . .	. . .	. . .
		Annealed	B	52180	33780	34.25	63.2	64.7	. . .	. . .	. . .	. . .
8233	1/4	Natural	A	66360	59100	20.75	62.7	89.1	.11	.026	.37	.033
		Natural	B	58160	47630	24.50	60.3	81.9	.11	.020	.39	.028
		Annealed	A	52760	36940	33.00	65.0	70.0	. . .	. . .	. . .	. . .
		Annealed	B	51480	40480	28.75	56.0	78.6	. . .	. . .	. . .	. . .
8234	5/16	Natural	A	66300	49440	20.75	57.5	74.6	.15	.024	.49	.022
		Natural	B	61360	47930	27.00	61.7	78.1	.14	.021	.47	.023
		Annealed	A	55560	37360	28.25	60.0	67.2	. . .	. . .	. . .	. . .
		Annealed	B	54033	34443	31.75	63.7	63.7	. . .	. . .	. . .	. . .
8235	1/4	Natural	A	63220	58300	13.50	54.9	92.2	.10	.017	.33	.035
		Natural	B	58240	47630	21.25	53.5	81.8	.11	.017	.35	.034
		Annealed	A	47740	29930	33.25	63.9	62.7	. . .	. . .	. . .	. . .
		Annealed	B	47600	30530	34.00	57.2	64.1	. . .	. . .	. . .	. . .
8236	5/16	Natural	A	64020	49510	23.25	58.1	77.3	.11	.025	.46	.037
		Natural	B	58720	42960	30.25	60.0	73.2	.13	.017	.45	.022
		Annealed	A	53860	33710	29.25	58.6	62.6	. . .	. . .	. . .	. . .
		Annealed	B	50660	32710	35.00	64.7	64.6	. . .	. . .	. . .	. . .

homogeneity of steel, or of comparing two different samples, is to make the tests on annealed bars. This practice was pursued in Chapter XIII.

SEC. XVe.—*Effect of annealing on the physical properties of eye-bar flats.*—It does not follow that plates and bars should be annealed to put them into their best condition. On the contrary, the foregoing tests have shown that very little is gained in ductility, while there is quite a loss in working strength, and that it would be better and much cheaper to choose a softer steel in its natural state. Moreover, it must be considered that the bars which have been discussed in the foregoing tables have been small test-pieces which could be treated under fairly constant conditions, and even then the results are far from regular.

TABLE XV-H.

Comparative Tests of Eye-Bar Steel.

Heat number.	Longitudinal strip; cut from near the edge of eye-bar; natural.					Full-sized eye-bar; annealed.				
	Elastic limit; pounds per square in.	Ultimate strength; pounds per square in.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.	Elastic limit; pounds per square in.	Ultimate strength; pounds per square in.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
1	40710	68830	27.00	47.18	59.1	36500	62100	43.70	32.60	58.8
2	41570	71400	26.25	50.08	58.2	40400	65200	40.00	46.55	62.0
3	39780	69460	25.75	44.31	57.3	38300	63250	41.85	45.95	60.5
4	40380	69400	25.00	48.41	58.9	40600	67100	36.00	45.00	60.5
5	41480	72320	24.50	46.78	57.4	42100	65000	36.60	48.40	64.8
6	41310	73640	23.75	36.54	56.1	33700	57600	45.60	50.00	58.5
7	40370	72060	25.60	40.00	56.0	35400	64700	45.62	61.30	54.7
8	41900	76700	25.75	43.76	54.6	39600	67700	38.43	42.65	58.5
9	41070	69680	27.00	44.33	58.9	35900	65200	40.00	46.40	55.1
Av.	41008	71499	25.62	44.60	57.4	38056	64206	40 87	46.54	59.3

These deductions will be corroborated by Table XV-H, which gives the parallel records of pieces cut from a flat bar in its natural state, and the full-sized eye-bars after annealing. The steel was made and rolled by one of our largest American works. It is plain that there is a great gain in the elongation, but the reduction of area is unaffected and there is a decided loss in elastic and ultimate strength.

SEC. XVf.—*Methods of annealing.*—A different view of the subject is taken by Gus. C. Henning.* He states that steel is injured

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* *Trans. Am. Soc. Mech. Eng.*, Vol. XIII, p. 572.

by annealing if it is in contact with flame, while it is improved if it is reheated in a sealed muffle. I cannot assent to this broad conclusion, for, while it may be true that a flame can be run too hot and the piece be burned through carelessness, it by no means follows that such local overheating is necessary; nor is there any ground for assuming the absorption of deleterious gases from a proper flame. Moreover, the figures which he gives do not show a decided improvement of any kind in the bars which were heated in a retort.

TABLE XV-I.

Comparative Physical Properties of Natural and Annealed Flat Steel Bars; as given by Henning.*

Number of pieces.	Thickness of flats; in inches.	Average thickness of flats; in inches.	Condition of bar.	Elastic limit; pounds per square inch.	Ult. strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
10	$\frac{7}{8}$ to $1\frac{5}{16}$	1.12	Natural	38737	71226	23.89	47.0	54.4
			Annealed	40299	69296	25.53	53.5	58.2
16	$1\frac{3}{8}$ to $1\frac{7}{16}$	1.41	Natural	35411	68465	24.38	46.65	51.7
			Annealed	38298	67971	24.95	49.17	56.3
12	$1\frac{1}{2}$ to $1\frac{7}{8}$	1.62	Natural	35729	60490	24.25	47.27	51.4
			Annealed	38692	60411	25.28	49.85	55.7

It is stated (*loc. cit.*, p. 577) that most of the "flats" were "properly" annealed, and so I have averaged the records which he gives of the natural and the reheated pieces, separating them into three groups according to thickness. The results are given in Table XV-I. It will be seen that the metal has undergone very little change at all, and it is impossible to see anything which can be called a radical improvement.

Any attempt to carry out a general system of annealing plates and shapes will result in wide variations in temperatures and rates of cooling, for it will be impossible to have a large pile of metal heated uniformly throughout, since the outside of the lot will be at

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* *Trans. Amer. Soc. Mech. Eng.*, Vol. XIII, p. 586, *et seq.* The factor which Mr. Henning calls the "yield point" is here called the elastic limit. I have omitted from the averages the tests which are noted in the original as being wrongly marked, and also three tests which show such extremely low elongation that it is certain the material was not properly treated, or that there is an error in the records.

a full heat when the interior is unaffected. Since the manufacturer may always manipulate the operation so as to affect the test-pieces in preference to the rest of the steel, and since it will be to his interest to keep the temperature as low as possible to avoid warping, there will be no certainty either that the work has been properly carried out or that it has been of the least advantage.

SEC. XVg.—*Further experiments on annealing rolled bars.*—The experiments on annealing related in this chapter were performed by the usual method of estimating temperatures by the eye. They were, however, conducted under conditions exceptionally favorable to uniform results, as the pieces were small and were enclosed in a muffle and were carefully watched. No ordinary annealing of eye-bars or plates would be carried out under such favorable auspices. For purposes of comparison, I have repeated some of the experiments, the temperatures being determined by the Le Chatelier pyrometer. In Table XV-J it is shown that the heat treatment has reduced the tensile strength, the elastic limit and the elastic ratio, and has raised the elongation and reduction of area. In Table XV-K are compared the bars showing similar ultimate strength. The annealed pieces show greater elongation, but a lower elastic ratio, and in order to obtain the same elastic limit it would be necessary to take a harder steel, whereby the elongation would be somewhat lowered. It would seem doubtful therefore whether the bars under the most careful annealing are

TABLE XV-J.

Effect of Annealing at about 800° C. (1472° F.) on the Physical Properties of Structural Steel. (Bars are rolled flats 2″x⅜″.)

Limits of Ultimate Strength lbs. per sq. inch.	Kind of Steel.	No. of bars.	Condition of bar.	Average ultimate strength lbs. per sq. in.	Average elastic limit lbs. per sq. inch.	Elongation in 4 inches; per cent.	Reduction of area; per cent.	Elastic ratio.
57 to 61,000	Acid open hearth.	10	Natural	60.110	39.770	33.3	52.0	66.1
		15	Annealed	55,690	36,180	36.3	56.8	64.9
56 to 64,000	Basic open hearth.	12	Natural	61.740	38,861	33.0	52.3	63 0
		17	Annealed	57,870	35.320	36.6	57.6	61.0
58 to 68,000	"Transferred." See Section XIIa.	10	Natural	62,050	39.590	33.4	54.9	64.6
		15	Annealed	55,590	34,790	37.3	59.0	62.6

more suitable for structural work than the ordinary product of a mill, while assuredly the extra cost of such careful treatment of long and heavy sections would make it commercially out of the question in almost all cases. It is, of course, understood that the treatment of eye-bars is a different question, this being made necessary by the work done in shaping the ends.

TABLE XV-K.

Comparison of the Natural and Annealed Bars shown in Table XV-J, which show about the same Ultimate Strength.

Limits of Ultimate Strength; lbs. per sq. inch.	Kind of Steel.	No. of bars.	Condition of bars.	Average ultimate strength lbs. per sq. in.	Average elastic limit; lbs. per sq. inch.	Elongation in 4 inches; per cent.	Reduction of area; per cent.	Elastic ratio.
54 to 58,000	**Acid.**	10	Natural	56.200	39,550	29.7	58.8	70.4
52 to 59 000		15	Annealed	55,690	36 180	36 3	56.8	64.9
55 to 58,000	**Basic.**	12	Natural	56.870	37,760	30.4	56.4	66.4
54 to 64,000		17	Annealed	57,870	35,320	36.6	57.6	61.0
55 to 60.000	**Acid.***	4	Natural	58 130	40 400	30.1	61.7	69.5
55 to 60,000		7	Annealed	55.021	31,576	30.4	60.0	57.4

SEC. XVh.†—*General remarks on the determination of temperatures.*—For the commercial operation of annealing, the temperature may be conveniently and accurately determined by the use of a platinum or copper ball with the usual water receiver. In more accurate work it is advisable to use a Le Chatelier pyrometer, but in either case considerable care must be taken to insure that the piece of metal which registers the temperature, whether it be the ball or the electric couple, is of the same degree of heat as the forging or the casting under treatment.

It is generally taken for granted that if the juncture of a Platinum—Platinum—ten per cent. Rhodium couple is in contact with the steel under treatment, the temperature as registered is correct. Practically, although not absolutely, this is true, for if the conditions of heating are the same, that is, if the furnaces are of the same general size and plan and the pieces under treatment are

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* These constitute Group III in Table XV-C.

† The remainder of this chapter is mainly the work of J. W. Campbell.

approximately the same size, the readings are relative, and being relative may be considered to be correct. Now is this true under conditions radically different? If a small piece of steel is placed in a muffle and heated, the muffle having been at a high temperature before the introduction of the piece, it will be found even while the piece is black or very dark red, say not over 650° C., that the needle of a Le Chatelier pyrometer, the couple of which is in contact with the steel, will indicate a temperature some thirty degrees higher. This is probably due to the fact that while it takes some time for the mass of steel to absorb the heat from the muffle, the fine wires of the couple arrive at the high temperature in perhaps twenty or thirty seconds. Of course, the juncture, being in contact with the cooler steel, is considerably cooler than the furnace, but nevertheless it is some degrees higher than the piece, and this higher temperature is the one which sets up the difference of potential which affects the galvanometer.

This is undoubtedly the case in still greater measure with larger furnaces and larger masses, and if it is desired to compare a small piece with a large one the temperature of treatment must be the same. There is one way of arriving at this with certainty, and this is in accordance with what Howe describes as the condition of invisibility. He sets forth that a certain color is indicative of a certain temperature, whatever the material, and proves it by stating that if pieces of several different kinds of metals be placed in a furnace and heated carefully and slowly, and held till it is certain that they are heated equally through and through, on looking into the furnace nothing can be seen but the walls of the furnace. The pieces are invisible. He then shows that since the only light is that given off by the heated surfaces themselves and since if there were even the slightest difference in color, the edges of the pieces could be seen, the whole furnace and contents must be the same color and this he calls "invisibility."

Now if a large piece of metal is heated until the wires of the couple cannot be seen in contact with the piece, and if this heating be continued until the piece shows an uniform color all over its surface, and until it has been heated throughout to this color, an absolute reading is obtained—at least absolute within the limits of error of the galvanometer. In this connection it should be stated that the Le Chatelier pyrometer is the best practical method of taking readings of high temperatures. That a piece has been heated thoroughly can only be discovered by practice and a knowledge of the heating capacity of the furnace. As good a way perhaps as any is to note the time of heating to a certain indicated temperature, then cool under conditions which may be duplicated and note time of cooling; then heat to this temperature again, soak for some time and cool under previous conditions, and if the cooling takes longer the piece is heated more nearly uniformly. After a few trials in this way the necessary time may be estimated with sufficient accuracy. It may seem that this is an unnecessary refinement, but up to the present time, except in a limited number of grades of steel and at a few works, proper attention has not been given to the annealing of steel.

SEC. XVi.—*Definition of the term "critical point."*—If a piece of steel containing over 0.50 per cent. of carbon be allowed to cool slowly from a high temperature, certain peculiar phenomena will be noticed. The cooling at first proceeds at a uniformly retarded rate, but when a temperature of about 700° C. is reached there is an interruption of this regularity. In some cases the rate of cooling may become very slow, in other cases the bar may not decrease in temperature at all, while in still other cases the bar may actually grow hotter for a moment in spite of the fact that it is free to radiate heat in every direction and that it has been cooling regularly down to that particular temperature. Moreover, it will be found that when this "critical point" is passed, the bar cools as before until it reaches the temperature of the atmosphere. It is, of course, a matter of common knowledge that a bar will cool in less time from 1000° C. to 900° C. than it will from 200° C. to 100° C. and the term "uniformly retarded," as above used, is intended to cover this fact.

It is quite clear that there must be some change taking place within the metal itself giving rise to heat, and any point at which such an action takes place in any steel is called a "critical point" and in metallography such a point is denoted by the letter A, the particular one just described in which there is a retardation in the cooling of a piece of steel being denoted by the term Ar. In heating a piece of steel through this range of temperature, we naturally encounter an exactly opposite phenomenon, there being an absorption of heat by internal molecular reaction, with a consequent retardation in the rise of temperature, and this point is called Ac. It has been shown by Prof. Howe that Ac is some 30° C. higher than Ar, but it is also found that in order to induce the change Ar the steel must first be heated past the point Ac, while the change at Ac cannot take place unless the steel has first been cooled to a point below Ar. It is clear therefore that these two retardations are simply opposite phases of the same phenomena.

The previous discussion has considered only steels containing as much as one-half of one per cent. of carbon and mention has been made of only one critical point, when as a matter of fact it is quite certain that there are three, although it will be shown later that the three points are practically coincident in steels containing over 0.30 per cent. of carbon. At one of these points, recently proven to be the second, is the point of magnetic transformation. Below this point carbon steel is attracted by a magnet. Above this point it is attracted only slightly if at all. It has been before explained that the critical points are found at a slightly different temperature according to whether the metal is being heated or being cooled, and it is evident that the point of magnetic transformation, which coincides with the second critical point, will vary in the same way.

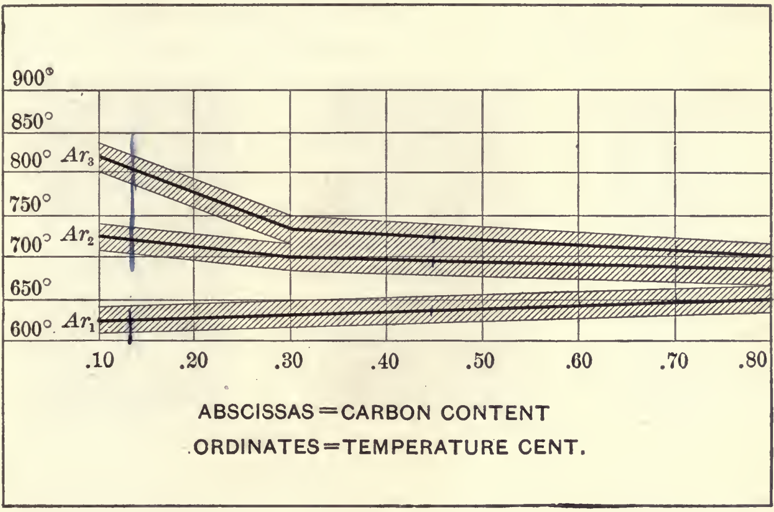
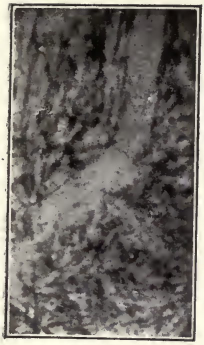


FIG. XV-A.—VARIATIONS IN THE CRITICAL POINTS IN DIFFERENT STEELS.

In soft steels these three points are readily distinguished, but as the carbon content is increased the difference in temperature between these points grows less and less, until in the harder steels the variations are hardly beyond the limits of experimental error. Moreover, there are several elements beside carbon, like manganese, phosphorus, etc., which influence the location of the critical point, so that with two steels of the same carbon content, but with varying manganese, the upper critical point of one may be lower than the lower critical point of the other.

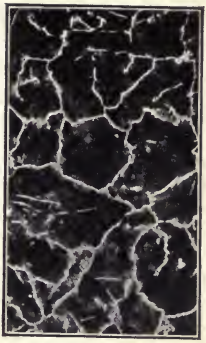
The three critical points in a cooling bar are distinguished as Ar_3, Ar_2, Ar_1, the point Ar_3 being the one at the highest temperature and Ar_1 at the lowest. In heating a bar the same three interruptions take place and the points are designated Ac_1, Ac_2, Ac_3, it being understood that in each case the lowest numerals Ac_1 and Ar_1 refer to the lowest temperatures, and the highest numerals Ac_3 and Ar_3 to the highest temperatures, and that points bearing the same exponent like Ac_1 and Ar_1 represent practically the same degree of temperature. In Fig. XV-A is shown a diagram which aims to represent the variations in the critical points for different steels. The data given by different experimenters vary considerably, but the heavy lines representing Ar_1, Ar_2 and Ar_3 are found by striking a sort of average from the available information. On each side of these heavy lines are shaded areas which represent the variations in the position of the critical point caused by differences in the content of manganese, phosphorus, etc. In the case of the soft steels the critical points are so far apart that the variations caused by these elements do not cause the maximum of one point to coincide with the minimum of the one just above, but as the content of carbon increases, the range between the highest and lowest critical points decreases, while the variations do not decrease, and as a consequence the maxima and minima run together so that they are indistinguishable.

The nature of the change that takes place at any one of these critical points is not known, but it is known that at each such point there is a great change in the micro-structure of the steel. It is known that the structure of the metal is quite different on either side of the critical points; that the forms, in which the iron and its alloyed constituents present themselves, change quite suddenly at certain definite points, and the structures found under certain well understood conditions are so characteristic that they form the basis of a science, but it is not known whether the heat liberated or ab-



No. 1.

No. 2.

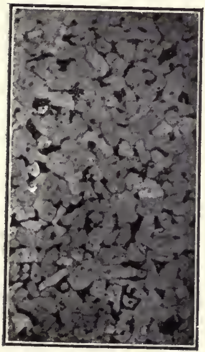


No. 3.

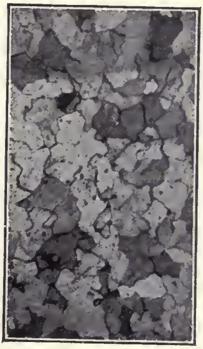
No. 4.

No. 5.

No. 6.



No. 7.



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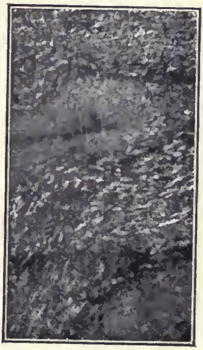
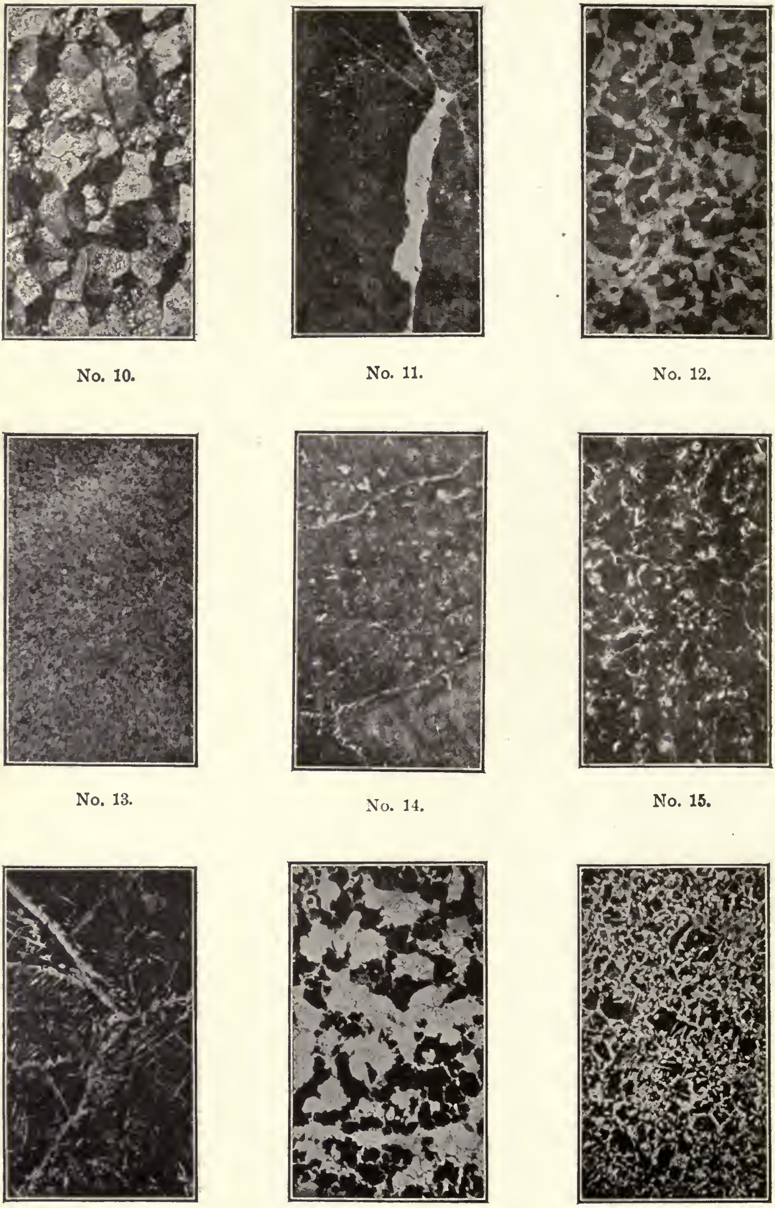


No. 9

Fig. XV-B.

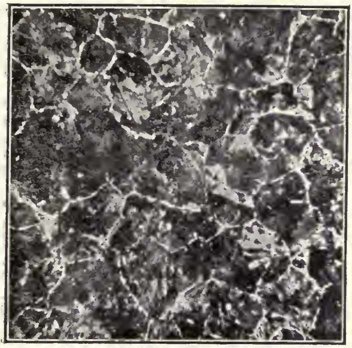


No. 10. No. 11. No. 12.

No. 13. No. 14. No. 15.

No. 16. No. 17. No. 18.

FIG. XV-C.



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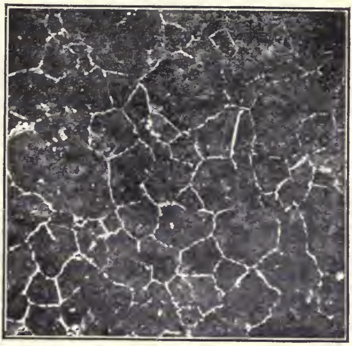
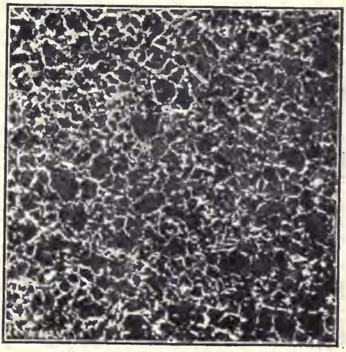


No. 20.

No. 21

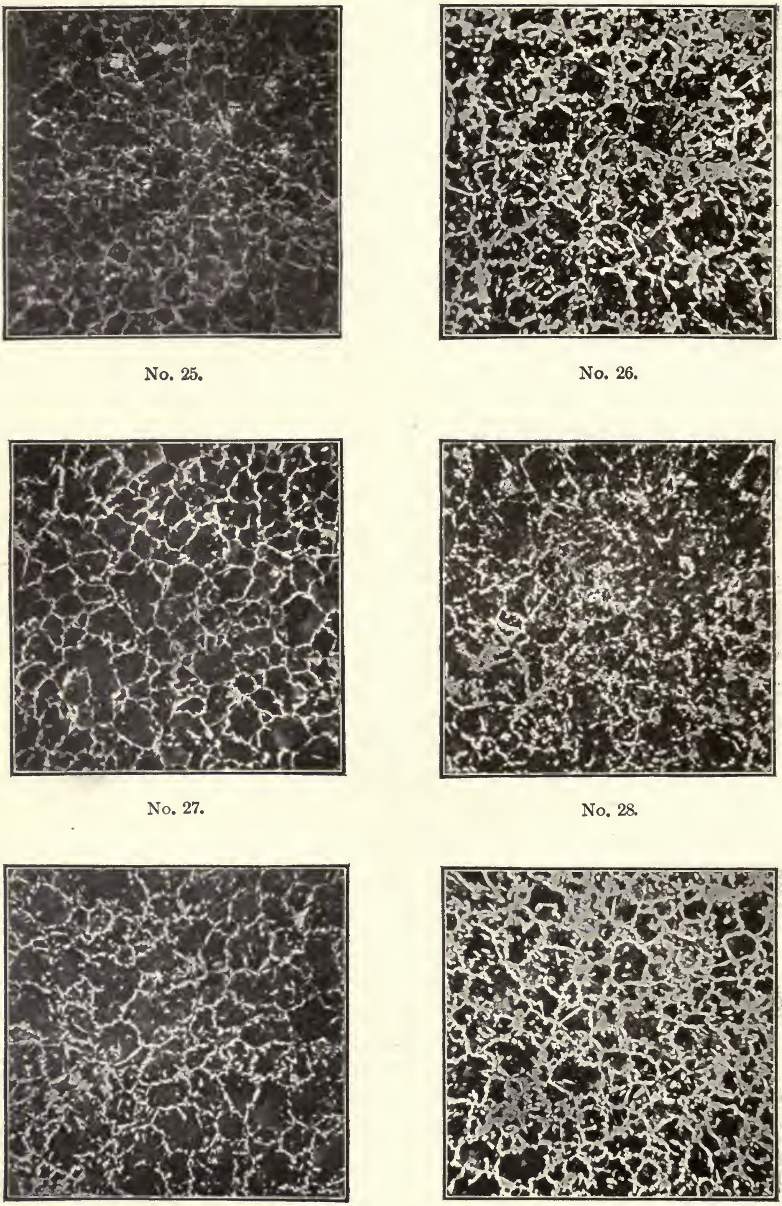
No. 22.

No. 23.



No. 24.

FIG. XV-D.



No. 25.

No. 26.

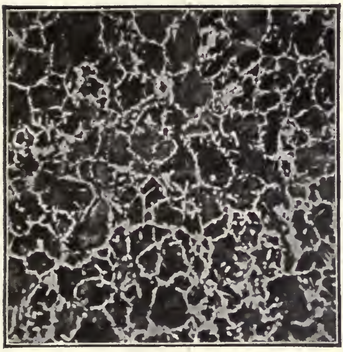
No. 27.

No. 28.

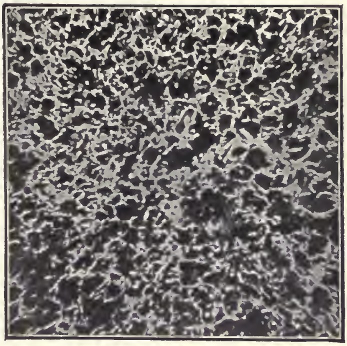
No. 29.

No. 30.

Fig. XV-E.



No. 31.



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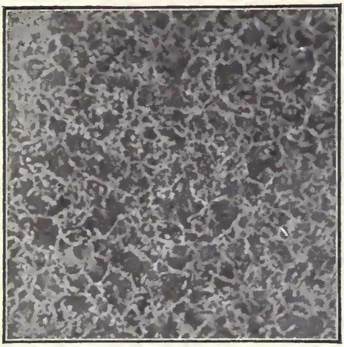
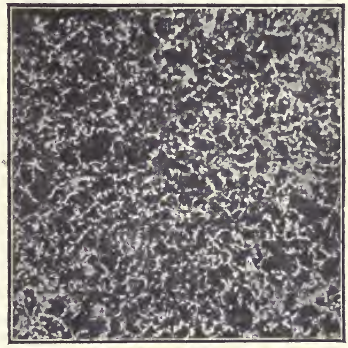
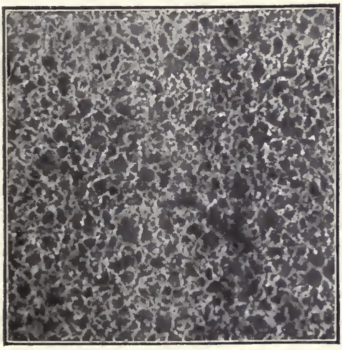


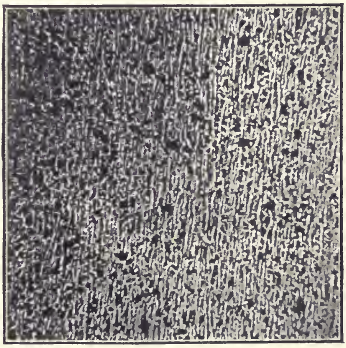
No. 33.



No. 34.

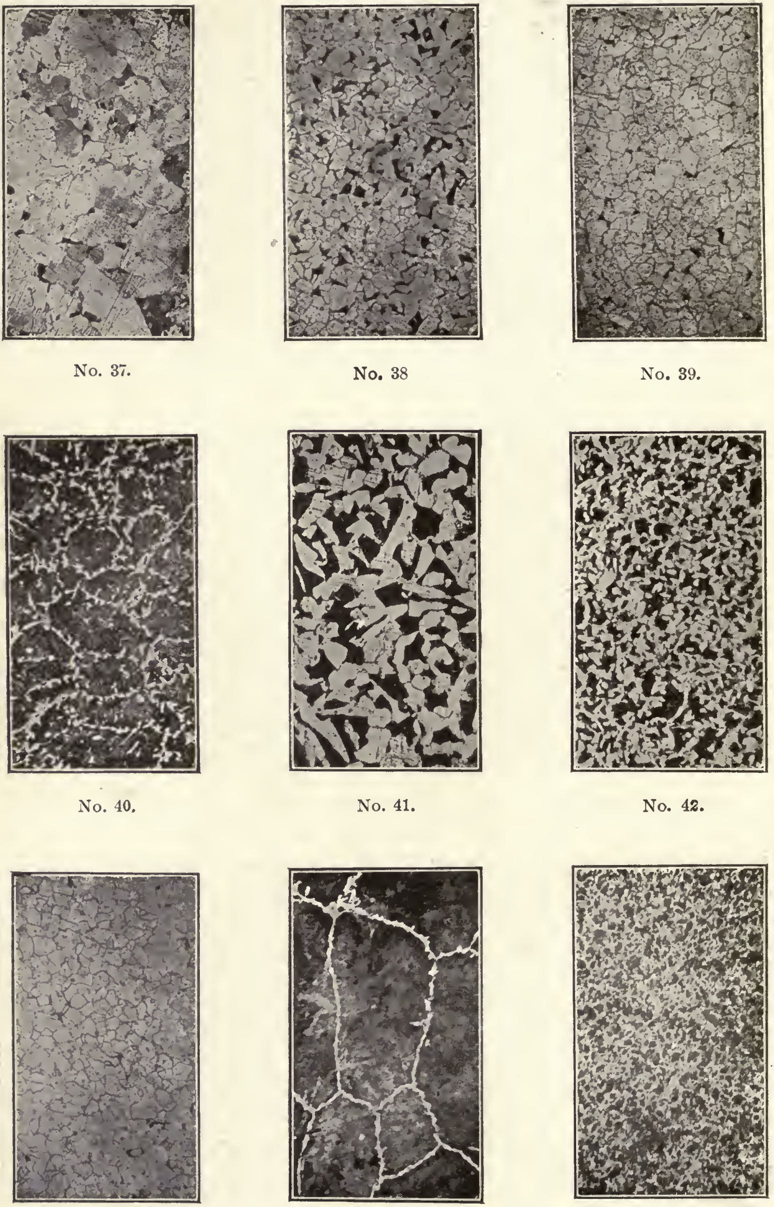


No. 35.



No. 36.

Fig. XV-F.



No. 37.

No. 38

No. 39.

No. 40.

No. 41.

No. 42.

No. 43.

No. 44.

No. 45.

Fig. XV-G.

sorbed at a critical point is due to the change from one structure to another, or whether both the change and the heat are due to some unknown molecular phenomena.

The next section will discuss the structures and forms which are best known and which must be studied to understand the effect of heat treatment.

SEC. XVj.—*Definitions of the different structures seen under the microscope.*—The microscopic examination of almost any piece of steel properly polished and etched will show that it is not entirely homogeneous, but that it is usually made up of at least two different forms of matter. It will not do to say that it is always made up of different substances, for it is generally agreed that some of these forms are allotropic,* the particular forms present in any one piece depending upon the way in which that piece has been heated and cooled. Considering all variations in heat treatment, the following forms will be encountered by the investigator: austenite, martensite, pearlite, cementite, ferrite, troostite and sorbite. Austenite is produced only by quenching steel containing more than 1.30 per cent. of carbon in ice water from above 1050° C. Its appearance is intended to be represented by the white portion of No. 1, Fig. XV-B, but this may be cementite in spite of the fact that the piece was steel containing 1.40 per cent. carbon, one-quarter of an inch thick, and was quenched in melting ice from a dazzling heat. Even under these conditions it is impossible to obtain a large quantity of austenite, since the tendency to revert to the next form is very strong when the proper temperature is reached. The theory of austenite, as well as of martensite, will be taken up in Section XVo. At about 1050° C. a change occurs, and in this grade of steel quenched below this point and above Ar_1 the second form, martensite, appears. This phase, together with a certain amount of cementite or of ferrite, depending on the carbon content, is found in carbon steels containing less than 1.30 per cent. of carbon quenched at any point above Ar_1, as will be shown in Table XV-M. Martensite is the constituent which confers hardness on steel and corresponds to the maximum hardness obtainable by

---

* The word "allotropic" is used by some of the metallographists to designate the character of the metallic aggregates. This is not strictly correct, since allotropy refers to unlike forms of the same element, while the different metallic aggregates found in microscopical investigations of masses of steel are not elements and are not of the same composition. The term "phase" was introduced by Gibb and is used later in this discussion.

carbon alone. It may be compared to a sugar solution which is more or less sweet according to the proportion of sugar present. Martensite may be easily recognized by its appearance, shown in Fig. XV-B No. 2. At the upper critical point Ar_3, the conditions become more favorable for the production of cementite and ferrite, and variable amounts of one or the other are formed, depending on the carbon content; at the second critical point, Ar_2, no radical change is noticeable, the only effect being an increase in the amount of cementite or ferrite, but at the lower critical point, Ar_1, the martensite disappears, and in steels cooled slowly to below this temperature the structure is composed entirely of ferrite, or entirely of pearlite, or of pearlite mixed with ferrite or cementite. Ferrite is iron free from carbon and forms almost the whole of a low carbon steel, while cementite is considered to be a compound of iron and carbon denoted by the formula Fe_3C, the carbon of this form being known as cement carbon. Pearlite is formed by the structural union of ferrite and cementite in definite proportions, not being a compound, but simply an intimate mixture. It appears in two forms, granular and lamellar, the former being seen in steel which has been worked or reheated to a low heat, while the latter is found only in steel which has been cooled slowly through the critical range. It is to the lamellar variety that its name is due, the structure by oblique light giving an effect like mother of pearl. In addition to these common forms there are two others, troostite and sorbite, of which little is known at present. As steel cools through the critical range, the transition from martensite to one of the forms contained in unhardened steel is not abrupt, but appears to be in two steps. Thus by quenching during this critical change a new condition will be obtained—troostite—and if this quenching takes place at the end of the critical range in cooling, a second effect is noticed, which is called sorbite. Quenching in lead, or reheating quenched steel to a purple tint may also produce sorbite, and Osmond states that when small pieces are cooled in air the chilling is sufficiently rapid to prevent the complete transformation into ferrite and cementite, some sorbite being formed. Thus austenite, martensite and troostite are found only in steel quenched at or above the critical range, while ferrite, cementite, pearlite and sorbite, are characteristic of unhardened steel. It is difficult to develop troostite and sorbite in the process of etching in such a way that they will be clearly visible under the microscope, and it has already been stated that the conditions of their existence are uncertain, so that for practical purposes these two forms may be neglected until their properties have been further studied, and since the conditions under which austenite is formed are never realized in practice, this also may be passed by. Ferrite and cementite present very nearly the same appearance, but they never occur together, and as they differ very much in hardness it is easy to distinguish them, for ferrite is pure iron and if the point of a needle is drawn across it the surface will be easily scratched, while cementite is a compound of carbon and iron and the point will make very little impression. It is generally admitted that ferrite is structureless even under the highest powers of the microscope.

Pearlite is an "eutectic alloy," a term which may possibly not be familiar to all readers. An eutectic alloy is formed by the simultaneous crystallization of different metals in a liquid mixture, as for example a mixture of copper and silver. These metals form an alloy in the proportions of 72% silver and 28% copper at a temperature of 770° C. (1418° F.), and if a melted mixture of these two metals contain any different proportion than this, and if it be allowed to cool, the element in excess of this proportion crystallizes out, the crystals remaining uniformly distributed throughout the molten mass. When the critical point of 770° C. is reached, the alloy of 72 silver and 28 copper becomes solid, and entrains the innumerable crystals of the excess element which have separated from the mother liquid. A little consideration will show that under the microscope the element solidifying first and the eutectic alloy will occupy areas exactly proportional to the original constitution.

In steel at high temperatures the same conditions exist as in the mass of silver and copper just described, save that the elements are in what is called "solid solution," martensite at the lowest critical point going through a transition into ferrite and cementite. The element in excess separates by itself, and when the proper relation has been established the ferrite and cementite crystallize together in most intimate mixture to form pearlite. As stated previously, the excess of cementite or ferrite begins to form by itself at the upper critical point, a small amount being found in steel quenched just below this, and at the second point this amount is increased, but this excess is always small except in the case of low carbon steel.

The foregoing argument may be summarized as stated by Sauveur:

(1). All unhardened steels are composed of pearlite alone, or of pearlite associated with ferrite or cementite.

(2) Without taking into consideration austenite and troostite, hardened steel is composed of martensite alone, or of martensite associated with ferrite or cementite.

(3) Ferrite and cementite cannot exist together in the same piece of steel.

(4) The presence of the lamellar variety of pearlite is almost certain proof that the steel has been annealed.

Following the proposition that ferrite is iron free from carbon and that cementite is a compound represented by the formula, Fe_3C, it is evident that in very low steels, say ranging from .02-.10 carbon, the structure will be almost entirely ferrite, and that in steel of 2.00 per cent. carbon there will be an excess of cementite. There will therefore be one point of carbon content at which the component ferrite and cementite will both be satisfied, which is to say that the original proportion will be that of the eutectic alloy. This occurs in a pure steel containing about .80 per cent. of carbon, the micro-structure of this grade showing no ferrite or cementite.

Late investigations seem to prove that in hypereutectic steels, that is, those containing more than .89 per cent. of carbon, the upper critical point, A_3, follows the curve, SE, in Fig. XV-H. This is the point at which cementite begins to form and, according to Howe and Roberts-Austen, progressively separates out within the martensite in cooling and forms a network whose coarseness is proportional to the temperature to which the steel has been heated. No break in the cooling curve has been noticed, but the first appearance of cementite is considered to mark the point, Ar_3, while Ar_2 and Ar_1 are as given in diagram Fig. XV-A.

Tables taken from Prof. Sauveur give results as shown in Tables XV-L and XV-M, the numerals being intended to represent per cent. of volume, since if a body containing an infinite number of particles, uniformly distributed, is cut by a plane, the ratio of the sum of the small areas to the total area is equal to the ratio of the volume of the small particles to the total volume. Theoretically, of course, this is not true of a mass of steel, but for practical purposes it is correct.

The different photographs in Fig. XV-B represent the appearance of steels of different carbon content. No. 3 is a steel containing 1.39 per cent. of carbon and is from a bar in the condition in which it left the rolls. It shows a pearlite grain surrounded by walls of cementite. Nos. 4 and 5 represent lamellar and granular pearlite respectively. No. 6 is a steel containing .67 per cent. of carbon, the appearance of which is similar to No. 3, but there is really quite a difference, in that there is not a sufficient amount of carbon to form the eutectic alloy. Consequently there is an excess of ferrite and this forms the walls, whereas when the carbon ex-

TABLE XV-L.

Theoretical Micro-Structure of Carbon Steels.

Carbon per cent.	Pearlite.	Fe.	Cem.
0	0	100	0
.10	12	88	0
.40	50	50	0
.70	87	13	0
.80	100	0	0
1.00	97	0	3
1.20	93	0	7
2.50	71	0	29

TABLE XV-M.

Micro-Structural Composition of some Quenched Carbon Steels.

<table>
<tr><th rowspan="2">Carbon, per cent.</th><th colspan="3">Quenched above Ar_3</th><th colspan="3">Quenched between Ar_3 and Ar_2.</th><th colspan="3">Quenched between Ar_2 and Ar_1.</th><th colspan="3">Quenched below Ar_1 or slowly cooled</th></tr>
<tr><th>Mart.</th><th>Fer.</th><th>Cem.</th><th>Mart</th><th>Fer.</th><th>Cem.</th><th>Mart.</th><th>Fer.</th><th>Cem.</th><th>Pearl.</th><th>Fer.</th><th>Cem.</th></tr>
<tr><td>0.09</td><td>77</td><td>23</td><td>0</td><td>27</td><td>73</td><td>0</td><td>11</td><td>89</td><td>0</td><td>10</td><td>90</td><td>0</td></tr>
<tr><td></td><td colspan="6">Quenched above Ar_2.</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2">Martensite.</td><td colspan="2">Ferrite.</td><td colspan="2">Cementite.</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>0.21</td><td colspan="2">100</td><td colspan="2">0</td><td colspan="2">0</td><td>31</td><td>69</td><td>0</td><td>23</td><td>77</td><td>0</td></tr>
<tr><td>0.35</td><td colspan="2">100</td><td colspan="2">0</td><td colspan="2">0</td><td>56</td><td>44</td><td>0</td><td>50</td><td>50</td><td>0</td></tr>
<tr><td></td><td colspan="6">Quenched above Ar_1.</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2">Martensite.</td><td colspan="2">Ferrite.</td><td colspan="2">Cementite.</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>0.80</td><td colspan="2">100</td><td colspan="2">0</td><td colspan="2">0</td><td></td><td></td><td></td><td>100</td><td>0</td><td>0</td></tr>
<tr><td>1 20</td><td colspan="2">94</td><td colspan="2">0</td><td colspan="2">6</td><td></td><td></td><td></td><td>92</td><td>0</td><td>8</td></tr>
<tr><td>2 50</td><td colspan="2">80</td><td colspan="2">0</td><td colspan="2">20</td><td></td><td></td><td></td><td>77</td><td>0</td><td>23</td></tr>
</table>

ceeds .89 per cent. there is an excess of cementite, which therefore forms the walls. Nos. 7 and 8 contain very little carbon, No. 8 being especially soft, showing almost no pearlite.

Index of Micro-Photographs, Figs. XV-B to G.

No.		Magnification. Diameters.
1	Austenite	900
2	Martensite..	175
3	Pearlite with cementite walls C=1.39	75
4	Lamellar pearlite	900
5	Granular pearlite	900
6	Pearlite with ferrite walls C=0.67	75
7	Mild steel C=0.20 showing ferrite and pearlite	75
8	Ferrite C=0.03	75
9	Cold worked steel showing lines of flow and in center actual rupture	30
10	Nickel steel roll, fracture in relief	1
11	Same steel as No. 10, polished and etched	50
12	Nickel steel roll shown in No. 10, annealed at 800° C	50
13	Small piece of same nickel steel roll annealed three times at 850°, 800°, 750° C.	50
14	Special high carbon steel, unannealed	50
15	Special high carbon steel, annealed	50
16	Carbon steel casting, unannealed	20
17	Same steel as No. 16, annealed	50
18	Same steel as No. 16, annealed twice	50
19	75-lb. T rail, center of head; broken in service	46
20	75-lb. T rail, center of head; broken in service	46
21	85-lb. T rail, center of head; broken on drop test	46
22	100-lb. T rail, center of head; finished at 1000° C	46
23	85-lb. T rail, center of head; "hot rolled"	46
	This rail was one of two from the same ingot rolled under different conditions. See Section XVe, Par. 1 and 2.	
24	85-lb. T rail, center of head; "cold rolled." See No. 23	46
25	107-lb. girder rail, Sec. 228, P. S. Co	44
26	107-lb. girder rail, Sec. 228, P. S. Co.	46
27	90-lb. girder rail, Sec. 200, P. S. Co.	46
28	90-lb. girder rail, Sec. 200, P. S. Co	46
29	70-lb. T rail, Sec. 237, P. S. Co., center of head	46
30	70-lb. T rail, Sec. 237, near surface	46
31	M. S. Co. 100-lb. T rail, center of head	46
32	M. S. Co. 100-lb. T rail, near surface	46
33	M. S. Co. 85-lb T rail, near surface	46
34	M. S. Co. 85-lb. T rail, "hot rolled." See No. 23	46
35	M. S. Co. 85-lb. T rail, near surface, "cold rolled." See No. 23..	46
36	Bessemer steel, C=0.45. Finished at 490° to show effect of cold rolling	50
37	Ingot structure, C=0.06	20
38	Center of 1" round, C=0.06	75
39	Near surface of same piece as No. 38, showing loss of carbon by heating	75
40	Ingot structure, C=0.47	20
41	Bloom 8"x8", rolled from 32"x38" ingot; C=.40	75
42	Billet 2"x2" hammered from bloom shown in No. 41	75
43	Section of a finished angle	75
44	Ingot structure, C=1.00	20
45	1" round rolled from ingot shown in No. 44	50

SEC. XVk.—*Effect of work on the structure of soft steel and forging steel.*—Steel as usually cast, cooling slowly from the liquid state with no work done upon it, forms in crystals and shows in general the same structure throughout. The outer skin has a structure different from the rest of the mass, as it cools quickly and is under heavy strains as long as any of the metal is hot, and there is also an area of abnormal crystallization at the top of the ingot due to segregation, but the greater part of an ingot is of the same general crystalline character. Rolling tends to break up this grain and prevent further growth during the process, but immediately after cessation of work the formation of grains begins and continues until the metal has cooled to the lower critical point. Hence it is evident that the lower the temperature to which steel is worked the more broken up the structure will be, but on the other hand if the rolling be continued below the critical point, the effect of cold work will be shown and strains will be set up which will make the piece unfit for use without annealing. Consequently it is necessary to stop the work somewhat above the critical point and in practice with large pieces it is customary to finish some 150° C. to 200° C. above this point, since the metal becomes so stiff at the lower temperature that the wear and tear on the rolls is excessive.

In blooms, billets and such hard steels as are to be reheated for hardening, the need of an extremely low finishing temperature is not so evident. If the grain be reasonably fine, the metal is solid and dense, and the crystallization of the steel when put in service will be determined by the final heat treatment. This will be taken up more in detail in Section XVm. It would appear that the smaller the piece the finer the grain, and this arises partly from the necessity of finishing a large piece while the center is still hot and partly from the slower rate of cooling of the large piece. In No. 37, Fig. XV-G, is shown the micro-structure of a low-carbon ingot magnified 20 diameters and in Nos. 38 and 39 the same grade of steel rolled into 1″ rounds and magnified 75 diameters. These last two are the center and outside respectively of the same piece and show the effect of a high temperature in burning the carbon of the steel near the surface. The dark element in No. 38 is pearlite, the light is ferrite. It will be noticed that very little pearlite is shown in No. 39. This is in accordance with the explanation in Section XVm, where it is shown that if the carbon were partly burned away it would leave just so much less cementite to mix with the ferrite to form pearlite, and consequently leave more ferrite free. In No. 40 is shown the structure of an ingot containing 0.47 per cent. of carbon magnified 20 diameters. No. 41 gives the structure of an 8″ bloom rolled from a 32″x38″ ingot, and No. 42 a test from the same bloom hammered to a piece 2″ square. These last two are magnified 75 diameters, and it should be noted that the areas of the ingot structure shown in the photographs are to the areas of the finished pieces as one to fourteen.

Figs. 44 and 45 show the structure of a steel containing about one per cent. of carbon before and after rolling, the first being a section from a 16″x20″ ingot, the latter a section from a piece 1″ in diameter cooled on the hot bed. It will be seen that the grain is well broken up without any sign of cold work, and the bar is consequently in very good condition for the hardening and tempering to which such hard steels are usually subjected. This bar was taken at random from the hot bed at Steelton.

If steel is worked below the critical point, strains are developed which injure the metal and may even rupture it. In No. 9, Fig. XV-B, is shown a piece of forging steel magnified 30 diameters. This illustrates the distortion of cold work, and the black line in the middle of the print is a crack where the tension became greater than the cohesion of the metal.

Sec. XVI.—*Effect of work upon the structure of rails.*—Nos. 19 and 20, in Fig. XV-D, show the micro-structure of two rails which broke in service. No data are available as to how long they had been in use, but it is probable that it was only a short time. No. 21 is an 85-lb. T rail, which broke under the drop test. These three fractures, as well as all the other photographs, are selected not as exceptional, but as representative of what will usually be found under similar conditions. Fig. 22 is made from a heavy rail section finished at a temperature of 1000° C., and it will be noticed that its appearance is almost if not quite the same as that of Nos. 19, 20 and 21. In Nos. 23, 24, 34 and 35 are shown the results of some experiments performed by Mr. S. S. Martin at the works of the Maryland Steel Company at Sparrow's Point. An ingot was rolled into blooms and two adjacent blooms were rolled into rails without further heating, the first being held before rolling in order to allow it to cool so that all work should be done at as low a temperature as possible, without, of course, reaching the lower critical point, while the second was rolled as quickly as possible through all the passes except the last, but was then held at the finishing pass 1¾ minutes, the result being that both pieces went through the finishing pass at the same temperature, which was about 750° C. I will designate as the "hot-rolled rail" the one which was rolled rapidly, but which was cooled down just before the finishing pass, and as the "cold-rolled rail" the one which was rolled at a lower temperature during the whole operation.

No. 34 represents the micro-structure of a portion of the hot rolled rail at a place very near the surface and No. 35 the structure of the cold-rolled rail at a similar place. It is evident that a superficial examination of photographs, without any knowledge of certain fundamental conditions, might lead to the conclusion that the two methods of rolling gave identical results, but the testimony of Nos. 23 and 24 proves quite the opposite. No. 23 is from the center of the head of the hot-rolled rail and No. 24 from the center of the cold-rolled rail, and it is clear that there is a radical and fundamental difference in the results, the reason for which is perfectly clear.

The finishing pass in almost every set of rolls does very little work, for it is unusual to have over ten per cent. of reduction upon the piece, oftentimes there being much less, while in all other passes, save one regulating the height, it is usual to have from twice to three times as much. Consequently the effect of the last pass does not penetrate to any great depth. Such a penetration is necessary if the grain is to be broken up, for the head of a heavy rail offers a thicker mass of metal than is found in almost any other structural shape, and the very fact that it is considered necessary to hold a rail before finishing proves that the grain needs to be broken. If the rail is at a sufficiently low temperature the grain will not grow coarser as the rail stands, and the rail might as well be finished at once; but if it is at a high temperature and the grain is coarse, then it will do no good to hold it before the last pass, or to shower it with water, for this will merely perpetuate the coarse crystallization that exists. The holding of the rail therefore before the last pass is a delusion; it gives a lower finishing temperature and a low shrinkage, and it renders possible a very nice looking photograph from a piece of the outside skin, but it does not give any of the fundamental good qualities which should accompany such a finishing temperature, and which will accompany it if the temperature of the finishing pass is a true exponent of the rolling conditions. The attempt to estimate the structure of the rail from the amount of shrinkage is simply putting the cart before the horse; it is much like the practice in vogue a few years ago of rolling octagon spring steel and then defacing the bar by hitting it with a hammer to make it resemble the bars turned out by the tilting hammer. This tilting consisted in a rapid succession of blows continued during the cooling of the piece until a very low temperature was reached, and by this means the crystalline structure was rendered very fine and the steel was in the very best condition. The rolls did not finish the bar as cold, nor did the effect of rolling penetrate as thoroughly as the blow of the hammer, and this lack could hardly be atoned for by duplicating an incidental accompanying condition.

There will always be some difference between the structure of the center of the head of the rail and the portion near the surface, but if the rail is rolled at a proper temperature during the passes when considerable work is put upon the piece, this difference will not be serious. No. 25, in Fig. XV-E, shows the center of the head of a girder or tram rail weighing 107 pounds per yard, and No. 26 shows the surface of the head. No. 27 shows the center of the head of a 90-pound girder rail and No. 28 the surface. No. 29 is the center of a 70-pound T rail and No. 30 the surface. All these were rolled at Steelton on regular orders and it will be noted that while there is a difference, the structure of the center is very good.

Fig. XV-F shows the structure of T rails rolled at Sparrow's Point at the works of the Maryland Steel Company and represents the best modern practice. No. 31 is the center of a 100-pound T rail and No. 32 the surface; No. 33 the center of an 85-pound T rails, these structures representing the regular practice at the works. Nos. 34 and 35 have already been discussed as hot-rolled and cold-rolled rails. No. 36 represents the structure of a small test bar of rail steel which was rolled for the purpose of this experiment as cold as the strength of the rolls would allow, the finishing temperature being 490° C. (915° F.), which is considerably below the critical point, as shown by the lines of work appearing in the photograph. This evidently is the finest structure obtainable, and it may be used as a standard by which to estimate the condition of the other pieces. All the photographs in this rail steel series are cross-sections that are magnified forty-six diameters.

SEC. XVm.—*Effect of heat treatment upon the structure of cast-*

ings.—It has been proven by many investigators and is generally acknowledged that in heating steel through the lowest critical point the crystalline structure is obliterated, the metal assuming the finest condition of which it is capable. Above this point the size of the grain increases with the temperature. There is a difference of opinion as to whether the increase in size takes place during the heating or at the moment when cooling begins, but it is unnecessary to determine this question, the general proposition being true that the higher a piece of steel is heated above this point the larger the grain becomes.

At the corresponding point in cooling, the structure ceases to change, except in very soft steel, as shown by Stead, and any size of grain is retained and cannot be changed by heat treatment below this point. There is, however, a change from hardening to cement carbon, which may take place at comparatively low temperatures. This is the principle on which the tempering of steel is founded, quite a definite amount being changed at temperatures which are represented approximately by the color of the bar. Cement carbon is that form which confers the softest possible condition and greatest ductility, while hardening carbon gives the condition of greatest hardness. Hence the temper is drawn by every rise in temperature.

At the lowest critical point the change from cement to hardening carbon takes place almost instantly, all carbon above this temperature being of the hardening variety, but the reverse change in cooling appears to require a certain length of time. This is the explanation of hardening by quenching, the more rapidly the steel is cooled through this point, the less being the chance of the carbon to change its state. A sudden cooling in ice water prevents any change, while annealing is effective only in proportion as the time of exposure to this temperature was long or short. Since fine structure and cement carbon are the principal factors of toughness and ductility, both of which are the aim in annealing, it would seem that the best method of tempering would be to heat to the lowest critical point and not higher, and quench from this heat and subsequently draw the temper. Similarly the best way of annealing, since the reverse change takes place several degrees below this, would be to cool at once to just above this lower point and allow several hours for the metal to cool past the critical temperature, and long enough from this point to the cold state to prevent the setting up of strains from too rapid cooling.

Practically, however, it seems to be necessary to heat considerably above the lowest critical temperature in order to insure the thorough breaking up of the cell walls to allow the enveloping form to permeate the grain. This arises from the fact that the changes by which ferrite is formed attain their maximum effect only when the metal is subjected to a range of temperature which includes the three critical points. When steel cools slowly a certain amount of ferrite forms at the upper point, Ar_3, an additional amount at the second point, Ar_2, while the principal change occurs at the lowest point, Ar_1. Thus if the metal be considered as a solid solution, it may be said that crystallization takes place at the upper point, the solution of martensite becoming more concentrated. When the steel is heated, as in the case of annealing, the reverse phenomenon takes place, for at the lowest point the grain is broken up, the pearlite becoming martensite, somewhat diluted by the portion of ferrite which it takes up. If now the piece be cooled slowly without further heating, the resulting structure will be quite different from the original. The size of the grains will be much smaller and the piece will therefore be in much better physical condition, but there will still remain room for improvement, for throughout the mass will be found a certain proportion of ferrite, corresponding to the amount which, as already explained, is transformed at the higher temperatures of Ar_2 and Ar_3.

In order therefore to thoroughly disseminate the ferrite and encourage to the greatest extent the formation of martensite, it is necessary to heat to the upper critical point Ac_3. This high temperature, however, gives rise to a somewhat larger grain than if the lower critical point, Ac_1, had not been exceeded, so that while there is a gain in the extent of the transformation, the grain of the resulting steel is coarser and there is consequently a loss in strength. The best result is obtained by combining the two methods, the steel being first heated to the upper critical point, Ac_3, and allowed to cool slowly, by which complete transformation is effected, and then reheated just above the lower critical point, Ac_1, by which the grain is rendered fine and all strains obliterated. In case two heatings are out of the question, it is generally better to heat to the upper critical point, as it is preferable to have a slightly larger grain with a fine division of the microscopic forms, than to have a piece of metal of somewhat finer grain but much less homogeneous. Considerable care must be exercised in heating pieces which are not to be machined after treatment, since at a high temperature the carbon near the surface of steel is burned out to an appreciable depth by the action of the flame, unless the metal is protected in some way from oxidation. An effect of this kind may be noticed under the microscope with little difficulty. If the carbon has been driven off it follows that there is less cementite left to combine with ferrite to form pearlite when the metal is cooling through the critical point. Consequently there will be less pearlite formed in the oxidized surface than in the remainder of the piece. This effect is shown in Nos. 38 and 39, these being the center and the outside respectively of a soft steel bar.

In No. 11, Fig. XV-C, is shown a large pearlite grain surrounded by a thick wall of ferrite. This represents the micro-structure of a 28-inch steel roll casting containing .25 per cent. carbon and 3.5 per cent. nickel, which was put in service unannealed and broke within a few hours. In No. 10 is shown the fracture in natural size, and the photograph was made from the broken specimen without any polishing or other treatment. It is a striking illustration of intergranular weakness, the lines of rupture following almost entirely the ferrite envelope and leaving the individual grains intact. No. 12 shows the micro-structure of this broken roll after one annealing at 800°, and notwithstanding the exceedingly coarse structure of the original casting the annealed micro-structure is quite fine and shows a grain outline very much broken up. It is probable that a second annealing would have almost obliterated the crystallization, and it would have been interesting to carry this on for several more heat treatments, but as this was impracticable a piece was cut off and heated successively to 850°, 800° and 750° Centigrade and allowed to cool slowly with a complete destruction of crystallization as shown in No. 13.

It should be noted that No. 11 and No. 12 are results obtained with full size pieces, and not with small tests, as is too often the case, under which circumstances the results are not always comparable with the effect on a large piece. The two pieces were taken from the same relative positions and represent, it is believed, the structure of the roll. The casting conditions, so far as could be determined, were normal. The annealing was effected at 800° C. as registered by the pyrometer, it being necessary to consider that this does not always represent the temperature exactly unless the "invisible" condition is obtained.

No. 16 represents the micro-structure of a steel casting unannealed, magnified 20 diameters. It is almost impossible to give an idea of the structure in a small photograph, but the illustration shows parts of three grains, and like all the other reproductions, is typical. No. 17 shows the same casting after annealing. The picture is not all it should be, but by careful examination a remarkably small grain may be distinguished; the areas of pearlite and ferrite are indicative of an insufficient breaking up of the microscopic forms. No. 18 represents the casting after a second annealing. No. 14 and No. 15 show the structure before and after annealing of a special high carbon casting used in railroad work where ability to withstand shock is of prime importance.

As stated in Section XVi, the second critical point is characterized by a loss of the magnetic properties in heating; this point is very easily determined by using an electro magnet, the wires of which are connected with a sensitive galvanometer. The act of moving the magnet into and away from contact with the metal moves the needle of the galvanometer as long as the metal is magnetic. It would seem as if this should be a good point to agree upon as the temperature to which castings shall be heated for annealing. Sufficient data are not available to state positively that such treatment would give the best results possible, but it seems quite certain that treatment on this line would give good structure and be a great improvement on most of the haphazard methods now in use.

SEC. XVn.—*Effect of heat treatment on the structure of rolled material.*—In order to determine the effect of heat treatment on the structure of rolled material, tests were taken from finished angles, the general method of procedure being as follows:

A piece five feet long was sheared from the angle and cut into five equal lengths. An ordinary test bar was taken from one of the legs of each piece in the same relative place and numbered from 1 to 5. From each of the extremes 1 and 5 a section was cut for the microscope and the bars pulled in the testing machine to prove that the piece was homogeneous. The bars, 2, 3 and 4, were treated in a muffle heated by an electric coil at temperatures varying from 625° C. to 890° C., the temperature in all experiments being taken by a Le Chatelier pyrometer. No attempt was made to heat the pieces quickly, as it was intended to work under normal conditions, the operation usually occupying from one to three hours. The bars were held at the high temperature only long enough to insure uniform heating and then cooled for several hours to about 350° C. A longer annealing would probably have given slightly different physical results on account of the more nearly perfect elimination of strains and transformation to cement carbon, but the difference would have been slight, and as the object was to determine the effect of heat on the structure it was unnecessary to consider this phase of the problem.

Small sections were cut from the treated pieces, as well as from the untreated, and were polished and etched. They were invariably taken from the same relative position and etched on the surface representing the cross section of the angle. A great majority of these specimens when examined under the microscope showed well defined structures similar to those exhibited in Nos. 8 and 43. The orientation was apparently the same in both the treated and the untreated bars, and the size of the grains did not appear to be affected by the treatment, although bars from different heats showed considerable variation. It would therefore seem probable that as finely divided a grain can be produced by rolling as by any of the usual annealing processes, although there is room for further investigation on this point.

Sec. XVo.—*Theories regarding the structure of steel.*—There are several theories now before the scientific world to account for the hardening and the magnetic transformations in steel and the phenomena of the so-called critical points. It would be better perhaps to call them hypotheses, as they are in each case offered tentatively and as lines of thought on which to base experimental research. It is beyond the province of this book to enter into a full discussion of these various conceptions, but it may be well to give a brief summary of the most prominent.

The carbon theory considers that the effect of hardening is due entirely to a change in the carbon contained in the steel. In common with the other theories, it supposes that at temperatures below the critical point the carbon is in the state of cement carbon, combined with iron in the proportion Fe_3C. At the lower critical point a change in carbon is supposed to occur, and since from temperatures above this point carbon steels are hardened by sudden cooling, the advocates of this theory have devised the name "hardening carbon." The cause of evolution of heat at this point in cooling is considered to be the change from hardening to cement carbon, but no satisfactory explanation is given by this theory for the changes at the second and third critical points.

The allotropic theory holds that the iron of the steel is in different allotropic forms between the different critical points, and that below the second critical point the iron exists as *alpha* iron, but at this point *beta* iron is formed, and at the upper *gamma*, the carbon being diffused in the iron. The cause of the evolution of heat is explained by the change from *gamma* to *beta* iron at Ar_3, from *beta* to *alpha* at Ar_2, while at Ar_1 the carbon combines with *alpha* iron to form Fe_3C. The retention of a hard allotropic state of iron, this retention being helped by the presence of carbon, is considered to be the cause of hardening.

The carbo-allotropic theory is similar to the allotropic theory, except that hardening is supposed to be due to the retention by sudden cooling of a hard carbide of iron.

The Phase Doctrine. Prof. Bakhuis-Roozeboom explains* the detail of the Phase Doctrine, a phase being defined as a mass chemically or physically homogeneous, or as a mass of uniform concentration. Thus he states that a phase may be liquid or solid, may be an element or a compound, or a homogeneous mixture of variable concentration. Carbon, *alpha, beta* and *gamma* iron, liquid solutions, solid solutions of carbon in *gamma* iron or martensite, cementite and ferrite are all phases, while pearlite is a conglomerate of phases. He gives a diagram shown in Fig. XV-H, which is intended to show the critical changes of alloys of iron and carbon containing different percentages of carbon at different temperatures.

From this it may be seen that the area, PSTN, represents the structure of slowly cooled steels containing less than .89 per cent. of carbon, and SKLT the structure of high carbon steels cooled slowly. MOSP is the region between A_1 and A_2, showing *alpha* iron, while GOM is that between A_2 and A_3, *beta* iron. Above GOS, which is the line A_3 in Fig. XV-A, the iron is in the phase *gamma*, the micro-structure being 100% martensite. As shown by the curve, SE, the higher the carbon in the steel the higher the heat needed to prevent the separation of cementite. Thus *m* in a 1.00 C steel is the temperature necessary to hold in solution the excess

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* *Zeitschrift fur Physikalische Chemie*, Vol. XXXIV, 1900. I. and S. Inst., September, 1900.

of cementite. At about 1050° C., however, cementite as such disappears even in high carbon steels and the carbon is considered as being in solution in *gamma* iron. This is the point above which it is necessary to heat in order to obtain austenite, from which it is argued that austenite is carbon dissolved in *gamma* iron.

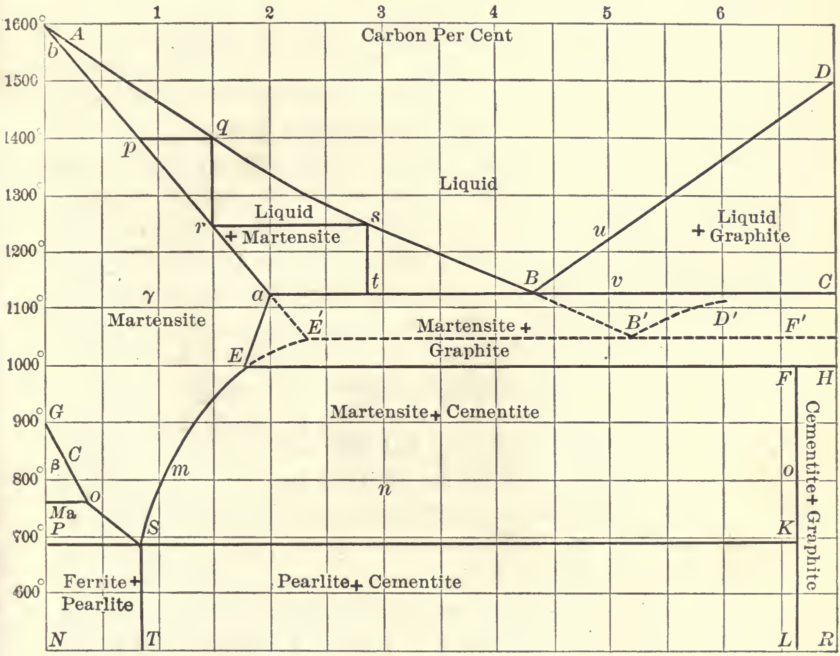

FIG. XV-H.—GRAPHICAL REPRESENTATION OF THE PHASE DOCTRINE.

Martensite is considered as a solution of Fe_3C in allotropic iron, being a saturated solution in steel containing about .89 per cent. carbon.

Prof. Arnold has disputed the allotropic theory in several articles and has evolved an hypothesis of his own which he calls the "sub-carbide theory," on the supposition that hardening is due to the retention of a hard sub-carbide of iron $Fe_{24}C$.

These theories will be found thoroughly considered in the volumes of the Iron and Steel Institute of the past few years. Enough is given here to show the variety of ideas, all of which have their strong and their weak points.

CHAPTER XVI.

THE HISTORY AND SHAPE OF THE TEST-PIECE.

SEC. XVIa.—*Differences in physical properties between the surface and the interior of worked steel.*—The first question that arises in the inspection of steel is the manner in which the test-piece shall be taken. In former days it was the custom to carefully plane or turn a piece to a standard size, with a certain length between shoulders and a certain radius for the terminal fillets; but this method is both tedious and expensive with no corresponding advantages. It is still used in steel castings, for it is impossible to cast a bar of sufficiently accurate section to be fit for a tensile test, and it is also used in the case of forgings where the piece is too large to be broken in full section, and when it is deemed advisable to carve a piece from the finished material. In all other work the test is either a part of the finished bar, as in the case of small rounds and flats, or is cut from the member, as in the case of angles, channels, etc., with two sides of the piece in the condition in which they left the rolls. A sufficient length is taken to allow about 10 inches between jaws, and the readings are made on an 8-inch length which is defined by marks of a center-punch.

A machined piece is generally inferior to a bar as it leaves the rolls. It is true that Table XIV-J shows no gain in ductility from continued stretching or polishing of the skin, but this is an entirely different matter from the full compression which the outer surface of a bar receives in the last pass. In a series of tests made at Chester, Pa., by the United States Government* in 1885, the machine was not powerful enough to pull a seven-eighth-inch round, so that rods of this size were turned down to three-quarter-inch in diameter. The comparative results are given in Table XVI-A, the figures in each case representing the average of 14 heats which were tested in both diameters.

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* *Report of the Naval Advisory Board on the Mild Steel used in the Construction of the Dolphin, Atlanta, Boston and Chicago;* 1885, pp. 81, 82.

TABLE XVI-A.

Comparative Physical Properties of ¾-inch Rolled Rounds in their Natural State, and ⅞-inch Rounds of the Same Heats Turned Down to ¾-inch.

Condition of bar.	Ult. strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.
¾ inch natural, ...	65764	27.53	42.7
⅞ inch turned to ¾ inch, ...	65038	25.30	42.0

The pieces cut from the seven-eighth-inch bar are evidently inferior to the three-quarter-inch tests, although it will be shown in Table XVI-K that the larger bar should give the better elongation. It is probable that the inferiority is due to the removal of the best part of the piece in the operation of turning. This phenomenon is more marked in larger sizes, as will be shown by Table XVI-B, which gives the results on bars cut from forged bridge-pins.

TABLE XVI-B.

Physical Properties of Test-Pieces ¾-inch in Diameter, cut from Forged Rounds.

Size of Ingot, 18x20 inches. Pennsylvania Steel Company, 1893.

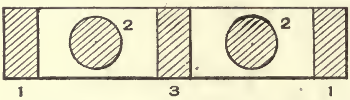
Diameter of forged round.	Place from which test was taken.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 in.; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
8 in.	At a depth of 1 inch from outside.	62720	32870	21.50	40.4	52.4
	At a depth of 2 inches from outside.	58100	29170	22.25	37.5	50.2
	The central axis.	58100	31490	20.25	34.1	54.2
10 in.	At a depth of 1 inch from outside.	66070	37080	19.50	33.9	56.1
	At a depth of 2½ inches from outside.	62750	35670	18.00	32.7	56.8
	The central axis.	60900	32140	19.50	23.8	52.8
Preliminary test of same heat from 6 in. ingot		63930	42250	26.25	41.7	66.1

SEC. XVIb.—*Physical properties of strips cut from eye-bar flats.* —Similar differences will be found if test-pieces be cut from different parts of rolled bars such as are used for making eye-bars. This will be illustrated by Table XVI-C.

These results display considerable uniformity in the higher strength of the test bars which were rolled from the large ingot, but the number of specimens is not sufficient to fully establish the fact. Such a comparison is often invalidated by certain unknown factors, for if the test bar be finished hot and the "flat" cold, the relation may be reversed. Table XVI-D shows the comparative results on nine heats of steel made at one of our large steel works, and will illustrate how widely the preliminary test may differ from the finished bar in individual cases, while the average of the two is nearly the same. In the light of such facts it seems absurd to reject a heat of steel because the preliminary test falls a few hundred pounds below an arbitrary standard.

Table XVI-C.

Physical Properties of Test-Pieces of Different Section Cut from Rolled Flats, together with the Results on ¾-inch Rounds of the Same Heats Rolled from a 14-inch Square Ingot.



1, 1 = edge of bar; 2, 2 = ¾-inch rounds cut on a machine; 3 = center of bar; 4 = ¾-inch round rolled from an ingot.

Number of group.	Limits of ultimate strength in group, of the ¾-inch round rolled from the ingot; pounds per square inch.	Number of heats in group.	Place from which test was taken; see head of table.	Ult. strength pounds per square inch.	Elastic limit; pounds per square inch.	Elastic ratio; per cent.	Elongation in 8 inches; per cent.	Reduction of area; per cent.
I	55000 to 60000	2	1	57450	35085	61.1	28.50	51.97
			2	57095	31575	55.3	27.87	54.43
			3	56990	33185	58.2	25.13	48.89
			4	59463	43489	73.1	27.90	63.01
II	60000 to 65000	6	1	61586	36677	59.6	26.78	48.60
			2	60712	34572	56.9	26.82	53.22
			3	60370	34512	57.2	26.66	44.36
			4	64461	43872	68.1	26.17	50.67
III	70000 to 75000	3	1	63816	38938	61.2	26.72	51.02
			2	64430	35940	55.8	27.37	54.43
			3	62955	37892	60.2	26.38	46.69
			4	70541	47045	66.7	24.51	49.96

Sec. XVIc.—*Comparison of longitudinal and transverse test-pieces from sheared plates.*—Striking differences may also be found between strips cut lengthwise from a plate and those cut crosswise. In steel imperfectly worked the variation is very marked. Mr. A. E. Hunt, whose opinion is entitled to great weight, states in a private communication that "in plates up to 30 inches wide there is ordinarily a difference of 10 per cent. in tensile strength, and even up to 20 or 25 per cent. in ductility in favor of pieces cut with the grain. In wide plates the difference is not as marked on account of the effect of the cross-rolling."

I believe that these differences will be less in plates rolled from a slab than in those made directly from an ingot. In any event, it is quite certain that plates can be made by the first method which exhibit practically the same properties in both directions.

Table XVI-D.

Comparison of Strips Cut from Eye-Bar Flats with the Preliminary Test.

Heat number.	Preliminary test; ¾-inch rolled round; natural.					Longitudinal strip; cut near edge of eye-bar; natural.				
	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
1	42220	71820	26.25	53.47	58.8	40710	68830	27.00	47.18	59.1
2	41900	66440	28.25	58.96	63.1	41570	71400	26.25	50.08	58.2
3	41330	69760	25.00	52.94	59.3	39780	69460	25.75	44.31	57.3
4	42440	73640	25.00	55.86	57.6	40880	69400	25.00	48.41	58.9
5	41880	74470	26.25	53.37	56.2	41480	72320	24.50	46.78	57.4
6	43570	72720	24.50	54.48	59.9	41310	73640	23.75	36.54	56.1
7	43210	70240	27.50	58.21	61.5	40370	72060	25.60	40.00	56.0
8	41890	68640	25.00	56.09	61.0	41900	76700	25.75	43.76	54.6
9	42020	69390	28.75	57.14	60.6	41070	69680	27.00	44.33	58 9
Av.	42273	70791	26.28	55.61	59.7	41008	71499	25.62	44.60	57.4

This will be shown by Table XVI-E, which gives the averages of 100 plates which were rolled from Pennsylvania Steel Company slabs by the Central Iron and Steel Company, Harrisburg, Pa. The total number of plates rolled on the order was 104; of these, one was rejected on account of gauge, and three on account of tensile strength. No plate was thrown out for deficient ductility, although an elongation of 25 per cent. in 8 inches was required in both longitudinal and transverse strips, both these tests being made on each separate plate. The thickness of the plates varied from one-half-inch to three-quarter-inch, and the width from 52 inches to 87 inches. The steel was basic open-hearth, with an average composition as follows: Carbon, 0.17 per cent.; phosphorus, 0.014 per cent.; manganese, 0.37 per cent.; sulphur, 0.027 per cent.

TABLE XVI-E.

Comparative Physical Properties of Longitudinal and Transverse Strips from Sheared Plates, rolled by the Central Iron and Steel Company, Harrisburg, Pa., from Pennsylvania Steel Company Slabs.

Composition, per cent.: C, 0.17; P, .014; Mn, 0.37; S, .027.

Average of 100 plates.	Longitudinal.	Transverse.
Ultimate strength; pounds per square inch . .	56960	54540
Elastic limit; pounds per square inch	33350	32260
Elongation in 8 inches; per cent	27.46	27.90
Reduction of area; per cent	51.07	50.87

SEC. XVId.—*Comparative physical properties of parallel-sided and grooved test-pieces.*—The United States Treasury Department prescribed the grooved test on marine boiler steels up to the year 1895, but it is well known to be entirely misleading, and the present regulations call for a piece with parallel sides. The relation existing between the two different systems is shown in Table XVI-F, which gives the results obtained by The Lukens Iron and Steel Company, Coatesville, Pa., from duplicate strips cut side by side from the same plate. I am indebted to Mr. A. F. Huston, first vice-president of the company, for permission to use these records.

TABLE XVI-F.

Comparative Ultimate Strength of the Same Steel in Parallel and Grooved (Marine) Sections.

Thickness of plate in inches.	Number of plates tested.	Average ultimate strength; pounds per square inch.			Reduction of area.	
		Grooved.	Parallel.	Difference.	Grooved.	Parallel.
1	4	65600	53100	12500	52.0	58.0
$\frac{3}{4}$	6	62700	52800	9900	51.4	64.5
$\frac{5}{8}$	5	60900	51400	9500	und.	63.2
$\frac{7}{16}$	4	61300	53500	7800	61.7	65.2
$\frac{3}{8}$	3	60600	54100	6500	60.0	66.5

SEC. XVIe.—*Effect of shoulders at the ends of test-pieces on the physical properties.*—The flow of force, by which the tensile tests on the grooved section are rendered almost worthless, occurs also in 2-inch test-pieces when there are shoulders at each end. The difference is very much less, but I believe its existence will be shown by the following records. At a certain works it was the custom to cut two tests from one plate of each heat and pull one piece in a section 2 inches long and 1½ inches wide, with shoulders on each end, while the other piece was pulled in a parallel-sided section 8 inches long and 3 inches wide. Table XVI-G gives the results found by averaging the records of the two kinds of tests.

Table XVI-G.

Comparison of the Ultimate Strength of 2-inch Tests with Shoulders, and 8-inch Parallel-Sided Tests, the Two Pieces being Almost Always Cut Side by Side from the Same Plate.

All plates were rolled direct from the ingot at one heat.

Relation of ultimate strength of 2-inch and 8-inch test-pieces.	Difference in ultimate strength between 2-inch and 8-inch test-pieces; pounds per square inch.	Ultimate strength; 50000 to 58000 pounds per square inch; below .04 per cent. phosphorus.			Ultimate strength; 58000 to 64000 pounds per square inch; below .04 per cent. phosphorus.			Total heats.
		¼ to ⅜ thick.	⅜ to ½ thick.	½ to ⅝ thick.	¼ to ⅜ thick.	⅜ to ½ thick.	½ to ⅝ thick.	
2 inch gave less strength than the 8 inch.	less than 1000	6	10	3	4	7	4	34
	bet. 1000 and 2000	3	4	2	1	1	....	11
	bet. 2000 and 3000	1	3	....	4	2	....	10
	bet. 3000 and 4000	1	....	1	1	3	1	7
	bet. 4000 and 5000	....	2	....	1	....	....	3
	over 5000	....	....	....	3	3	....	6
	Total	11	19	6	14	16	5	71
2 inch gave more str'ngth than the 8 inch.	less than 1000	23	28	4	2	7	4	68
	bet. 1000 and 2000	23	36	4	8	16	6	93
	bet. 2000 and 3000	15	15	3	8	8	4	53
	bet. 3000 and 4000	4	13	5	3	3	....	28
	bet. 4000 and 5000	5	5	2	....	2	2	16
	over 5000	2	15	2	1	2	1	23
	Total	72	112	20	22	38	17	281

It will be a revelation to some engineers that such wide variations can exist in plates, but it will be evident that they are more apt to occur in plates rolled directly from an ingot than in those made from a slab. The records show that in only 71 plates did the 2-inch test show less tensile strength than the 8-inch, and in half of these cases the difference was less than 1000 pounds; on the other hand there were 281 cases where the 2-inch test showed greater strength, and the differences are more marked, the largest group showing an increase of from 1000 to 2000 pounds. It will be shown by Table XVI-L that the width of the piece has very little effect upon the strength, so that these records give evidence of the reinforcement of the 2-inch test from the shoulders at the ends.

SEC. XVIf.—*Use of the preliminary test-piece as a standard.*—Granting that the test is to be made on a parallel-sided piece, and knowing also, as proven in Section XIVe, that the results on different-sized bars will be practically uniform as long as they are made from a large ingot and bloom, it has been proposed that the steel be tested by making what is known as a "preliminary test," by which is meant a trial bar, either round or flat, rolled from a small ingot. Mr. A. E. Hunt formerly* advocated this system, but afterward† changed his opinion.

TABLE XVI-H.

Comparison of Strips, cut from Angles, with the Preliminary Test.

History of test-piece.	No. of heats in average.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 in.; per cent.	Reduction of area; per cent.
Cut from $\frac{5}{16}$-inch and $\frac{3}{8}$-inch angles	39	41300	60190	28.89	58.0
Rolled from 6-inch test ingot	39	42270	60200	26.44	42.4
Cut from $\frac{7}{16}$-inch and $\frac{1}{2}$-inch angles	46	40170	60660	29.05	56.4
Rolled from 6-inch test ingot	46	43070	61360	25.01	40.0
Cut from $\frac{9}{16}$-inch and $\frac{5}{8}$-inch angles	37	39710	61520	28.96	53.6
Rolled from 6-inch test ingot	37	42990	62930	23.10	38.2

It is the custom at Steelton to make such a preliminary test on every charge, but this is done merely to classify the metal. If the bar is rolled under proper conditions, its ultimate strength represents the ultimate strength of the finished material, and without regard to any results on elongation or other qualities, the steel is used or laid aside.

We are perfectly willing that the inspectors should see all the results, but we claim that these records have nothing to do with

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[*] *The Inspection of Materials of Construction in the United States. Journal I. and S. I.*, Vol. II, 1890, p. 316.

[†] See discussion of my paper on *Specifications for Structural Steel. Trans. Amer. Soc. Civil Eng.*, April, 1895.

the acceptance or rejection of the material. In other words, this test is our own work, while the business of the inspector is to test the material that he buys as fully and carefully as he may wish, without regard to whether a small test ingot has or has not fulfilled certain requirements, or whether it has been made at all.

Our experience in comparing results from the preliminary test with those from the finished material, differs radically from that recorded by Mr. Hunt,* although we agree on the important point that the ultimate strength remains nearly constant. Table XVI-H compares the data obtained from a large number of charges of acid open-hearth steel having a tensile strength between 56,000 and 64,000 pounds per square inch. They were all rolled into angles and the charges are grouped according to the thickness of the finished material.

The great inferiority of the tests from the 6-inch ingot is easily explained. It is very difficult to cast small ingots so that they will not be scrappy, and the bars rolled from them will oftentimes contain flaws; consequently we break down the ingot to a billet two inches square and chip out the flaws, after which the piece is reheated and gives a perfect bar. It does not receive sufficient work to ensure good elongation, but this is of no consequence, for it is only the strength of the material which is under investigation, and in this respect the results are found to be strictly comparable with the finished material.

SEC. XVIg.—*Comparative physical properties of rounds and flats.*—It has been mentioned that the properties of a flat bar are different from those of a round, and it will not be unprofitable to investigate the relation.

The points involved are three:

(1) The percentage of work on the piece.

(2) The finishing temperature.

(3) The shape of the piece.

(1) The amount of reduction from the bloom or ingot should not play too great a part in the problem, for it is the duty of the manufacturer to so conduct the operation that every piece, no matter how large, shall have sufficient work. But it must be considered that a large section, a 9-inch round for example, cannot possibly be finished under the same thorough and permeative com-

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* *Loc. cit.*

pression that can be put upon a bar only one inch in diameter or upon a thin flat.

(2) It is the business of the rolling mill to so arrange that every piece is rolled at a proper temperature, but it will be recognized as impracticable to finish bars of all diameters and thicknesses under identically the same conditions.

(3) The shape of the test-piece has an influence upon the nature of the results, but it is often difficult to isolate this relation from the effect of work and finishing temperature.

TABLE XVI-I.

Comparative Physical Properties of $\frac{3}{4}$-inch Rounds and 2x$\frac{3}{8}$-inch Flats Rolled from the Same Billet.

All bars were rolled from a 4x4-inch billet on the same mill.

	Limits of ultimate strength: pounds per square inch.	Kind of steel.	No. of heats in average.	Ult. strength; pounds per square inch.		Elastic limit; pounds per square inch.		Elongation in 8 inches; per cent		Reduction of area; per cent.		Elastic ratio; per cent	
				Round	Flat	Round	Flat	Round	Flat	Round	Flat	Round	Flat
Natural bars.	56000 to 60000	Bess. O. H.	11 4	58869 58568	58458 58130	42318 40300	41098 40400	27.75 29.09	31.45 30.13	58.83 60.78	56.13 61.75	71.88 68.81	71.33 69.51
	60000 to 64000	Bess. O. H.	6 7	62087 62187	60825 62089	45323 42606	43135 42441	27.04 28.04	30.42 30.14	55.31 62.16	56.20 60.86	73.00 68.51	70.92 68.36
	64000 to 68000	Bess. O. H.	9	66241	64621	47568	45194	25.68 . . .	23.42 . . .	50.07 . . .	47.80	71.81	69.94 . . . .
	68000 to 72000	Bess. O. H.	3 2	70457 70530	69773 69420	50263 49000	49060 45090	24.75 26.88	26.67 25.63	48.30 61.10	48.40 59.30	71.34 69.47	70.31 64.96
	72000 to 80000	Bess. O. H.	4 12	77440 76616	76900 75865	53760 51108	52240 49691	24.06 24.52	23.44 24.69	42.35 53.73	40.15 54.40	69.42 66.71	67.93 65.50
Same bars annealed.	56000 to 60000	Bess. O. H.	11 4	55703 54098	54194 51418	37828 31823	35603 30393	29.14 28.75	30.05 31.06	66.55 62.65	63.13 60.50	67.91 58.82	65.70 59.11
	60000 to 64000	Bess. O. H.	6 7	59372 58364	56192 55021	40570 35120	37542 31576	30.13 28.61	30.63 30.36	65.50 63.47	63.38 60.00	68.33 60.17	66.81 57.39
	64000 to 68000	Bess. O. H.	9	61694	58838	42228	38476	28.25	28.36	62.91	59.01	68.45	65.39 . . . .
	68000 to 72000	Bess. O. H.	3 2	65903 65500	64160 60850	44660 37685	43770 34000	26.08 23.38	28.58 26.50	63.23 55.30	59.50 52.10	67.76 57.53	68.22 55.87
	72000 to 80000	Bess. O. H.	4 12	71548 69402	68780 67618	47643 40505	43568 39403	25.81 23.04	26.38 26.31	57.53 56.54	51.00 51.36	66.59 58.36	63.34 58.27

The separation of these three intertwining influences is a complicated problem, the nature of which will be illustrated by Table XVI-I, which gives the results obtained from a large number of heats by cutting two billets from the same ingot and rolling one into a round and the other into a flat.

All the lessons of this table are not written on its face, but an examination discloses the following facts:

(1) Taking into consideration both natural and annealed bars, there are 18 comparisons between rounds and flats. The ultimate strength is less in the flat in every case. The elastic limit falls in 17 cases, and the gain in the exception is slight. The elongation is raised in 16 cases, while in the two exceptions the loss is small. The reduction of area is lowered in 14 cases and raised in four. The elastic ratio is lowered in 15 cases, while in the exceptions the increase is small.

TABLE XVI-J.

Comparative Physical Properties of Round and Flat Bars in the Natural and Annealed States.

Average of all heats given in Table XVI-I	Condition of bar.	Shape of bar.		Gain = + Loss = — in flat.
		Round	Flat	
Ultimate strength; pounds per square inch,	Natural	66679	65911	—768
	Annealed	62015	59567	—2448
Elastic limit; pounds per square inch,	Natural	46588	45268	—1320
	Annealed	39633	37106	—2527
Elastic ratio; per cent.,	Natural	69.87	68.68	—1.19
	Annealed	63.91	62.29	—1.62
Elongation in 8 inches; per cent.,	Natural	26.48	28.22	+1.74
	Annealed	27.16	28.73	+1.57
Reduction of area; per cent.,	Natural	54.98	54.05	—0.93
	Annealed	61.98	58.12	—3.86

(2) Comparing the loss of strength in passing from round to flat, as shown in Table XVI-J, there are nine possible comparisons between the loss in the natural bar and the loss in the annealed piece. The ultimate strength falls more in every case in the annealed than it does in the natural bar. The elastic limit falls in six cases and rises to a much less extent in three. The elongation rises in five cases and falls in four. The reduction of area falls in all cases. The elastic ratio falls in five cases and rises in four.

It will be found also that the exceptions and irregularities are not confined to any one kind of steel, so that it would seem proper to average the losses and gains in order to eliminate the errors due to the small number of heats in some of the groups. The results of such condensation are given in Table XVI-J, which shows the true average of all the heats and not the average of the groups.

It is shown that the loss of ultimate strength from the round to the flat is very much greater in the annealed than in the natural bars and that the elastic limit more than keeps pace with it, as shown by the elastic ratio. The difference can hardly be due to the effect of varying work, for the round was reduced to 2.6 per cent. of the area of the billet and the flat to 4.7 per cent., the reduction in both cases being so heavy that the results should be uniform as far as this factor is concerned. The effect of the finishing temperature may be ignored in the case of the annealed pieces, and yet there is a difference of 2448 pounds per square inch in ultimate strength between the flat and round.

The natural bars show less difference, which would indicate that the effect of the finishing temperature has raised the strength of the flat more than the round. This is contrary to the condition just noted that the reduction in rolling was less in the case of the flat, but it is in accord with the evident fact that a thin bar would cool faster than a round bar of somewhat less sectional area. The effect of the finishing temperature, therefore, was to raise the tensile strength of the flat more than it did the round, but not enough to overcome the difference in physical properties caused by the shape of the bars.

The reduction of area is less in the case of the flat, and the difference is more marked in the annealed than in the natural bars. The elongation is higher in both kinds of flats than in the corresponding rounds, but the difference is greater in the natural bars. This appears at first sight to be an exception, but on further consideration it will be seen that a decrease in gain is equivalent to a loss, and this brings it in accord with the decrease in the ductility, as shown by the lessened reduction of area. The net result may be summarized as follows:

(1) Flat bars differ from rounds in having less tensile strength, lower elastic limit, lower elastic ratio, greater elongation, and a slightly lower reduction of area.

(2) This difference is caused not by reason of a different finishing temperature, but in spite of it.

SEC. XVIh.—*Comparative physical properties of rounds of different diameter.*—The variation in strength of bars of the same steel is not by any means confined to pieces of different shape, for it will exist in rounds of different diameters. In Table XVI-K are given the results on a large number of rivet rods where several tests were made from the same heat. All the charges were of the same quality of steel, ranging from .11 to .15 per cent. in carbon, .02 to .04 per cent. in phosphorus, and .022 to .038 per cent. in sulphur.

TABLE XVI-K.

Comparative Physical Properties of Rounds of Different Diameters, Rolled from the Same Heats, Made by The Pennsylvania Steel Company.

Each figure is an average of from 4 to 16 determinations.

Heat No.	Ult. strength; pounds per square inch.		Elastic limit; pounds per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
	¾ in.	⅞ in.	¾ in.	⅞ in.	¾ in.	⅞ in.	¾ in.	⅞ in.
11478	60028	58215	40023	39433	29.52	30.63	60.56	60.80
11489	59170	57671	37333	37079	29.81	31.96	63.45	62.31
11550	58223	57707	39219	37482	29.73	30.40	62.70	64.10
11694	57833	58078	39373	38210	32.45	30.75	66.50	62.60
11796	57980	57517	38830	38288	30.14	31.04	60.45	63.50
11945	57456	56753	38498	37268	29.81	30.59	61.60	59.60
12006	57550	55878	38205	36485	29.58	30.58	60.81	65.05
12007	57943	57408	38752	37498	30.38	31.44	64.13	61.10
12519	58774	56106	39015	37485	29.80	31.34	62.40	59.45
2032	59670	56963	39050	36810	29.67	30.50	64.50	57.90
2073	59772	56425	39941	37007	30.25	32.79	64.90	63.70
Av.	58582	57156	38931	37550	30.10	31.09	62.91	61.83
	⅝ in.	¾ in.	⅝ in.	¾ in.	⅝ in.	¾ in.	⅝ in.	¾ in.
11478	60423	60028	41373	40023	29.44	29.52	65.40	60.56
12007	58120	57943	38200	38752	30.16	30.38	64.55	64.18
1523	59633	55735	42360	38756	30.06	31.66	64.22	65.40
2200	59421	59435	41276	39860	30.00	30.31	64.86	64.65
Av.	59399	58285	40802	39348	29.92	30.47	64.76	63.69
	⅞ in.	1⅛ in.	⅞ in.	1⅛ in.	⅞ in.	1⅛ in.	⅞ in.	1⅛ in.
12334	57820	59813	37770	37298	30.85	32.25	63.15	61.55
	⅞ in.	1$\frac{5}{16}$ in.	⅞ in.	1$\frac{5}{16}$ in.	⅞ in.	1$\frac{5}{16}$ in.	⅞ in.	1$\frac{5}{16}$ in.
12368	62683	60480	39985	36576	30.69	31.97	62.23	53.80
	. . . . .	1¼ in.	. . . . .	1¼ in.	. . . . .	1¼ in.	. . . . .	1¼ in.
11517	. . . . .	60633	. . . . .	36770	. . . . .	32.02	. . . . .	54.3

The number of heats given in the table would not be sufficient to justify a general conclusion if there were only a single bar of each heat, but it will be noted that each figure is the average of from 4 to 16 determinations. In the comparison of the three-quarter and seven-eighth-inch rounds there were 112 tests of the smaller size and 94 of the larger, while in the comparison of the five-eighth and three-quarter-inch there were 32 tests of the former and 34 of the latter. No average is given where less than four tests were taken of the same size from the same heat.

Comparing the seven-eighth-inch with the three-quarter-inch bars, it will be found that in the larger size the following changes occurred:

(1) The ultimate strength was lowered in ten heats and raised in one, the average showing a decrease of 1426 pounds per square inch.

(2) The elastic limit was lowered in all cases, the average showing a decrease of 1381 pounds per square inch; the elastic ratio was reduced from 66.5 per cent. to 65.7 per cent.

(3) The elongation was raised in ten cases and lowered in one, the average showing an increase of 0.99 per cent.

(4) The reduction of area was lowered in seven heats and raised in four, the average showing a decrease of 1.08 per cent.

Comparing the five-eighth and three-quarter-inch, it will be found that in the larger size the following alterations have taken place:

(1) The ultimate strength was lowered in three heats and raised a trifling amount in one, the average showing a decrease of 1114 pounds per square inch.

(2) The elastic limit was lowered in three cases and raised in one, the average showing a decrease of 1454 pounds per square inch; the elastic ratio was reduced from 68.7 per cent. to 67.5 per cent.

(3) The elongation was raised in every case, the average showing an increase of 0.55 per cent.

(4) The reduction of area was lowered in three heats and raised in one, the average showing a decrease of 1.07 per cent.

The consistent testimony of these records is corroborated by the data on the larger diameters. It is true that only one heat is given on each of these sizes, but it so happens that there were from twelve to sixteen bars in each case, and as the steel was of the same manufacture in all particulars the results may be accepted as fairly comparable. It seems quite certain that larger bars will give a lower ultimate strength, a lower elastic limit, a lower elastic ratio, a better elongation, and a lower reduction of area. Some of these characteristics may be due to differences in finishing temperature, but the data on elastic limits show that the pieces were all rolled at nearly the same degree of heat, and such small variations, even if due entirely to rolling conditions, are not sufficient to account for the increase in the elongation.

TABLE XVI-L.

Effect of Changes in the Width of the Test-Piece upon the Physical Properties.

	Thickness in inches.	No. of heats in av.	Width of test-piece in inches.					
			3	2	1½	1	¾	½
Ultimate strength; pounds per square in.	5/8	2	72510	73480	73840	73250	74420	75440
	9/16	8	72020	72220	72420	72643	71563	73531
	1/2	8	67945	68500	68710	68220	68050	68940
	7/16	2	73840	73550	74530	73370	73520	76130
	3/8	10	68111	68224	67950	67890	68338	67442
	True av.	30	69784	70069	70176	69968	69872	70578
Elastic limit; pounds per square in.	5/8	2	. . . . . .	41685	42185	41965	42975	46655
	9/16	8	. . . . . .	42485	42353	42711	42798	46058
	1/2	8	. . . . . .	41600	42190	41620	41630	45820
	7/16	2	. . . . . .	45840	46740	46085	46285	51820
	3/8	10	. . . . . .	45939	45346	45664	46676	45659
	True av.	30	. . . . . .	43571	43588	43579	44023	46285
Elongation in 8 inches; per cent.	5/8	2	29.87	28.87	28.37	25.00	23.75	24.25
	9/16	8	29.78	27.88	27.66	26.06	24.78	24.88
	1/2	8	30.75	28.69	27.72	27.34	26.31	24.03
	7/16	2	28.37	27.50	25.62	25.87	25.12	23.50
	3/8	10	28.50	27.23	26.65	25.85	24.98	22.93
	True av.	30	29.52	27.92	27.25	26.25	25.21	23.87
Reduction of area; per cent.	5/8	2	52.7	56.1	56.3	53.6	52.3	56.0
	9/16	8	53.7	54.2	57.3	57.2	57.6	58.9
	1/2	8	56.8	58.9	59.9	59.6	59.7	61.0
	7/16	2	52.1	53.9	56.8	60.0	58.2	56.1
	3/8	10	55.0	56.2	57.9	58.8	59.5	60.0
	True av.	30	54.79	56.23	58.09	58.32	58.48	59.45

This subject of variation in physical qualities, as produced by differences in diameter, has been discussed by Appleby.* In common with many others, he makes the vital and fundamental mistake of rolling all the bars to one size, *viz.*, 1½ inches in diameter, and turning the test specimens from these bars. It will be evident that a test-piece of one-half inch in diameter thus obtained will be merely the core or center of the original bar, and will be inferior both chemically and physically. On the one hand it embraces the area of maximum segregation, while on the other it has not under-

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* *Proc. Inst. Civil Eng.* (England), Vol. CXVIII, pp. 395-417.

gone the thorough compression that the exterior of the bar has received in the rolls or under the hammer, and a comparison of the bars is therefore invalid.

The method, which I have employed in this section, of comparing rolled bars of different sizes in the form in which they left the rolls, also presents some complicating conditions, inasmuch as the effect of work is not the same on large and on small sections, but it has the overwhelming advantage that it represents actual conditions, and portrays the exact results that may be expected in practice.

SEC. XVIi.—*Influence of the width of the test-piece upon the physical properties.*—Conclusive testimony that variations in the elongation may be due solely to the cross-section of the test-piece is furnished by Table XVI-L, which gives the results obtained in breaking strips of different width when the pieces were cut side by side from the same plate.

It must be kept in mind that no comparison can be made between the different thicknesses, since the individual heats were not the same. In the matter of widths, however, the case is otherwise, for every heat in the group was tested in all the widths, the bars from each heat being cut from the same small strip of plate, and this should give a perfectly valid basis of comparison.

The conclusions which must be drawn from the table are as follows:

(1) Variations in the width of the test-piece have very little effect upon the ultimate strength per square inch.

(2) They probably have little influence upon the elastic limit. The narrowest pieces show a decided increase, but this needs corroboration. The three-inch pieces were pulled at the works of the Pottstown Iron Company, being beyond the capacity of the machine at Steelton, and the determinations of elastic limit are therefore not comparable.

(3) The elongation increases regularly as the width increases.

(4) The reduction of area decreases regularly as the width increases.

The same subject was investigated by Barba,* his results being given in Table XVI-M.

The figures seem to show a continual increase in elongation until

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* *Résistance des Matériaux; Memoires de la Société des Ingénieurs Civils.* Vol. I, 1880, p. 682.

the width is six times the thickness, after which the stretch grows less. The latter point is not an important matter in practice since there is no occasion to use such a wide section, and in the case of plates of ordinary thickness the strength of such pieces is beyond the capacity of most machines.

TABLE XVI-M.

Influence upon the Elongation of Changes in the Width of the Test-Piece (Barba).

Number of sample.	Dimensions in inches.			Ratio of width to thickness.	Elongation; per cent.
	Length.	Width.	Thickness.		
1	3.94	0.394	0.394	1	31.0
2	3.94	0.787	0.394	2	34.0
3	3.94	1.181	0.394	3	35.0
4	3.94	1.575	0.394	4	37.2
5	3.94	1.964	0.394	5	39.0
6	3.94	2.352	0.394	6	40.8
7	3.94	2.756	0.394	7	38.5
8	3.94	3.150	0.394	8	34.5

The increase in elongation in greater widths has also been shown by E. A. Custer, of the Baldwin Locomotive Works, Philadelphia, Pa., who has given me in a private communication the results obtained by him in testing strips from boiler plate. The steel ranged in ultimate strength from 55,400 to 61,300 pounds per square inch, and was of nearly uniform chemical composition. The records are given in Table XVI-N.

TABLE XVI-N.

Effect of an Increase of Width upon the Elongation.[*]

Thickness in in.		Width of piece in inches.				
		1	1¼	1¾	2¼	3
½	Number of pieces	180	120	30	30	18
	Average ultimate strength; lbs. per sq. inch	57950	57878	58102	57800	57675
	Elongation in 8 inches; per cent.	26.27	26.98	28.01	29.49	30.82
¾	Number of pieces	20	25	20	20	20
	Average ultimate strength; lbs. per sq. inch	56680	57001	56720	56860	55870
	Elongation in 8 inches; per cent.	26.92	26.96	27.91	30.17	31.02

SEC. XVIj.—*Influence of a change in length upon the physical*

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[*] E. A. Custer, private communication.

properties.—In order to determine the relative elongation with varying length, I have carried out the following investigation: Twenty rods, three-quarter-inch in diameter, were selected from one heat of acid open-hearth steel. From each rod seven bars were cut, one of which was tested in a length of 2 inches, and one each in 4, 6, 8, 10, 12 and 14 inches. The results are given in Table XVI-O. The individual records of elongation are shown to prove that the averages are not formed by the combination of unlike members. These data are plotted in Curve *AA*, Fig. XVI-A.

TABLE XVI-O.

Influence upon the Physical Properties of Changes in the Length of the Test-Piece.

¾-inch rounds; Pennsylvania Steel Company acid open-hearth rivet steel.

	No. of bar.	Length of test-piece in inches.						
		2	4	6	8	10	12	14
Ult. strength; lbs. per square inch.	Av.	60685	60343	60099	60123	60068	60059	60066
Elastic limit; lbs. per square inch.	Av.	42548	43134	42951	43159	43161	43024	43234
Elastic ratio; per cent.	Av.	70.11	71.48	71.47	71.78	71.85	71.64	71.98
Reduction of area; per cent.	Av.	66.7	66.9	67.1	66.8	67.3	67.2	67.1
Elongation; per cent.	1	47.50	35.00	30.67	30.50	28.20	27.17	26.43
	2	46.00	35.50	30.67	30.50	29.80	27.67	26.43
	3	47.00	34.50	32.33	28.25	27.80	27.50	26.43
	4	48.50	35.50	32.00	30.25	28.20	25.00	27.00
	5	47.00	35.50	33.00	28.75	29.00	27.17	28.14
	6	46.50	39.00	32.67	28.75	31.60	29.33	23.21
	7	47.50	37.50	31.33	30.50	29.40	27.33	25.71
	8	46.00	33.00	30.00	30.00	26.60	28.00	24.43
	9	47.50	35.50	34.33	31.75	30.40	29.33	28.21
	10	47.50	36.00	30.33	29.50	28.80	28.50	25.29
	11	49.00	34.75	30.00	31.00	30.20	27.75	27.57
	12	49.00	36.50	31.33	29.50	27.80	29.83	28.71
	13	47.00	35.50	32.33	29.00	26.60	27.00	26.43
	14	47.50	38.00	31.67	32.75	31.00	30.50	26.79
	15	48.50	37.00	33.33	30.75	29.00	28.33	27.64
	16	47.50	37.00	33.00	31.25	31.00	27.75	29.29
	17	48.50	37.00	32.50	29.00	28.20	27.33	27.21
	18	46.00	35.00	34.67	28.75	28.00	28.75	25.86
	19	47.00	37.00	33.00	30.00	27.50	27.00	26.29
	20	47.50	37.50	34.33	32.50	30.00	26.25	28.14
	Av.	47.43	36.11	32.17	30.16	28.96	27.87	26.76

A similar series of tests was made by Barba,* the results being given in Table XVI-P, and plotted in Curve *BB*, Fig. XVI-A.

The linear elongation of a fractured bar is made up of two factors. First, the excessive stretch in the immediate neighborhood

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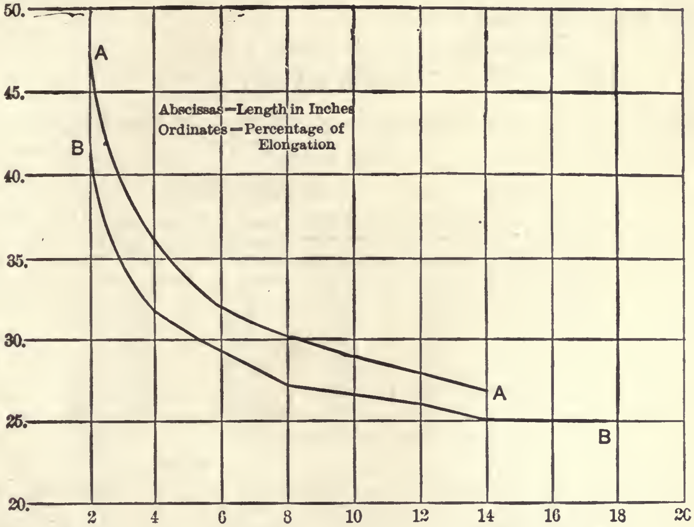
* *Résistance des Matériaux; Memoires de la Société des Ingénieurs Civils.* Vol. I, 1880, p. 682.

of the break, due to the deformation known as "necking." Second, the "permanent set" which occurs throughout the rest of the bar. It will be plain that the first factor will bear a greater ratio to the sum total as the length grows less, while it will bear a less ratio as the length increases. It will therefore follow that if the length of the piece is reduced so that it is all included in the region of necking, as, for instance, when the piece is only 2 inches long, the percentage of elongation will increase rapidly. On the other hand, when the length is increased beyond 14 inches, the ratio of the first factor to the second is not great and consequently the change in total percentage with each linear increment is not marked.



Construction points.				
No.	Curve AA.		Curve BB.	
1	x= 2	y=47.43	x= 1.97	y=42.0
2	x= 4	y=36.11	x= 3.94	y=32.0
3	x= 6	y=32.17	x= 5.91	y=29.3
4	x= 8	y=30.16	x= 7.87	y=27.2
5	x=10	y=28.96	x= 9.84	y=26.6
6	x=12	y=27.87	x=11.81	y=26.0
7	x=14	y=26.76	x=13.78	y=25.1
8	. . . .		x=15.75	y=25.0
9	. . . .		x=17.72	y=24.9

Fig. XVI-A.—Curves Showing Law of Elongation with Varying Length.

If the length were zero the percentage of elongation would be infinite, while if the length were infinite the percentage of extension would be represented by the permanent set of those portions of the bar where no necking occurs. The true curve therefore expressing the law of relative elongation is undoubtedly an hyperbola, one asymptote of which will correspond to a length of zero, while the other will be the percentage due to the permanent set, which will vary with every kind of steel.

TABLE XVI-P.

Influence upon the Elongation of Changes in the Length of the Test-Piece.*

No. of bar.	Dimensions; inches.		Ratio of length to diameter.	Elongation; per cent.
	Length.	Diameter.		
1	1.97	0.677	2.91	42.0
2	3.94	0.677	5.81	32.0
3	5.91	0.677	8.72	29.3
4	7.87	0.677	11.60	27.2
5	9.84	0.677	14.50	26.6
6	11.81	0.677	17.40	26.0
7	13.78	0.677	20.30	25.1
8	15.75	0.677	23.30	25.0
9	17.72	0.677	26.20	24.9

I had thought it possible to deduce the law of elongation for all lengths by expanding the data in Fig. XVI-A by the methods of analytic geometry. It is well known that any five points, no matter how situated, may be included in the line of a conic section, and it would seem possible, therefore, to select five points in either curve and deduce their equation, which could then be expanded indefinitely.

The application of this method to points 1, 2, 3, 5 and 7 in Curve *AA*, in Fig. XVI-A, derived from Pennsylvania Steel Company steels, gives Curve *AA*, in Fig. XVI-B. The line is very far from the truth, for it indicates only 65 per cent. elongation for a length of zero, and an elongation of zero for a length of 73 inches.

Curve *BB*, in Fig. XVI-B, represents the result of expanding points 1, 3, 5, 7 and 9 in Curve *BB*, Fig. XVI-A, derived from Barba's work. It will be noted that point 1 of this curve, where $x=1.97$ and $y=42.0$, as shown in Table XVI-P, is on the upper and return side of the ellipse, and this fact may be taken as proof

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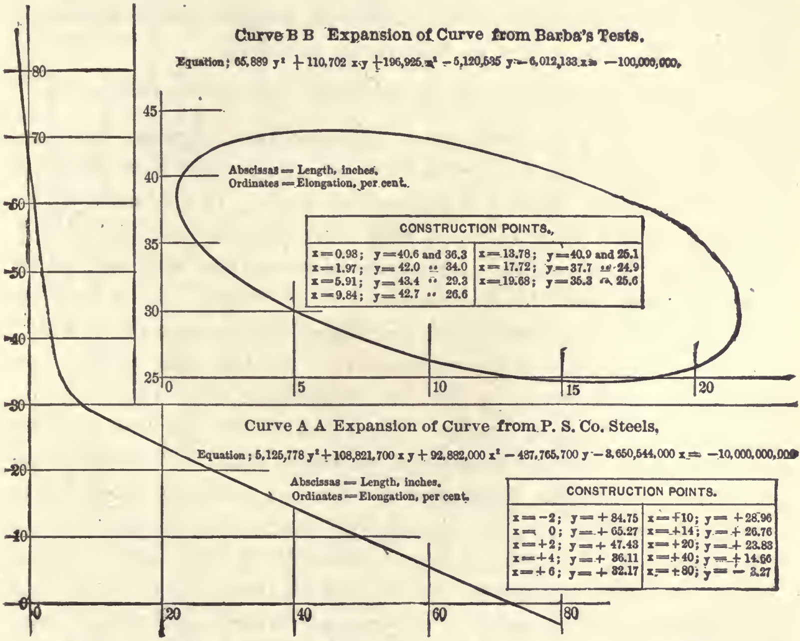
* Barba, *Proc. French Soc. Civil Eng.*, Vol. I, 1880, p. 682.

by *reductio ad absurdum* that the method is inapplicable to the expanding of such functions into extra-experimental territory. It is deemed pertinent, however, to place this investigation on record to show that the determinative errors in the most carefully constructed records are sufficient to destroy the value of this mathematical calculation, which seems at first sight to be logically correct.



Equation; $65,889\, y^2 + 110,702\, xy + 196,925\, x^2 - 5,120,535\, y - 6,012,133\, x = -100,000,000$.

CONSTRUCTION POINTS.

x = 0.98; y = 40.6 and 36.3
x = 1.97; y = 42.0 " 34.0
x = 5.91; y = 43.4 " 29.3
x = 9.84; y = 42.7 " 26.6
x = 13.78; y = 40.9 and 25.1
x = 17.72; y = 37.7 " 24.9
x = 19.68; y = 35.3 " 25.6

Equation; $5,125,778\, y^2 + 108,821,700\, xy + 92,882,000\, x^2 - 487,765,700\, y - 8,650,544,000\, x = -10,000,000,000$

CONSTRUCTION POINTS.

x = −2; y = + 84.75
x = 0; y = + 65.27
x = + 2; y = + 47.43
x = + 4; y = + 36.11
x = + 6; y = + 32.17
x = + 10; y = + 28.96
x = + 14; y = + 26.76
x = + 20; y = + 23.83
x = + 40; y = + 14.66
x = + 80; y = − 3.27

FIG. XVI-B.—EXPANSION OF CURVES IN FIG. XVI-A.

The percentage of elongation in the portion of the piece which does not undergo "necking" may be calculated from the records in Table XVI-O. As a matter of experience it is found that a length of about two inches includes the region wherein necking occurs, and this length is a constant, no matter what the total length of the test-piece may be. In other words, a test-piece two inches long is practically all "neck," while in one four inches long there will be one length of two inches which is all neck, and another length of two inches which will remain nearly a true cylinder after fracture.

In the case of the 2-inch test-pieces, given in Table XVI-O, the average elongation was 47.43 per cent., representing a linear elongation of 0.9486 inches. In the case of the 4-inch test-pieces the stretch, by the above assumption, was the same in the necked region, while the total elongation was 36.11 per cent., representing a linear elongation of 1.4444 inches. Hence the elongation in the two inches of the cylindrical portion was 1.4444—0.9486=0.4958 inches, or 24.79 per cent.

In the same manner the elongation in the cylindrical portion may be calculated for all the different lengths given in Table XVI-O. The results are as follows, in per cent.:

4″=24.79; 6″=24.54; 8″=24.40; 10″=24.34; 12″=23.96; 14″=23.32.

It will be seen that there is a decrease in elongation with an increase in length, and the relation is so regular that it is probably due to something besides experimental error. If the necking be assumed to take place within a length of only one inch, instead of two inches, the calculated percentage of elongation will be a little more uniform, but the improvement is so slight, even with this extreme hypothesis, that some other cause is shown to be at work.

I believe that the true explanation is in the fact, which was called to my attention by Mr. W. R. Webster, that the breaking speed varies with each length. The speed of the machine was the same in every case. but a moment's consideration will show that a constant speed of the grips does not mean a constant rate of distortion in the bar. In the case of the 2-inch piece the stretch was 47.43 per cent., indicating a linear extension of 0.95 inches; in the case of the 14-inch piece the stretch was 26.76 per cent., indicating an extension of 3.75 inches. The rate of distortion, therefore, was nearly four times as great in the 2-inch test as in the 14-inch bar, and this condition would give a slightly higher elongation with each decrease in length, as shown in Section XVIm.

Owing to this complication it is impossible to deduce a theoretically accurate answer from the foregoing data, but it may be considered as practically demonstrated that in a three-quarter-inch round bar of infinite length, of the same steel as shown in Table XVI-O, the elongation would be about 24 per cent.

Sec. XVIk.—*Tests on eye-bars.*—Through the courtesy of The Union Bridge Company, of Athens, Pa., I have had access to its records of eye-bar tests, and have classified them in various ways to determine the influence of width, thickness and length upon the physical properties. The steel was made by different manufactur-

TABLE XVI-Q.

Physical Properties of Eye-Bars, Classified According to Method of Manufacture, Name of Maker, Thickness, Width and Tensile Strength.

NOTES.—The bar was broken in full-sized section, but the elongation here given is the percentage in the 12 inches which included the fracture. "Narrow" signifies not over 6 inches wide, the average being about 5 inches; "Wide" signifies over 6 inches wide, the average being about 7 inches. "Thin" signifies under 1½ inches thick, the average being about 1 inch. "Thick" signifies not less than 1½ inches thick, the average being about 1⅞ inches.

Name of maker.	Method of manufacture.	Limits of ultimate strength in group; pounds per square inch.	Relative thickness of piece.	Relative width of piece.	Number of heats in average.	Average ultimate strength; pounds per square inch.	Average elastic limit; pounds per square inch.	Average elastic ratio; per cent.	Elongation in 12 inches; per cent.	Reduction of area; per cent.
A	Open-hearth.	54000 to 64000	Thin	Narrow	109	61528	39017	63.4	34.72	49.6
				Wide	18	59950	37937	63.3	38.72	48.6
			Thick	Narrow	33	60838	37470	61.9	37.43	50.0
				Wide	11	60307	36688	60.8	39.61	46.3
		64000 to 74000	Thin	Narrow	72	66702	41967	62.9	32.58	47.5
			Thick	Narrow	19	66570	41853	62.9	34.22	47.5
	Bessemer.	54000 to 64000	Thin	Narrow	102	59557	36086	60.6	34.43	50.3
				Wide	5	61988	38706	62.4	36.20	44.2
			Thick	Narrow	19	60855	36166	59.4	34.16	47.8
				Wide	26	60932	37019	60.8	37.96	48.1
		64000 to 74000	Thin	Narrow	22	66441	41665	62.7	31.93	47.3
				Wide	6	66947	39330	58.7	32.43	45.0
			Thick	Narrow	3	67370	37103	55.1	30.90	42.6
				Wide	3	67263	37290	55.4	33.00	41.8
B	Bessemer.	54000 to 64000	Thin	Narrow	47	59379	35395	59.6	34.08	49.2
				Wide	19	58582	35141	60.0	37.47	47.8
			Thick	Narrow	18	59355	34162	57.6	34.83	46.4
				Wide	61	59536	34403	57.8	36.63	46.4
		64000 to 74000	Thin	Narrow	21	66231	40756	61.5	30.19	47.7
				Wide	5	67184	40766	60.7	35.76	49.3
			Thick	Wide	22	66874	37880	56.6	33.02	45.0
	Open-hearth.	54000 to 64000	Thin	Narrow	103	59018	33901	57.4	33.79	48.3
				Wide	23	59950	32650	54.5	36.65	44.8
			Thick	Narrow	24	58985	33460	56.7	34.80	46.6
				Wide	55	58454	31971	54.7	39.22	48.0
		64000 to 74000	Thin	Narrow	23	66230	40332	60.9	30.13	44.7
				Wide	3	69350	39506	57.0	30.80	36.3
			Thick	Narrow	3	65690	38427	58.5	33.50	44.7
C	Open-hearth.	54000 to 64000	Thin	Narrow	121	60553	35592	58.8	33.57	48.7
				Wide	18	59366	34053	57.4	36.53	46.1
			Thick	Narrow	20	60870	34440	56.6	35.20	48.2
				Wide	21	60240	33245	55.2	39.07	46.2
		64000 to 74000	Thin	Narrow	81	66515	39206	58.9	32.06	46.2

ers, and it was necessary to divide the bars on that basis. Some works were represented by such a small number of bars that it was thought best to omit them from the list as well as the bars from a foreign works which gave results quite inferior to those of domestic manufacture. There were also cancelled all bars which showed 100 per cent. crystalline fracture, and pieces of miscellaneous lengths when there were less than three bars of the same steel in the group. A few pieces were discarded when the percentage of elongation in 12 inches was the same as in the full length, for this indicates either a clerical error or that fracture took place in the eye.

After these eliminations it was found that only three works were represented, two of them by both open-hearth and Bessemer steel. The records are given in Table XVI-Q, and they show that there is no radical difference in the character of the metal furnished by the three makers, or between the two methods of manufacture. This does not disprove the statement already emphasized that Bessemer metal is more treacherous in service under continued shock, and that therefore it should never be used in bridge eye-bars, but it does serve the purpose of this investigation in allowing the averaging of all the records in order to increase the number of members in each group and thereby eliminate determinative errors.

The result of such combination will be found in Table XVI-R, wherein all pieces of the same length and section are added together without regard to method of manufacture or name of maker. The number of bars given does not agree in each case with the number given in the previous list. Thus Table XVI-Q shows 83 bars that are classed as "wide and thin" and as having a tensile strength between 54,000 and 64,000 pounds, while Table XVI-R gives only 72 bars. This arises from the fact that some of the 83 bars were shorter than 13 feet or longer than 30 feet, and that there was not a sufficient number of any one size to warrant combining them to make an average. It is evident that the elongation in 12 inches and the reduction of area will be quite independent of the length of the bar, so that each of the divisions is again summarized in the true averages, *A, B, C* and *D*. The influence of width will be found by comparing *A* with *B*, and *C* with *D*, and the influence of thickness by comparing *A* with *C*, and *B* with *D*.

It is shown that the average elongation in 12 inches of the wider bars is about 3 per cent. better than the narrow pieces, while the narrow bars are superior in reduction of area. It is also indicated that the thick bars give about one per cent. more elongation, but that the difference in thickness does not seem to have a marked or regular effect upon the reduction of area.

TABLE XVI-R.

Physical Properties of Eye-Bars, Classified According to Length, Width and Thickness.*

Kind of bar.	Number of group.	Number of heats in group.	Limits of length of pieces in group; feet.	Average length of group; feet.	Average ultimate strength; pounds per square inch.	Average elastic limit; pounds per square inch.	Elongation in full length; per cent	Elongation in the 12 in including the fracture; per cent.	Reduction of area; per cent.
Narrow and thin; 54000 to 64000 pounds per square inch.	1	65	13 to 16	14.8	60070	35890	18.56	34.55	48.97
	2	132	17 to 20	18.6	59950	36160	16.17	33.93	49.40
	3	118	21 to 25	22.7	60280	35940	15.56	34.38	48.81
	4	82	26 to 30	28.1	60140	36530	15.26	34.25	49.95
	5	71	31 to 35	33.2	60120	35990	13.81	33.81	50.11
	True av. A	468	all lengths	. . .	60110	36100	. . .	34.17	49.40
Wide and thin; 54000 to 64000 pounds per square inch.	6	15	13 to 16	14.8	59380	35730	17.53	37.58	46.75
	7	21	17 to 20	19.0	59050	34070	17.18	36.79	45.12
	8	22	21 to 25	22.8	60860	35540	15.92	36.00	45.81
	9	14	26 to 30	28.1	58390	33930	14.94	39.61	47.89
	True av. B	72	all lengths	. . .	59540	34840	. . .	37.26	46.21
Narrow and thick; 54000 to 64000 pounds per square inch.	10	38	17 to 20	17.9	60050	35770	17.36	35.94	48.17
	11	38	21 to 25	22.8	61080	36040	15.87	34.46	46.79
	12	17	26 to 30	28.0	57730	32380	15.38	36.83	49.28
	True av. C	93	all lengths	. . .	60050	35260	. . .	35.50	47 80
Wide and thick; 54000 to 64000 pounds per square inch.	13	18	10 to 13	12.0	59708	35130	19.30	35.90	46.10
	14	22	13 to 16	14.8	59460	33990	16.90	38.02	47.97
	15	24	17 to 20	18.9	58930	33080	17.09	38.26	45.92
	16	67	21 to 25	23.2	59990	34270	15.98	37.42	46.94
	17	32	26 to 30	27.8	59360	34330	15.84	39.98	48.05
	18	11	31 to 35	33.1	58480	32090	16.50	40.61	48.15
	True av. D	174	all lengths	. . .	59540	34030	. . .	38.13	47.12
Narrow and thin; 64000 to 74000 pounds per square inch.	19	25	13 to 16	14.7	66590	40830	16.06	31.68	47.12
	20	58	17 to 20	18.5	66620	40420	15.32	31.57	46.19
	21	64	21 to 25	22.9	66230	40730	14.91	32.38	46.84
	22	33	26 to 30	28.7	66150	40590	14.09	32.37	46.36
	23	34	31 to 35	33.1	66560	40620	14.50	30.78	47.55
	True av. E	214	all lengths	. . .	66420	40620	. . .	31.82	46.74

The differences are not extreme in any case, and it is always unsafe in such investigations to formulate general laws from an average which may be the combination of positive and negative values, but by analyzing the individual records of the table it will

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* See notes to Table XVI-Q.

be seen that corroborative evidence is at hand of the correctness of the averages. Referring to the groups by the numbers in the first column, there are seven comparisons for width, *viz.,* 1 to 6, 2 to 7, 3 to 8, 4 to 9, 10 to 15, 11 to 16, 12 to 17; there are seven comparisons for thickness, *viz.,* 2 to 10, 3 to 11, 4 to 12, 6 to 14, 7 to 15, 8 to 16, 9 to 17.

Inspection shows that in every case the wider and the thicker pieces gave the greater elongation in 12 inches. The narrow pieces gave the better reduction of area in every case except one, and in this instance the difference was trifling. In thickness the results on reduction of area are contradictory, there being three cases where the thin bars were superior and four cases where the thick were better. It seems quite certain that either an increase in width or an increase in thickness improves the elongation in the 12 inches that includes the fracture, but that the reduction of area is improved in much less measure or not at all.

Table XVI-S.

Physical Properties of Eye-Bars, Classified According to Length; being the Same Bars Referred to in Tables XVI-Q and XVI-R.

Number of heats in group.	Limits of length in group; feet.	Average length of group; feet.	Average ultimate strength; pounds per square inch.	Average elastic limit; pounds per square inch.	Elongation in full length; per cent.	Elongation in the 12 inches including the fracture; per cent.	Reduction of area; per cent.
41	10 to 12	11.8	59880	35240	18.07	34.68	46.95
102	13 to 16	14.8	59830	35460	18.05	35.75	48.43
215	17 to 20	18.6	59770	35540	16.58	35.04	48.37
245	21 to 25	22.9	60380	35460	15.75	35.37	47.72
145	26 to 30	28.0	59520	35310	15.37	36.36	49.25
82	81 to 35	33.1	59900	35470	14.17	34.73	49.85
830	all lengths	. . . . .	59930	35440	. . . . .	35.41	48.42

Applying the same method of inspection to the records of elongation in full length, it will be found that the wide bars were superior in four cases and inferior in three cases, while the thick bars were superior in five cases and inferior in two cases. Thus there seems to be quite a difference between the records of full-length tests and those from 12-inch lengths, so that it is justifiable to conclude that while wider and thicker bars do give greater elongation after fracture, the advantage is confined to the region of the "necking," and the percentage of stretch throughout the body of the bar is independent of the section. If this is true, it is a most important fact and has a wide application in structural engineering.

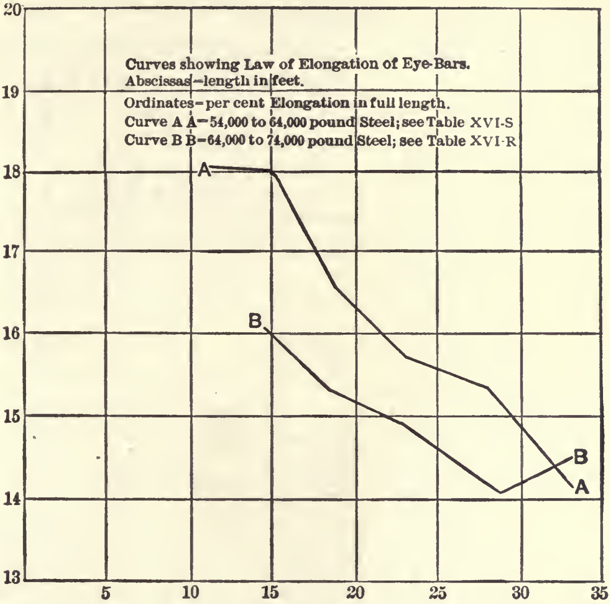

FIG. XVI-C.—CURVES SHOWING LAW OF ELONGATION OF EYE-BARS.

Since it has been thus shown that there is very little, if any, difference in the percentage of elongation in pieces of the same length, although they be of different section, it becomes possible to further combine the records by putting together all widths and thicknesses and classifying by length alone. This is done in Table XVI-S. It may be noticed that there are 41 bars running between 10 and 12 feet in length, while in Table XVI-R there are only 18 of this size. This arises from the fact that there were a few of this length in each of the groups as classified by section, but they were not in sufficient number to be of value for comparison except in the case of Group 13 (see Table XVI-R). In Table XVI-S these scattering bars are combined with those of Group 13 in order to have a larger number in the average. The results are plotted in Fig. XVI-C, which thus shows the law of elongation in long bars. A further point to be considered is the proportion of bars that fall below a given standard, since an average may be made up of widely different kinds of metal or it may be made from a uniform product.

TABLE XVI-T.

Proportion of Rejections Caused by Applying a Standard Sliding Scale of Elongation to the Eye-Bar Records in Table XVI-Q.

NOTE.—The standards assumed are the same as specified for different classes of metal in Section XVIII g

	Name of maker.		"A."						"B."						"C."			Total for all kinds.		
	Kind of steel.		Bessemer.			Open-hearth.			Bessemer.			Open-hearth.			Open-hearth.					
	Length of bars; in feet.	Standard of elongation; per cent.	No. of bars.	No. below standard.	Per ct. below standard.	No. of bars.	No. below standard.	Per ct. below standard.	No. of bars.	No. below standard.	Per ct. below standard.	No. of bars.	No. below standard.	Per ct. below standard.	No. of bars.	No. below standard.	Per ct. below standard.	No. of bars.	No. below standard.	Per ct. below standard.
Specification I. Ultimate strength, 54000 to 64000 pounds per square inch. (See Class VI, Section XVIIIg.)	10 to 20	14.0	64	4	. .	82	10	. .	58	1	. .	60	10	. .	105	24	. .	369	49	13
	21 to 25	13.0	47	0	. .	37	3	. .	43	6	. .	85	16	. .	33	1	. .	245	26	11
	26 to 30	12.5	34	1	. .	22	0	. .	33	3	. .	39	8	. .	17	7	. .	145	19	13
	31 to 35	12.0	26	2	. .	11	2	. .	11	5	. .	21	7	. .	25	9	. .	94	25	27
	Total, all lengths,		171	7	4	152	15	10	145	15	10	205	41	20	180	41	23	853	119	14
Specification II. Ultimate strength, 64000 to 74000 pounds per square inch. (See Class VIII, Section XVIIIg.)	10 to 20	12.5	30	0	. .	14	2	. .	10	0	. .	10	5	. .	38	10	. .	102	17	17
	21 to 25	12.0	36	1	. .	16	2	. .	23	3	. .	7	4	. .	17	6	. .	99	16	16
	26 to 30	11.5	11	0	. .	4	0	. .	11	2	. .	6	3	. .	10	1	. .	42	6	14
	31 to 35	11.0	14	0	. .	. .	. .	. .	4	0	. .	6	0	. .	16	1	. .	40	1	3
	Total, all lengths,		91	1	1	34	4	12	48	5	10	29	12	41	81	18	22	283	40	14

In Table XVI-T is given an analysis of the records showing the number and percentage of bars in each division which give less than a certain percentage of elongation.

Table XVI-U.

Alteration in the Physical Properties of Steel by Rest after Rolling.*

Number of group.	Limits of ultimate strength; pounds per square inch.	Hand rounds.						Guide Rounds.					
		No. of bars tested.		Alteration. Gain = + Loss = —				No. of bars tested.		Alteration. Gain = + Loss = —			
		Less than 24 hrs. rest.	More than 24 hrs. rest.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Less than 24 hrs. rest.	More than 24 hrs. rest.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.
I	55000 to 60000	.	.	. . .	. . .	. . . .	. . . .	6	10	+719	+437	+.65	+ .96
II	60000 to 65000	10	5	—1207	+385	+1.11	+2.14	10	22	—453	+596	+.73	+1.13
III	65000 to 70000	32	12	— 471	—180	— .25	+2.07	22	36	—170	+382	+.33	+1.45
IV	70000 to 75000	21	20	+ 302	+197	+ .66	+2.95	24	36	—166	+638	+.44	+1.14
V	75000 to 80000	10	8	— 809	+107	+1.06	+6.76	35	47	—314	+201	—.81	+2.33
VI	80000 to 85000	7	3	+ 213	+ 36	+ .29	+ .44	16	30	—165	+767	+.42	+1.24
VII	85000 to 90000	.	.	. . .	. . .	. . . .	. . . .	8	16	+ 92	+525	+.46	+ .62
Av. of all tests.		80	48	— 394	+109	+ .56	+2.87	121	197	—270	+507	+.32	+ .99

The standards assumed are those which are specified for different grades of structural steel in Chapter XVIII. A study of the table will show that the number of rejections on longer lengths is fully as great as with the shorter bars, and this proves that the decrease in the specified elongation for an increase in length is not greater than should justly be allowed. In the bars made by "*A*" the rejections under Specification I amount to 4 per cent. in Bessemer metal, and 10 per cent. in open-hearth; in those made by "*B*" they are 10 per cent. in the Bessemer and 20 per cent. in the open-hearth, while with "*C*" they are 23 per cent. Taking into consideration that the records cover only the products of large and well known works, and that all bars having a crystalline fracture

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* *Notes on Results Obtained from Steel Tested Shortly after Rolling. Amer. Soc. Mech. Eng.,* Vol. IX, p. 38.

and those breaking in the eye were discarded, it must be acknowledged that the standard calls for good material.

SEC. XVII.—*Alterations in the physical properties of steel by rest after rolling.*—In addition to the variations which may be caused by differences in the working of the test-piece and in its shape, there is probably another factor in the length of time which elapses between rolling and testing. This subject was investigated at The Pennsylvania Steel Works by E. C. Felton, now President of the Company, a condensation of whose work is given in Table XVI-U. The changes are not very strongly marked, but there seems to be consistent testimony of a molecular rearrangement, progressing for several hours after the bar is thoroughly cold, whereby there is a lowering of the elastic limit, and an increase in the ultimate strength, the elongation, and the reduction of area.

SEC. XVIm.—*Probable error in current practice in determining the physical properties.*—It is the rule in most practical work that at least two sides of the test-piece are not machined, and hence it is impossible to make a perfectly accurate measurement. In order to find how great an effect may be caused by such errors and by differences in machines and the method of operating them, the experiment was tried of sending a bar from six different acid open-hearth heats to six different testing laboratories. The pieces were rolled flats, 2″x3/8″, and each series was made up of one piece from each of the six bars, so that the only possible difference between the steel sent to the various places would be the difference between parts of the same bar.

All pieces were tested in the shape in which they left the rolls without any machining, and although the edges were not perfectly smooth, they were so nearly true that only one operator referred to any difficulty in making a true measurement. Table XVI-V exhibits the results reported. The bars were tested by The Central Iron and Steel Works, Harrisburg, Pa.; The Baldwin Locomotive Works, Philadelphia, Pa.; The Pottstown Iron Company, Pottstown, Pa.; The Carnegie Steel Company, Pittsburg, Pa.; The Carbon Steel Company, Pittsburg, Pa., and The Pennsylvania Steel Company, Steelton, Pa., but the identity of the different works is purposely concealed in the table under the letters *A, B, C,* etc., to avoid invidious comparisons.

An examination will show that there are quite important variations in every one of the factors. Moreover, the divergence is not the result of averaging erratic individuals, for whenever one average is higher than another, it is because the majority of the bars are higher when taken separately.

TABLE XVI-V.

Physical Properties of the Same Bars of Steel, as Determined by Different Laboratories.

NOTE.—All bars were rolled flats, 2″x⅜″, and were not machined.

	Number of heat.	Tested by					
		A.	B.	C.	D.	E.	F.
Ultimate strength; pounds per square inch.	10027	58130	57880	58560	57710	57980	59230
	10028	60790	60140	61740	60080	60660	61830
	10030	63560	63330	64530	63180	63450	64280
	10065	60840	61160	62180	60440	61290	62200
	10066	62840	62700	63480	61970	62630	64170
	10072	61160	62190	61730	61390	61640	62110
	Average,	61220	61233	62037	60795	61275	62303
Elastic limit; pounds per square inch.	10027	42400	37350	38900	37490	39020	39730
	10028	42200	37940	41400	38720	39730	41320
	10030	43620	40780	42540	38940	40740	42770
	10065	41540	38150	42250	38710	40210	41250
	10066	42610	40350	42110	38905	40180	43140
	10072	41400	37650	41770	38710	40950	39860
	Average,	42295	38703	41495	38579	40138	41345
	Elastic ratio,	69.1	63.2	66.9	63.5	65.5	66.4
Elongation in 8 inches; per cent.	10027	29.25	29.00	30.50	30.37	30.75	29.75
	10028	30.75	30.00	32.00	29.75	31.00	29.50
	10030	29.00	29.00	31.00	28.12	29.00	28.50
	10065	29.25	28.75	30.50	30.25	29.50	32.50
	10066	29.25	32.25	30.50	29.12	33.25	29.50
	10072	30.00	33.75	34.25	29.37	30.75	29.00
	Average,	29.58	30.46	31.46	29.50	30.71	29.79
Reduction of area; per cent.	10027	61.3	61.3	60.6	56.2	54.1	61.2
	10028	63.1	59.7	62.9	58.9	53.3	62.3
	10030	60.1	57.0	60.0	55.9	52.7	57.8
	10065	61.8	58.4	60.6	56.7	55.9	61.6
	10066	61.5	59.9	60.9	54.0	52.5	60.0
	10072	61.8	57.6	61.2	57.4	54.1	61.3
	Average,	61.6	59.0	61.0	56.5	53.8	60.7

The variations in contraction of area may easily be explained, for the determination rests upon the most accurate measurements of an irregular broken body. In a bar having an original section of 2″x⅜″, the fractured end will have a thickness of about 0.20 inch, and almost invariably will be of irregular form, the sides being concave rather than flat. A true estimation of the broken area could be made only by the most careful duplicate readings and by the aid of the calculus. These refinements are out of the question in practice, but the chances of error must always be considered when a test-bar falls a little short of the requirements.

The variations in elongation may be partially accounted for by unlike methods of measurement, for if the original punch-marks be put on the outer edge of the bar, they will give a different reading after fracture than if they were put in the center line, owing to the unequal distortion of the bar. This complication would not occur in the case of a round test-piece.

The differences in ultimate strength and elastic limit are due in some measure to slight variations in the original measurements of the bar. The elastic limit was found by noting the "drop of the beam," this being the universal practice in American steel works and rolling mills. This method has been criticized by some investigators, who advocate an autographic device for registering the point where the elongation ceases to be exactly proportionate to the load. The introduction of such a system would result in endless confusion, since all specifications and contracts of the present day are based upon the elastic limit as now determined by the fall of the beam.

The statement that the current method is especially inaccurate is open to debate. In the series of tests given in Table XVI-V, it will be found that the elongation, as determined by different observers, varies from 29.50 to 31.46 per cent., these figures being in the ratio of 100 to 106.6, or range of error of 6.6 per cent. The reduction of area varies from 53.8 to 61.6 per cent., a ratio of 100 to 114.5, or a range of error of 14.5 per cent. The elastic ratio varies from 63.2 to 69.1 per cent., a ratio of 100 to 109.3, or a range of error of 9.3 per cent.

Thus the determination of the elastic ratio is much more accurate than the results on contraction of area, and nearly as accurate as the results on elongation, both of which are determined by exact measurements made on the piece when at rest. It would be quite in order for reformers to apply their energies to the accurate determination of the reduction of area and the elongation, instead of trying to substitute a new method for determining the elastic limit, especially when this method has been publicly branded as inaccurate.*

As a rule the autographic device gives a slightly lower reading than is found by the drop of the beam; thus in a paper by Gus. C. Henning† there are given the determinations of the elastic limit

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* Lewis. *Trans. Am. Soc. Civil Eng.*, Vol. XXXIII, p. 351.

† *Trans. Am. Soc. Mech. Eng.*, Vol. XIII, p. 572.

on a series of tests, as found by the two methods. I have averaged the list of heats where both readings are given, and find that in thirty-eight cases the autographic record was 46.6 per cent. of the ultimate strength, while the beam dropped at 52.9 per cent.; in the annealed bar the first method gave 51.6 per cent., and the second 56.9 per cent.

Such a marked difference is not found in all cases, as shown by Table XVI-W, which gives the results obtained by E. A. Custer, who at the time was connected with The Baldwin Locomotive Works, Philadelphia, Pa.

In the case of the slow speed there is less difference between the two determinations of the elastic limit than is shown by Henning, while with the fast speed there is more. This matter of the influence of the pulling speed upon the recorded physical properties is considered in the next section.

Table XVI-W.

Parallel Determinations of the Elastic Limit by the Autographic Device and by the Drop of the Beam.*

No. of tests.	Pulling speed.	Ultimate strength; pounds per sq. in.	Elastic limit; pounds per square in. as determined by		Elastic ratio; per cent., as determined by	
			Autographic device.	Fall of beam.	Autographic device.	Fall of beam.
6	1 inch in 3 minutes.	56820	36120	37510	63.6	66.0
3	4 inches in 1 minute.	58870	35890	40530	61.0	68.8

The whole subject of the determination of the elastic limit was discussed in *The Engineering News*, of July 25, 1895. After reviewing at great length the arguments presented by several engineers in previous issues, and after quoting from many authorities, the following conclusions were reached:

"Having thus shown the impossibility of determining by micrometric measurement the elastic limit, when it is defined as the point at which the rate of stretch begins to change, and the extreme variability of the position of the so-called 'yield-point' with the method of running the machine and with the method of measuring and recording results, had we not better drop these new definitions and methods of attempting to locate points whose position

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* From E. A. Custer, Baldwin Locomotive Works, Philadelphia, Pa.

is so extremely variable, and whose determination depends so largely upon the personal equation of the observer, and return to the good, old-fashioned definitions and methods? If for scientific purposes there is any need for determining microscopically that point at which the rate of stretch begins microscopically to change, let us call that point the 'limit of proportionality,' as Bauschinger did, and leave its determination to the college professors.

"Let us keep the old term elastic limit with its old significance as that point at which a permanent set visible to the naked eye takes place, at which the rate of stretch increases so that the increase may be (albeit with some difficulty) distinguishable by the use of a pair of dividers and a magnifying glass, or more easily and certainly by the drop of the beam, or by the increase in the number of turns of the crank needed to produce a given increase in stretch.

"For the purpose of determining this elastic limit let the testing machine be run by hand until the limit is passed and the record taken (or run by hand between the load of 30,000 pounds and the elastic limit), and then let the power gear be thrown in and the test completed in the present rapid fashion. Since the term 'yield point, is quite recent, and has no meaning essentially different from the words 'elastic limit' in time-honored practice, why need it be used at all?"

These conclusions represent common sense in their summary dealing with the petty theories of enthusiasts, who are so wrapped up in the accurate determination of a micrometrical measurement that they ignore the more important variations inherent in the method itself, not to mention the still more overwhelming differences caused by changes in the history and shape of the material. I do not see, however, why it is necessary to revert to the primitive and laborious method of driving a machine by hand when there is a power attachment with different pulleys. The speed should be lower during the determination of the elastic limit than can be used for breaking the piece, but a specification that this work must be done by hand is a confession of lack of ingenuity which is neither creditable to engineering science, nor justified by facts.

SEC. XVIn.—*Effect of variations in the pulling speed of the testing machine upon the recorded physical properties.*—To find the effect of variations in pulling speed, ten different rivet rods were taken from an acid open-hearth heat. From each rod five bars were cut, and each one of these was broken at a different speed. The results are given in Table XVI-X.

Table XVI-X.

Effect of Variations in the Pulling Speed of Testing Machine upon the Recorded Results.

Note.—Tests were made by The Pennsylvania Steel Company.

	Number of bars.	Pulling speed; inches per minute.				
		4.50	3.00	0.67	0.38	0.07
Ultimate strength; pounds per square inch.	1	61060	61360	60640	60240	59660
	2	61140	60760	59200	59440	59100
	3	61610	61230	59910	59680	59100
	4	61500	61150	58950	59620	59220
	5	61870	61580	59960	59910	59760
	6	60200	59720	59040	58240	59100
	7	60620	60140	59290	59380	58200
	8	60520	59580	58760	58400	58160
	9	61200	61100	60000	59620	58870
	10	61030	60100	59480	59340	59100
	Av.	61075	60672	59523	59387	59027
Elastic limit; pounds per square inch.	1	46640	44930	43240	42650	39610
	2	44070	43500	44810	41980	39480
	3	46920	44680	42220	41270	39250
	4	46730	45560	42720	41830	40300
	5	45080	46300	43120	43430	40480
	6	44360	43400	41690	40810	39240
	7	47500	43670	43090	41830	38950
	8	44680	44680	42650	41370	39720
	9	45000	43440	42380	40860	39720
	10	46100	43940	43120	41600	39720
	Av.	45708	44410	42904	41763	39647
Elastic ratio; per ct.	Av.	74.84	73.20	72.08	70.32	67.17
Elongation in 8 inches; per cent.	1	29.50	28.25	31.00	28.00	34.00
	2	32.00	30.50	30.75	29.50	31.25
	3	31.75	32.00	27.50	29.25	31.25
	4	27.75	27.00	28.50	28.00	32.25
	5	31.50	30.50	30.00	29.50	30.25
	6	30.50	30.75	29.00	30.00	32.00
	7	29.50	30.50	31.00	31.00	32.75
	8	31.00	28.50	29.25	28.00	32.75
	9	30.00	32.00	28.00	30.00	30.75
	10	29.65	31.75	29.50	30.00	32 00
	Av.	30.32	30.18	29.45	29.33	31.93
Reduction of area; per cent.	1	66.1	65.9	66.7	67.0	68.4
	2	67.1	66.0	66.0	66.7	67.1
	3	62.3	62.4	63.9	63.2	63.4
	4	64.9	65.0	64.9	65.9	67.7
	5	63.3	64.4	64.2	63.7	65.0
	6	66.0	66.2	66.7	67.3	66.0
	7	66.8	66.3	67.4	67.1	67.9
	8	62.4	62.6	68.0	63.1	64.8
	9	64.5	63.5	64.3	65.8	66.9
	10	66.2	66.0	66.1	67.1	67.6
	Av.	64.96	64.83	65.82	65.69	66.48

It will be seen that a decrease in pulling speed is accompanied by a decrease in the ultimate strength, elastic limit, elastic ratio, and elongation. The differences are not extreme, but their regularity, when viewed in connection with the uniform conditions of the experiment and the evident homogeneity of the material, makes the testimony almost conclusive. In the case of the slowest speed there is an exception to this rule in a marked increase of extension, and an inspection will show that this does not arise from an average of erratic members, but from an increase in every bar. This point is not of great practical importance, since it requires nearly an hour to break a single bar of ductile steel at this speed. The reduction of area seems to remain practically constant throughout the series.

The natural result of this investigation would be a tendency toward higher breaking speeds. It is believed, however, that this may be carried too far, since with fast work it is more difficult to take accurate readings.

CHAPTER XVII.

THE INFLUENCE OF CERTAIN ELEMENTS ON THE PHYSICAL PROPERTIES OF STEEL.

SECTION XVIIa.—*Difficulties attending the quantitative valuation of alloyed elements.*—Numerous investigations have been conducted to discover the influence of different elements on the strength and ductility of steel, a common method being to melt definite combinations in crucibles and ascribe the physical result to the known variables, under the assumption that all other things are equal. This system of experiment will answer in noting the effect of large proportions of certain elements, or in showing the qualitative influence of unusual ingredients; but it is worthless in the accurate quantitative valuation of minute proportions of the metalloids, since small variations in the chemical equation are masked by irregularities in the detail of casting and working. The problem is also complicated by numberless combinations of different percentages of the various elements, so that it is difficult to obtain groups of charges where there is only one variable.

It has, therefore, not infrequently happened that inconclusive data have been joined to bad logic, and the conclusions of special investigators have been at variance with all the teachings of experience. It is not my purpose to enumerate all the theories or deductions of experimenters, but I shall aim to give a general survey of the situation and to review the opinions and work of different leading authorities. In Part I each element is considered separately, and I believe that the views therein advanced are in accord with the general consensus of opinion among metallurgists. Parts II and III give the result of special investigations into the effect of carbon, silicon, manganese, phosphorus and sulphur upon the tensile strength of steel, and a determination of the strength of pure iron. The results of this work are condensed into empirical formulæ from which may be calculated with reasonable accuracy the ultimate strength of any ordinary structural steel whose composition is known.

Part I.

EFFECT OF CERTAIN ELEMENTS AS DETERMINED BY GENERAL EXPERIENCE AND BY THE USUAL METHODS OF INVESTIGATION.

Sec. XVIIb.—*Influence of carbon.*—The ordinary steel of commerce is carbon-steel; in other words, the distinctive features of two different grades are due for the most part to variations in carbon rather than to differences in other elements. There are often wide variations in manganese, phosphorus, silicon, etc., but it is rarely that the carbon content does not determine the class in which the material belongs. This selection of carbon as the one important variable arose primarily from the fact that primitive Tubal Cains could produce a hard cutting instrument with no apparatus save a wrought-iron bar and a pile of charcoal; and the natural developments in manufacture have led to the conclusion that a given content of carbon will confer greater hardness and strength, with less accompanying brittleness, than any other element.

There are certain exceptions to be taken to this statement in the case of hard steels made by manganese, chromium, or tungsten, but it may be accepted as true in soft steel. It follows, therefore, that no limit should ever be placed to the carbon allowed in any structural material if a given tensile strength is specified. It is, of course, true that every increment of carbon increases the hardness, the brittleness under shock, and the susceptibility to crack under sudden cooling and heating, while it reduces the elongation and reduction of area, but the strength must be bought at a certain cost, and this cost is less in the case of carbon than with any other element.

Sec. XVIIc.—*Influence of silicon.*—The contradictory testimony concerning the effect of silicon on steel has been well summarized by Prof. Howe,* who records many examples of exceptional steels with abnormal contents of silicon, and who fully discusses the theories advanced by different writers. He finds no proof that silicon has any bad effect upon the ductility or toughness of steel, and he concludes that the bad quality of certain specimens is not necessarily due to the silicon content, but to other unknown conditions. A Bessemer steel with high silicon is sometimes produced by hot blowing, but it will be entirely wrong to compare such metal

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* *The Metallurgy of Steel*, p. 36.

with the common product and ascribe all differences to the chemical formula, rather than to the circumstances which created that formula.

Since the appearance of *The Metallurgy,* an able paper has been written by Hadfield,* who produced alloys with different contents of silicon by melting wrought-iron and ferro-silicon in crucibles. The metal was cast in ingots 2½ inches square, and these were reduced by forging to 1¾ inches square and then rolled into bars 1⅛ inches in diameter. In the list of analyses in the paper referred to, there are slight differences in the composition of drillings from different bars of the same ingot, but in Table XVII-A I have averaged the results of each cast so as to show the nature of the material under investigation, and have given the physical results on the rolled bars in their natural state.

TABLE XVII-A.

Physical Properties of Silicon Steels.†

Mark.	Carbon; per cent.	Silicon; per cent.	Manganese; per cent.	Sulphur; per cent.	Phosphorus; per cent.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elastic ratio; per cent.	Elongation in 2 inches; per cent.	Reduction of area; per cent.	Ultimate strength after annealing; pounds per square inch.
A	.14	.21	.14	.08	.05	73920	49280	66.7	30.05	54.54	56000
B	.18	.77	.21	. . .	. .	76160	56000	73.5	29.50	54.54	64960
C	.19	1.57	.28	. . .	. .	84000	62720	74.7	31.10	50.58	73920
D	.20	2.14	.25	.06	.04	88480	69440	78.5	18.48	28.02	76160
E	.20	2.67	.25	. . .	. .	95200	71680	75.3	17.60	24.36	71680
F	.21	3.40	.29	. . .	. .	106400	78400	73.7	11.10	14.22	87360
G	.25	4.30	.36	. . .	. .	109760	100800	91.8	0.004	0.20	85120
H	.26	5.08	.29	.06	.04	107520	not visible	. . .	0.30	0.70	56000

Bars *A, B, C* and *D* showed a silky fracture after breaking, but with higher silicon the crystallization was very coarse. They also showed no great hardening or brittleness after being quenched in water from a yellow heat, while even the higher alloys, although made quite stiff by the chilling, were not rendered very hard, and preserved a good degree of ductility. With the exception of *A* the ingots forged well even up to 5.5 per cent. of silicon, but all attempts at welding were unsatisfactory.

These results are of the highest value in showing that silicon

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* ***On Alloys of Iron and Silicon.*** *Journal I. and S. I.,* Vol. II, 1889, p. 222.

† **Condensed from Hadfield.** *Journal I. and S. I.,* Vol. II. 1889, p. 222.

cannot be classed among the highly injurious elements, for in similar proportion phosphorus and sulphur would be out of the question, manganese would give a worthless metal, and carbon would change the bar to pig-iron. It will, therefore, be only reasonable to suppose that small quantities cannot exert a very deleterious influence.

The only bar in the table which contains a moderate content of silicon is *A* with .21 per cent., and it is recorded that this ingot did not forge well and did not weld, but it must be considered that the manganese was only .14 per cent. while the sulphur was .08 per cent. and the phosphorus .05 per cent. Assuredly, it would hardly be expected that such metal would forge very well, and it is not singular that it gave trouble, while other experimenters have forged and welded steel with similar contents of silicon when the associated elements were in proper proportion.

TABLE XVII-B.

Influence of Silicon on the Tensile Strength as Shown by Data in Table XVII-A.

Mark.	Carbon; per cent.	Silicon; per cent.	Manganese; per cent.	Ultimate strength; pounds per square inch.	Difference in strength between each test and the bar B.	Difference in strength due to difference in carbon.	Difference bet. the last two columns showing increase in strength due to silicon.	Increase in percentage of silicon compared with bar B.	Increase in strength due to .01 per cent. of silicon.
B	.18	.77	.21	76160	. . . . .	. . . . .	. . . . .	. . . .	. . . .
C	.19	1.57	.28	84000	7840	1210	6630	.80	83
D	.20	2.14	.25	88480	12320	2420	9900	1.37	72
E	.20	2.67	.25	95200	19040	2420	16620	1.90	87
F	.21	3.40	.29	106400	30240	3630	26610	2.63	101
G	.25	4.30	.36	109760	33600	8470	25130	3.53	71
H	.26	5.08	.29	107520	31360	9680	21680	4.31	50

In the whole series it must be considered that the amount of work done upon the ingot in reducing it from 2½ inches square to 1⅛ inches in diameter was wholly insufficient to give a proper structure, so that little weight can be attached to the determination on any one bar. This renders it difficult to calculate the exact effect of silicon, especially since the bars *A* and *B* present some contradictions. Thus *B* contains .04 per cent. more carbon than *A*, .07 per cent. more manganese, and .56 per cent. more silicon, and yet has only 2240 pounds more tensile strength per square inch.

Inspection shows that *A* is probably the erratic member, for its strength is altogether too high for its composition. Moreover, the annealed bars show a loss in strength of 24 per cent. from the natural in *A*, while bars *B, C* and *D* gives 15, 12 and 14 per cent., respectively, so that it is likely that *A* is finished at too low a temperature and has a higher strength than really belongs to it. For this reason it will be set aside as abnormal, and in Table XVII-B the bar *B* is taken as a basis from which to investigate the differences in tensile strength. No allowance is made for manganese, since this element is fairly constant in all the specimens, but a value of 1210 pounds per square inch is given to carbon in accordance with the formula given in Table XVII-U. After this allowance the remaining variations are ascribed to silicon, but this is not strictly correct as no data are at hand concerning the content of phosphorus, so that the answer is open to question.

TABLE XVII-C.

Physical Properties of Steels Containing from .01 to .50 Per Cent. Silicon.*

NOTE.—All bars rolled well; they bent well both hot and cold except No. 11, which broke cold at an angle of 50°; they all welded perfectly; the differences in hardness were scarcely perceptible.

Number of test.	Silicon; per cent.	Carbon; per cent.	Sulphur; per cent.	Phosphorus; per cent.	Manganese; per cent.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elastic ratio; per cent.	Elongation in 10 inches; per cent.	Reduction of area; per cent.
1	.010	.16	.050	.060	.550	49280	66394	74.3	23.1	48.8
2	.061	.16	.028	.058	.619	49750	70806	70.3	20.4	40.7
3	.070	.15	.084	.051	.500	47152	66102	71.3	22.9	51.5
4	.092	.21	.084	.064	.634	50243	75398	66.6	19.4	44.1
5	.102	.18	.028	.066	.662	47622	75197	63.4	20.6	51.4
6	.121	.19	.064	.068	.576	50848	71367	71.2	21.9	43.7
7	.315	.13	.028	.057	.480	47690	65901	72.4	24.8	56.6
8	.247	.19	.028	.074	.642	49795	77728	64.0	17.6	49.6
9	.320	.15	.040	.081	.490	49997	74435	67.1	16.7	36.1
10	.382	.16	.042	.087	.533	55373	79901	69.3	18.0	30.7
11	.504	.18	.094	.121	.455	59024	82253	71.7	19.4	34.8

This table cannot be called a conclusive equation of the effect of silicon, for the carbon was determined by color instead of combustion, the number of tests is altogether too limited, and no account is taken of phosphorus, but there seems to be a strengthening effect of about 80 pounds for every .01 per cent. of silicon up to a content of 4 per cent., while beyond this there is a deterioration

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* Report of British Association, 1888.

of the metal, as shown in Table XVII-A. This would mean an increase of only 1600 pounds for .20 per cent. silicon, being one-third more than that produced by .01 per cent. of carbon. (See Table XVII-U.) It has already been noted that *A*, which was the only bar containing an ordinary percentage of silicon, gave abnormal results in tensile strength, but this cannot be due to silicon, for the elastic ratio is quite normal, the elongation fair, and the reduction of area very good.

An investigation into the effect of ordinary proportions of silicon was conducted by Turner under the auspices of the British Association. Table XVII-C gives the results as published in *Journal I. and S. I.*, Vol. II, 1888, p. 302. There are considerable variations in the elements other than silicon, and the bad character of No. 11 may well be explained by its high content of phosphorus. For better comparison Table XVII-D gives the averages of the first four tests, all of which are below .10 per cent. in silicon, and the last three, which are above .30 per cent.

TABLE XVII-D.

Comparative Physical Properties of Low-Silicon and High-Silicon Steels; from Data in Table XVII-C.

Group.	Number of heats in group.	Composition; per cent.					Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elastic ratio; per cent.	Elongation in 10 inches; per cent.	Reduction of area; per cent.
		Si.	C.	S.	P.	Mn.					
1	4	.056	.170	.061	.058	.576	49106	69675	70.5	21.5	46.3
2	3	.402	.160	.059	.096	.493	54798	78863	69.5	18.0	33.9

The effect of the difference caused by elements other than silicon may be calculated from the formula given in Table XVII-U, carbon being taken at +121 pounds for .001 per cent., and phosphorus at +89. The result is as follows:

	Lbs. per sq. in.
Group II should be stronger than Group I.	
On account of phosphorus, 38 × 89	3382
Group II should be weaker than Group I.	
On account of carbon, 10 × 121	1210
Net strengthening from constituents other than silicon .	2172
Strengthening from all constituents including silicon . .	9188
Strengthening due to .35 per cent. of silicon	7016
Strengthening due to each .01 per cent. of silicon	200

This signifies that .20 per cent. of silicon would give an increase in ultimate strength of 4000 pounds per square inch, which is only a little more than would be given by .03 per cent. of carbon. (See Table XVII-U.)

The influence of silicon upon the tensile strength is often confounded with that of carbon. It is well known that the addition of high-silicon pig-iron to a charge of low steel strengthens the metal more than a similar addition of ordinary pig-iron. But the fact is lost sight of that this silicon prevents the burning of carbon, both by the absorption of oxygen and by the deadening of the bath, so that the resultant metal is of higher carbon.

If the ordinary color method were reliable, this would be detected and proper credit given to it, but it often happens that an increment of .03 per cent. of carbon is not shown by analysis, so that its effect upon the ultimate strength, which will amount to about 3500 pounds per square inch, will be incorrectly ascribed to whatever small percentage of silicon has survived the reactions during recarburization. This criticism on the determination of carbon applies to the data given in Tables XVII-A and XVII-C, and renders the calculations thereon of limited value.

These conclusions are corroborated by the testimony of Groups 49, 52, 54, 55, 56, 57, 60 and 61 in Table XVII-N, as shown in Fig. XVII-A. All of these groups contain high silicon, but they do not seem to differ materially from the normal steels. Between the limits of 82,000 and 100,000 pounds ultimate strength there are seven groups in Table XVII-N, Nos. 48, 49, 50, 51, 52, 53 and 54, some containing high silicon and some with a low percentage, but the great variations do not seem to have any decided effect in altering the trend of the curve, although the contents of sulphur, phosphorus and manganese are fairly constant. (This question is discussed more fully in Section XVIIp.)

It is well known that many continental works have habitually made their rails with from .30 to .60 per cent. of silicon, and that all requirements of strength and ductility have been met. All the authorities do not approve this practice, and it is stated by Ehrenwerth,* that the latest results are rather in the opposite direction in the case of low steels,† but I was told some years ago, by the manager of one of the French establishments, that the only way

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* *Das Berg- und Hüttenwesen auf der Weltausstellung in Chicago,* 1895.

† See page 78, *ante.*

in which he was able to fill one contract with particularly severe specifications, was by making the rails contain from .30 to .40 per cent. of silicon, since a less proportion would not stand the drop-tests. It is not necessary to question whether this conclusion was warranted or not; it is enough to know that the steel was of the best quality, whether on account of the silicon or in spite of it.

The fact that silicon may be allowed in rails has been acknowledged by Sandberg, who writes as follows:* "Silicon up to .30 per cent., with carbon .30 to .40 per cent., does not harden steel or make it brittle, and *diminishes its strength in such small degree* as not to imperil the safety of the rail." The italics in the quotation are my own, and are to call attention to the implication that silicon lowers the strength rather than raises it.

Exceptional cases have been recorded of soft steels with high silicon, like the very tough rail mentioned by Snelus,† with carbon below .10 per cent. and silicon .83 per cent. It must be considered, however, that although this might have been very tough for a rail, it does not follow that it was very tough for soft steel, but it is quite certain that it could not have been bad or brittle.

With the knowledge possessed concerning the relative effect of impurities upon hard and soft steels, the assumption would almost be justified that low-carbon metal might be allowed to contain a larger percentage of silicon than higher steel. There is no need, however, of such an admission, for structural steels do not often contain over .05 per cent. of silicon, while usually they hold less than .03 per cent.

Tool steel is subjected to the most severe of all tests in the exposure of a hardened edge to the blows of a hammer or the shocks of a planer. It was not the laboratory but the requirements of general practice from which was unconsciously evolved the formula for such metal, requiring low phosphorus, low sulphur and low manganese. In this process of natural selection no mention was made of silicon. It is true that some makers try to keep it as low as possible, but a large part of the best steel has regularly contained, year after year, from .20 to .80 per cent. of this element.

Notwithstanding all this testimony as to the harmlessness of silicon, it is firmly believed by many practical metallurgists that the

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* *Proc. English Inst. Mech. Eng.*, 1890, p. 301.

† *On the Chemical Composition and Testing of Steel Rails. Journal I. and S. I.*, Vol. II, 1882, p .583.

presence of even .03 per cent. materially injures the quality of soft steel, such as is used for fire-boxes. I cannot positively assert the contrary, but I believe that the effects ascribed to silicon may be due to the conditions of manufacture which gave rise to it, or to the conditions of casting which it produces. These conditions might be fatal under one practice, as, for instance, when ingots are rolled directly into plates, while they might be harmless, or even beneficent, when an ingot is roughed down and reheated. The opinions of practical men are sometimes of more value than the learned conclusions of theorists, and must never be ignored, but they are not always inerrant.

Sec. XVIId.—*Influence of manganese.*—Spiegel-iron or ferromanganese is added to a heat of steel at the time of tapping in order that it may seize the oxygen, which is dissolved in the bath, and transfer it to the slag as oxide of manganese; but this reaction is not perfect, as shown in Section Xj, and there is reason to believe that all common steels contain a certain percentage of oxygen.* Steel low in phosphorus and sulphur requires less manganese than impure metal, although it is difficult to see why there should be less oxygen to counteract, and this indicates that the function of the manganese is to prevent the coarse crystallization which the impurities would otherwise induce.

Besides conferring the quality of hot ductility, manganese also raises the critical temperature to which it is safe to heat the steel, for just as it resists the separation of the crystals in cooling from a liquid, so it opposes their formation when a high thermal altitude augments the molecular mobility. These two manifestations of the same general force render manganese one of the most valuable and essential factors in the making of steel, although there is no doubt that it has been used too freely in some cases.

Years ago some of the railmakers of the country looked upon it as a panacea for all bad practices in the Bessemer and the rolling mill, and steel often contained from 1.25 to 2.00 per cent. of manganese, but it was soon discovered that such rails were brittle under shock, so that the permissible maximum has been gradually lowered, and the standard product of the present day contains from .70 to 1.00 per cent. In higher steels the same lesson has been learned, but in this case the necessity of a low content is far

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* See Section XVIIk for a further discussion on this point.

more marked, since a percentage which is perfectly harmless in unhardened steel will cause cracking if the metal be quenched in water. For this reason it is advisable to reduce the proportion of this element in hard steel to the lowest possible point.

In structural metal there is no quenching to be done and the line of maximum manganese need not be drawn too low. It is much more convenient for manufacturers to produce a higher tensile strength by the use of spiegel-iron, which contains manganese, than with ordinary pig-iron, since the presence of manganese deadens the metal and prevents the oxidation of the carbon.

Thus it happens that an increased tensile strength resulting from the addition of more recarburizer is usually accompanied by an increase in the content of manganese, and it is currently assumed that a considerable part of the extra strength is due to the higher percentage of this element. In great measure this is an error, for the increase in carbon is often sufficient to account for the change.

Ferro-manganese containing 80 per cent. of manganese holds about 5 per cent. of carbon, and since about one-third of the manganese is lost during the reaction while very little carbon is burned, it follows that about $^2/_3 \times 80 = 53$ points of manganese will be added to the steel for every 5 points of carbon. Thus, if the content of manganese in any heat be raised .20 per cent. by an increase in the amount of the recarburizer, there will at the same time be an increment of .02 per cent. of carbon.

This slight change in carbon will not always be detected by the color method, particularly as an increase in manganese interferes with the accuracy of the comparison by altering the tint of the solution, and so the effect of this carbon, representing an increase in tensile strength of about 2400 pounds per square inch, is often ascribed to the increment of manganese. It is necessary, therefore, to carefully compare steels where the composition is thoroughly known to find the effect of this element, and this is done in Parts II and III of this chapter.

It is also currently believed that manganese reduces the ductility of steel to a great extent, but Table XVII-E will show that the effect is not well marked. This table is made by grouping together heats of the same general character and of about the same tensile strength, and separating them into two classes according to their manganese content. No arbitrary line is drawn between a high and low percentage, but each group is divided so that the number is as nearly equal as possible on each side. An unequal number is due solely to the fact that several heats may have exactly the same content, and these must all be placed either on one or the other side of the line.

TABLE XVII-E.

Comparative Physical Properties of Open-Hearth Steel with Different Contents of Manganese.

Made by The Pennsylvania Steel Company.

Group.	Kind of steel.	Limits of ultimate strength in group; pounds per square inch.	Phosphorus; per cent.	Relative manganese.	Number of heats.	Manganese; per cent.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.	Shape of test; in inches.
I	Acid	55000 to 60000	.08	Low High	7 6	.30 .37	57922 58881	38692 38598	29.91 28.08	59.02 57.07	66.8 65.6	¾ diam.
II	Basic	55000 to 63000	.03	Low High	11 11	.44 .57	58005 59563	38547 40133	30.16 30.36	60.21 58.55	66.5 67.4	2x⅜
III	Acid	60000 to 65000	.08	Low High	16 14	.35 .51	62180 62605	41308 41169	28.00 27.65	50.89 54.66	66.4 65.8	¾ diam.
IV	Acid	65000 to 70000	.08	Low High	26 32	.51 .78	67421 68192	43923 45854	25.96 25.82	51.29 51.50	65.1 67.2	¾ diam.
V	Acid	70000 to 75000	.08	Low High	18 25	.60 .91	72353 72115	46836 48359	24.23 24.63	47.79 47.73	64.7 67.1	¾ diam.
VI	Acid	75000 to 80000	.08	Low High	11 11	.65 .84	77520 78083	49411 50226	22.34 23.63	44.42 48.49	63.7 64.3	¾ diam.
VII	Acid	80000 to 85000	.08	Low High	9 9	.68 .82	81747 81860	51219 52231	20.63 22.67	41.04 47.75	62.7 63.8	¾ diam.
VIII	Acid	85000 to 90000	.08	Low High	5 5	.75 .83	86460 88034	54517 55409	20.41 20.66	40.56 41.92	63.1 62.9	¾ diam.

It will be evident that there is no marked difference between the steels of high and low manganese, and the results of the eight different groups are so uniform in their testimony that the work of chance must be almost absent. These records of ductility, however, do not take into account the very important quality of resistance to shock. It has always been a problem to devise some way of applying a satisfactory test in this direction, but the method is yet to be found. A few crude experiments which I performed on steel of high manganese, to see how it would act under shock, are given in Table XVII-F.

The bar was struck while in tension with a copper hammer, each blow being powerful enough to have permanently bent the bar if it had not been continually straightened by the action of the machine. One of the effects of this hammering is to momentarily loosen the bar in the grips and make a sudden jar upon the piece. This action coupled with the stress upon the outside fibres and the direct vibration, make the test quite exhaustive, although from the difficulty of measuring the force of impact it can hardly be called practical. Some of the bars were not struck until "failure," or until the maximum stress had been reached. This was on account of the trouble from slipping or jumping above noted which followed the hammering at earlier periods, and it was taken for granted that if a bar would break at all from shock, the fracture would be likely to occur about the time when the piece was under destructive tension.

Table XVII-F.

Resistance to Shock of Steel Containing about 1.00 Per Cent. of Manganese.

All tests ¾-inch rolled rounds, made by The Pennsylvania Steel Company.

Heat number.	Manganese; per cent.	Conditions under which test was made.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.
6960	1.00	Average of two tests, pulled quietly	71040	47055	25.87	55.05
		Average of two, hammered from start to finish	70770	46380	26.12	61.40
6961	1.03	Average of two tests, pulled quietly	72175	48075	27.00	54.98
		Average of two, hammered from start to finish	71120	47330	26.00	59.20
6962	0.94	Average of two tests, pulled quietly	74020	48165	25.62	52.60
		Average of two, hammered from start to finish	74490	48340	23.50	55.70
6963	1.13	One bar, pulled quietly	81070	52880	22.50	43.60
		One bar, hammered from elastic limit to fracture	80460	52760	23.50	48.30
		One bar, hammered from failure to fracture,	78050	51800	19.25	55.30
		One bar, began hammering at 72000 pounds, and moved scale weight back as the bar weakened	69040	52760	21.00	47.80
6981	0.82	One bar, pulled quietly	67340	46030	28.12	55.00
		One bar, hammered from failure to fracture,	65940	44430	28.00	57.90
6982	0.91	One bar, pulled quietly	66700	46310	26.00	55.93
		One bar, hammered from failure to fracture,	67240	46090	31.25	55.60
6983	1.03	One bar, pulled quietly	69700	47650	26.00	51.70
		One bar, hammered from failure to fracture,	70080	46360	27.12	53.70

It will be evident that the hammering did not in any case determine the time of breakage, for each piece gave as good an elongation and reduction of area as a part of the same rod which was pulled in the usual manner.

It is not the intention to advocate the use of such a high content of manganese as is shown in Table XVII-F. The general conclusion of metallurgists, evolved from experience, seems to point to as low a proportion as will ensure good working in the rolls. In the case of such ingots as are rolled directly into plates, the allowable content is limited by the requirement that the steel shall boil in the molds, but it does not follow because bad results accompany higher manganese in such practice, that the quality of the product is proportionally deteriorated when the ingot is roughed down and reheated.

The effect of large proportions of manganese upon steel is one of the most curious phenomena in metallurgy. As the content rises over 1.5 or 2.0 per cent. the metal becomes brittle and almost worthless, and further additions do not better the matter until an alloy is reached with about 6 or 7 per cent. manganese. From this point the metal is not only extremely hard, but possesses the rather peculiar property of becoming very much tougher after quenching in water, without any great change in hardness.

The physical properties of manganese steel are shown in Table XVII-G, which is taken from an article by Hadfield.* This alloy is used in the making of car wheels, dredger links and pins, and other articles where the maximum of hardness must be combined with toughness. Its great disadvantage is the difficulty of doing machine work upon it, for the best of hardened tools will rapidly crumble and wear out. In cases where finishing is essential it is necessary to grind by emery wheels.

SEC. XVIIe.—*Influence of sulphur.*—Nothing is better established than the fact that sulphur injures the rolling qualities of steel, causing it to crack and tear, and lessening its capacity to weld. This tendency can be overcome in some measure by the use of manganese and by care in heating, but this does not in the least disprove that the sulphur is at work, but simply shows that it is overpowered. The critical content at which the metal ceases to be malleable and weldable varies with every steel. It is lower with

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* See also *The Mineral Industry*, Vol. IV, for an essay on Alloys of Iron, by R. A. Hadfield.

each associated increment of copper, it is higher with each unit of manganese, and it is lower in steel which has been cast too hot.

Table XVII-G.

Physical Properties of Forged Steel Containing from .83 to 19.00 Per Cent. Manganese.*

No. of sample.	Composition; per cent.			Natural.		Quenched in water.		Annealed.	
	Carbon.	Silicon.	Manganese.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.
1	.20	.03	.83	73920	31	. . . . . .	. . . .	. . . . . .	. . . .
2	.40	.15	2.30	125440	6	. . . . . .	. . . .	. . . . . .	. . . .
3	.40	.09	3.89	85120	1	. . . . . .	. . . .	. . . . . .	. . . .
4	.52	.37	6.95	56000	2	51520	2	47040	2
5	.47	.44	7.22	60480	2	56000	2	60480	5
6	.61	.30	9.37	73920	5	87360	15	85120	16
7	.85	.28	10.60	76160	4	89600	17	91840	17
8	1.10	.16	12.60	87360	2	120960	27	82880	11
9	.92	.42	12.81	87360	5	136640	37	107520	20
10	.85	.28	14.01	80640	2	150080	44	107520	14
11	1.10	.32	14.48	87360	1	141120	37	109760	5
12	1.24	.16	15.06	109760	2	136640	31	105280	2
13	1.54	.16	18.40	114240	1	118720	10	87360	1
14	1.83	.26	18.55	96320	1	123200	5	. . . . . .	. .
15	1.60	.26	19.10	116480	1	132160	4	91840	1

In the making of common steel for simple shapes, a content of .10 per cent. is possible, and may even be exceeded if great care be taken in the heating, but for rails and other shapes having thin flanges it is advantageous to have less than .08 per cent., while every decrease below this point is seen in a reduced number of defective bars. It is impossible to pick out two steels with different contents of sulphur and say that the influence of a certain minute quantity can be detected, but it is none the less true that the effect of an increase or decrease of .01 per cent. will show itself in the long run, while each .03 per cent. will write its history so that he who runs may read.

The effect of sulphur upon the cold properties of steel has not been accurately determined, but it is quite certain that it is unimportant. In common practice the content varies from .02 to .10 per cent., and within these limits it seems to have no appreciable influence upon the elastic ratio, the elongation, or the reduction of area. It is more difficult to say that it does not alter the tensile

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* Condensed from Hadfield, *Journal I. and S. I.*, Vol. II., 1888, p. 70.

strength, for a change of one thousand pounds per square inch can be caused by so many things that it is a bold venture to ascribe it to one variable. Webster* has stated that sulphur probably increases the ultimate strength at the rate of 500 pounds per square inch for every .01 per cent. I am inclined to think his conclusion is not founded on sufficient premises, and shall try to prove this in Sections XVIIs and XVIIu.

In rivets, eye-bars and fire-box steel, the presence of sulphur is objectionable, for it will tend to create a coarse crystallization when the metal is heated to a high temperature, and reduce the strength and toughness of the steel. In other forms of structural material the effect of this element is probably of little importance.

Sec. XVIIf.—*Influence of phosphorus.*—Of all the elements that are commonly found in steel, phosphorus stands preëminent as the most undesirable. It is objectionable in the rolling mill, for it tends to produce coarse crystallization and hence lowers the temperature to which it is safe to heat the steel, and for this reason phosphoric metal should be finished at a lower temperature than pure steel in order to prevent the formation of a crystalline structure during the cooling. Aside from these considerations its influence is not felt in a marked degree in the rolling mill, for it has no disastrous effect upon the toughness of red-hot metal when the content does not exceed .15 per cent.

The action of phosphorus upon the finished material may not be dismissed in so few words. Prof. Howe† has gathered together the observations of different investigators, and the evidence seems to prove that the tensile strength is increased by each increment of phosphorus up to a content of .12 per cent., but that beyond this point the metal is weakened. Whether this last observation be correct or not is of little practical importance, for it would be criminal to use a metal for structural purposes that contained as much as an average of .12 per cent. phosphorus. Below this point it is absolutely certain that phosphorus strengthens low steels, both acid and basic, and a quantitative valuation of its effect will be found in Parts II and III of this chapter.

The same certainty does not pertain to any other effect of this metalloid. Prof. Howe‡ has ably discussed the whole matter, and

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* *Further Observations on the Relations between the Chemical Constitution and Physical Character of Steel. Trans. A. I. M. E.,* Vol. XXIII, p. 113.

† *The Metallurgy of Steel,* p. 67, *et seq.*

‡ *Loc. cit.*

I herewith make quotations from *The Metallurgy of Steel*, and place them in the form of a summary.

(1) The effect of phosphorus on the elastic ratio, as on elongation and contraction, is very capricious.

(2) Phosphoric steels are liable to break under very slight tensile stress if suddenly or vibratorily applied.

(3) Phosphorus diminishes the ductility of steel under a gradually applied load as measured by its elongation, contraction and elastic ratio when ruptured in an ordinary testing machine, but it diminishes its toughness under shock to a still greater degree, and this it is that unfits phosphoric steels for most purposes.

(4) The effect of phosphorus on static ductility appears to be very capricious, for we find many cases of highly phosphoric steel which show excellent elongation, contraction and even fair elastic ratio, while side by side with them are others produced under apparently identical conditions but statically brittle.

(5) If any relation between composition and physical properties is established by experience, it is that of phosphorus in making steel brittle under shock; and it appears reasonably certain, though exact data sufficing to demonstrate it are not at hand, that phosphoric steels are liable to be very brittle under shock, even though they may be tolerably ductile statically. The effects of phosphorus on shock-resisting power, though probably more constant than its effects on static ductility, are still decidedly capricious.

The difficulty of detecting a high content of phosphorus by the ordinary system of physical tests, will be shown by Table XVII-H, which is constructed by comparing the acid open-hearth angles in Table XIV-H, which are of the same ultimate strength and of the same thickness, but which contain different percentages of phosphorus.

Analyzing this record, it will be found that the higher phosphorus gives a higher elastic ratio in all six groups, the difference ranging from 0.45 per cent. to 1.59 per cent., but the elongation and the reduction of area are almost exactly the same in the two kinds of steel. It is the difference between static and shock ductility that makes phosphoric steel so dangerous. In the ordinary testing machine there is no important difference between a pure steel containing less than .04 per cent. of phosphorus, and a common steel with .08 per cent., or a bad steel with .10 per cent.

Not only constructive engineers, but men calling themselves metallurgists, have staked and have lost their reputations in promoting new processes designed to make good finished material out of steel containing high phosphorus. Many a time the metallurgical world has been stirred by some new discovery whereby such metal was induced to show a high ductility in the testing machine, and each time the new process has passed away unwept, unhonored and unsung as it was rediscovered that static and shock ductility were totally different properties, and that the high phosphorus metal gave lamentable failures as soon as it went beyond the watchful care of its parents and its nurses.

TABLE XVII-H.

Comparative Physical Properties of Low-Phosphorus and High-Phosphorus Steels; being a Comparison of the Acid Open-Hearth Angles given in Table XIV-H, that are of the Same Ultimate Strength and of the Same Thickness, but with Different Contents of Phosphorus.

Limits of ultimate strength; lbs per square inch.	No. of group.	Thickness of angle; in inches	Phosphorus; per cent.	Number of heats.	Average ultimate strength; lbs. per sq. in.	Average elastic limit; lbs. per sq. inch.	Average elastic ratio; per cent.	Average elongation in 8 in.; per cent.	Average reduction of area; per cent.
56000 to 64000	I	$\frac{5}{16}$ to $\frac{3}{8}$	.05 to .07	212	60845	40891	67.21	29.35	57.4
			.07 to .10	50	60064	41143	68.50	28.82	58.4
	II	$\frac{7}{16}$ to $\frac{1}{2}$	.05 to .07	126	60695	39415	64.94	29.23	55.6
			.07 to .10	50	60583	40170	66.30	29.05	56.3
	III	$\frac{9}{16}$ to $\frac{5}{8}$	.05 to .07	81	60558	38645	63.81	28.95	53.8
			.07 to .10	50	61049	39656	64.96	28.98	54.8
	IV	$\frac{11}{16}$ to $\frac{3}{4}$	.05 to .07	121	59906	37478	62.56	29.32	51.3
			.07 to .10	50	59763	38338	64.15	29.60	55.3
64000 to 72000	V	$\frac{5}{16}$ to $\frac{3}{8}$	.05 to .07	40	65656	43713	66.58	27.90	55.0
			.07 to .10	25	66365	44486	67.03	27.19	55.4
	VI	$\frac{7}{16}$ to $\frac{1}{2}$	.05 to .07	29	65631	42191	64.28	27.83	53.7
			.07 to .10	30	65777	42817	65.09	27.49	53.2

It is true that numerous cases can be cited of rails, plates, etc., containing from .10 to .35 per cent. of phosphorus, which have withstood a long lifetime of wear and adversity; but in the general use of such metal there has been such a large percentage of mysterious breakages that it seems quite well proven that the phosphorus and the mystery are the same.

Much information on the effect of phosphorus may be gathered from a study of high steels. A very severe trial is put upon a cold-chisel or similar tool in the resisting of the continued shock on the sharpened edge, and it is undeniable that each increment of phosphorus has its effect in rendering such a tool brittle. It is true that in this case the steel is quenched and also that it contains a considerable proportion of carbon, but there is no evidence to show that the effect of phosphorus is different when the carbon is high, even though it be true that it is more marked. Neither is there any reason to suppose that the quenching changes its nature, for experiments with high phosphorus steel of low carbon indicate that sudden cooling would rather counteract the influence of phosphorus than enhance it, since it tends to prevent the formation of coarse crystals.

It would seem therefore that the regularly increasing banefulness of phosphorus as the carbon is raised does not portray any change in nature, but that although the effect of the metalloid in lower steels is obscured, its character is the same. No line can be drawn that can be called the limit of safety, since no practical test has ever been devised which completely represents the effect of incessant tremor. For common structural material the critical content has been placed at .10 per cent. by general consent, but this is altogether too high for railroad bridge work. All that can be said is that when all other things are equal safety increases as phosphorus decreases, and the engineer may calculate just how much he is willing to pay for greater protection from accident.

SEC. XVIIg.—*Influence of copper.* The iron made from the ores of Cornwall, Pa., contains from .75 to 1.00 per cent. of copper, and large quantities of rails have been made from this iron alone, but it has oftener been the custom at eastern steel works to use from 25 to 50 per cent. of this iron in the mixture. Other deposits contain considerable quantities of this element, notably some beds in Virginia, while the ores of Cuba give an iron with about .10 per cent. of copper.

Not only has such metal been put into rails, but into all kinds of steel, both hard and soft, and large quantities have been worked in puddle furnaces and in foundries, so that the miscellaneous cast-iron, wrought-iron and steel scrap, throughout the East, is very apt to contain quite an appreciable quantity of copper, and as steel-makers will continue to have more or less of this element to handle, it is of pressing importance that its effect be understood. The necessity for such knowledge is the more marked as it is the custom in certain favored districts to intimate that copper is injurious, although definite proof is always lacking.

Most of the Bessemer steels which are recorded in this book contain from .30 to .50 per cent. of copper, while much of the open-hearth steel is of the same character, and this will be sufficient proof that the best of steel may contain a considerable proportion. If, therefore, it appears from a set of experiments that copper exerts a bad effect, then one of two things follows:

(1) That the experiments have left some factor out of the question.

(2) That the maker of good steel has some trick by which he overcomes the enemy.

It would be a cause for satisfaction if we could boast that the latter supposition were true, but, as a matter of fact, we have never known that copper injured the cold properties of steel in any way, and it is unnecessary to add that no system has been devised to obviate its influence.

Hard and soft steels of our manufacture have found their way into all channels of trade, and although many failures have come, as they have everywhere, from high carbon, high manganese, or high phosphorus, there have been no cases where it was necessary to invoke the aid of copper. This fact outranks and transcends in value any limited series of tests that might be given. In the same way there is no evidence that copper segregates, experience pointing rather to perfect uniformity. A story has been the rounds of the trade journals of a copper wire which crystallized out in the head of a rail, but, unfortunately, no method is known by which the phenomenon can be duplicated, since such rails might be of great value in electrical work.

Steel may contain up to one per cent. of copper without being seriously affected, but if at the same time the sulphur is high, say .08 to .10 per cent., the cumulative effect is too great for molecular cohesion at high temperatures and it cracks in rolling. This tearing occurs almost entirely in the first passes of the ingot, so that it is of little importance to the engineer who is concerned only with perfect finished material. In the purest of soft steels containing not more than .04 per cent. of either phosphorus or sulphur, the influence of even .10 per cent. of copper may be detected in the less ready welding of seams during the process of rolling, but ordinarily when the sulphur is below .05 per cent. the copper injures the rolling quality very little, even if present in the proportion of .75 per cent. In all cases the cold properties seem to be entirely unaffected.

These conclusions are not founded on any limited series of tests on special alloys; they are the fruit of years of experience in the making of millions of tons of cupriferous steels, and it is quite certain that any baneful influence of this constant companion would have been felt in the many investigations which have been made into the mechanical equation of structural metal.

The only facts ever brought out against copper as far as I am aware are in a paper by Stead,* who shows that steels containing from 0.46 to 2.00 per cent. of copper do not give good results in drawn wire when a high percentage of carbon is also present, but in the same paper it is stated that there is nothing to show that rails or plates are affected injuriously.

The quantitative effect of copper upon the tensile strength of steel was the subject of a paper by Ball and Wingham,† in which they showed that as much as 7 per cent. could be alloyed to iron, and that a specimen with 4 per cent. forged well both hot and cold. It was found also that the alloys were very hard, so that when the content was over 7 per cent. the metal could not be cut by a good tool. The experiments showed a considerable increase in tensile strength in the case of higher copper, but no great weight can be given to the determinations, for the methods used in making the alloy and in cutting the tests were too crude for conclusive results.

It is not easy to make a comparison between the ductility of high-copper and low-copper steels, for at works using such material it is customary to keep a fairly constant percentage in the mixture rather than to vary between wide limits. A limited number of heats have been grouped together in Table XVII-I, and although the list is not as long as might be desired, it should be considered that the heats were all made within a short period in the same Bessemer, and were all rolled in the same mill.

It will be noted that no difference is to be found in the ultimate strength between steels with high and low-copper, although all the heats were made in the same way as nearly as possible, the work-

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* *Jour. I. and S. I.*, Vol. II, 1901, p. 122.

† *On the Influence of Copper on the Tensile Strength of Steel. Journal I. and S. I.*, Vol. I, 1889, p. 123.

men not knowing either in the Bessemer department or in the rolling mill what kind of iron was in use.

Moreover, the high-copper gives a slightly higher elastic ratio, which is a benefit, and also a better elongation and reduction of area. These results can hardly be called conclusive, for the number of heats is too limited, but as the data on high-copper steels are uniform with the much larger number of similar angles given in Table XIVH, and as the two separate averages for low-copper correspond so closely to one another after allowance is made for the two different thicknesses, it seems quite justifiable to conclude that the high-copper is not in any way harmful.

TABLE XVII-I.

Comparative Physical Properties of Low-Copper and High-Copper Steel Angles.

Made by The Pennsylvania Steel Company, 1898.

Thickness in inches.	Copper; per cent.	Number of heats.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
$\frac{5}{16}$	.10	11	61376	44152	27.52	56.30	71.9
	.35	17	60283	43841	27.88	59.01	72.7
$\frac{3}{8}$	.10	10	58965	42218	28.85	55.50	71.6
	.35	11	59630	43478	29.02	57.86	72.9

A notable investigation into the effect of copper was conducted by Mr. A. L. Colby at the Bethlehem Steel Works, and was described in *The Iron Age,* November 30, 1899. He relates that steel containing 0.57 per cent. of copper was forged into crank shafts for the United States battleships and stood every test required by the government specifications. Another ingot was forged into gun tubes for 6-inch guns for the United States Navy and fulfilled every requirement of the department. Other exhaustive tests were made on plates and all the results pointed the same way.

SEC. XVIIh.—*Influence of aluminum.*—It is hardly necessary to discuss at length the effect of aluminum upon steel, for although it is often used to quiet the metal, it unites with the oxygen of the bath and passes into the slag. Sometimes a very small percentage remains in steel castings, while it is quite conceivable that other steels may receive a small overdose by mistake, so that Table XVII-J will be of interest as giving the results of an investigation by Hadfield.*

TABLE XVII-J.

Physical Properties of Aluminum Steel.

NOTE.—Size of bars $\frac{11}{16}$ x $\frac{1}{8}$ inch; all samples forged either very well or fairly well except No. 10 which was very shelly. The fractures from Nos. 1 to 7, inclusive, were granular, but Nos. 8, 9, and 10 showed increasing coarse crystallization. All bars bent double cold after annealing except No. 10. Attempts at welding were unsuccessful on samples Nos. 3, 5, and 8.

Group.	Composition; per cent.						Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 2 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
	C.	Si.	S.	P.	Mn.	Al.					
1	.22	.09	. . .	. . .	.07	.15	47040	64960	36.70	62.9	72.4
2	.15	.18	.10	.04	.18	.38	51520	67200	37.85	58.18	76 7
3	.20	.12	. . .	. . .	.11	.61	48160	62720	38.40	54.50	76.8
4	.18	.16	.09	.03	.14	.66	45920	64960	33.35	49.86	70.7
5	.17	.10	. . .	. . .	.18	.72	49280	62720	40.00	60.74	78.6
6	.26	.15	.08	.04	.11	1.16	51520	73920	32.05	51.46	69.7
7	.21	.18	. . .	. . .	.18	1.60	44800	69440	32.70	52.14	64.5
8	.21	.18	.09	.03	.18	2.20	47040	69440	22.75	27.80	67.7
9	.24	.18	. . .	. . .	.32	2.24	48160	72800	20.67	24 64	66.1
10	.22	.20	.08	.03	.22	5.60	. . . . .	85120	3.67	3.96	. . .

After making allowances for the variations in other elements, it will be found that the aluminum has little effect upon the tensile strength, while it does not materially injure the ductility until a content of 2 per cent. is reached.

These conclusions do not agree with the results which I have found by casting different alloys in the form of 6-inch square ingots. The aluminum was added in a solid state and it is quite possible that it was not disseminated uniformly, but the analysis was made on the test-bar itself, and the fusible nature of the metal makes it probable that the piece would be reasonably homogeneous. Either two or three ingots were cast from each heat, the first containing either no aluminum or only a trace, while the others were made so as to give fairly rich alloys. The results are given in Table XVII-K.

The casting and working of such ingots is a regular operation at the works where these experiments were made, and perfect uni-

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* *Aluminum Steel. Journal I. and S. I.,* Vol. II, 1890, p. 161.

formity is always obtained in respect to tensile strength, so that it is probable the variations in bars of the same heat are due to the different contents of aluminum. These changes are as follows:

(1) The addition of one-half of 1 per cent. of aluminum increases the tensile strength between 3000 and 8000 pounds per square inch, exalts the elastic limit in about the same proportion, and injures very materially the elongation and contraction of area. The effect both upon strength and ductility is more marked in the case of low than in high-steels.

TABLE XVII-K.

Effect of Aluminum upon the Physical Properties of Steel.

6-inch square ingots, made by The Pennsylvania Steel Company, rolled to 2x⅜ inch.

	Heat number.	Composition; per cent.						Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elastic ratio; per cent.	Elongation in 8 inches; per cent.	Reduction of area; per cent.
		C.	P.	Si.	Mn.	S.	Al.					
Soft basic open-hearth steels.	1791	.11	.024	. . .	.48	.035	.00	48800	33190	68.0	31.25	48.6
		.11	.022	. . .	.45	.035	.58	56880	41150	72.4	18.25	29.8
	1792	.11	.010	. . .	.45	.019	.00	46440	31640	68.1	30.00	49.9
		.11	.011	. . .	.41	.023	.45	53440	36900	69.1	22.50	31.5
	1793	.11	.013	. . .	.35	. . .	.00	47160	33490	71.0	31.25	45.8
		.11	. . .	. . .	. . .	. . .	.50	53900	38530	71.5	27.00	33.7
Soft acid open-hearth steels.	3681	.17	.035	. . .	.61	.025	.04	58560	39310	67.1	30.00	45.7
		.16	. . .	. . .	. . .	. . .	.473	63440	42100	66.4	23.00	36.3
		.14	. . .	. . .	. . .	. . .	.899	64160	39100	60.9	17.50	25.4
	3686	.14	.059	. . .	.58	.021	.03	65030	43260	66.5	24.00	46.2
		.14	. . .	. . .	. . .	. . .	.46	67810	47950	70 7	20.00	34.0
		.12	. . .	. . .	. . .	. . .	1.171	67420	48850	72.5	8.00	15.0
	3688	.12	.034	. . .	.51	.021	.013	55700	39550	71.0	28.7	51.8
		.12	. . .	. . .	. . .	. . .	.45	59880	39100	65.3	21.7	40.5
		.13	. . .	. . .	. . .	. . .	.80	61470	43710	71.1	21.2	34.2
Hard acid open-hearth steels.	3682	.47	.048	.21	.70	.018	.00	107450	65930	61.4	10.0	20.1
		.44	. . .	. . .	. . .	. . .	.571	110550	72420	65.5	9.2	17.5
		.43	. . .	. . .	. . .	. . .	1.135	105100	68080	64.8	12.5	21.0
	3683	.54	.044	.31	.75	.020	.00	124040	47830	38.6	10.0	18.0
		.47	. . .	. . .	. . .	. . .	.37	122080	47680	39.1	. . .	8.2
		.43	. . .	. . .	. . .	. . .	.94	128040	47440	37.0	7.5	9.4
	3684	.40	.040	.26	.67	.028	.01	95010	42740	45.0	18.7	41.0
		.36	. . .	. . .	. . .	. . .	.54	98375	43050	43.8	14.0	24.5
		.38	. . .	. . .	. . .	. . .	.90	98720	43150	43.7	12.5	20.4
	3685	.40	.046	.30	.63	.031	.00	94700	44610	47.1	16.2	31.3
		.38	. . .	. . .	. . .	. . .	.52	100055	47240	47.2	13.7	24.1
		.34	. . .	. . .	. . .	. . .	.73	98480	46910	47.6	12.5	17.5
	3689	.42	.046	.21	.71	.025	.00	90900	53550	58.9	15.5	22.0
		.40	. . .	. . .	. . .	. . .	.31	94560	59190	62.6	15.0	39.7
		.34	. . .	. . .	. . .	. . .	.66	96680	59460	61.5	14.7	25.4

(2) The addition of another half of one per cent. does not have much effect upon the ultimate strength or the elastic limit, but it still further decreases the ductility of the metal.

It is stated by Odelstjerna* that the use of aluminum, in the manufacture of steel castings, gives an inferior metal, even though the addition amount to only .002 per cent., and that such steel presents a peculiar fracture, the faces of the crystals being large and well defined. It must be kept in mind, however, that these conclusions apply to one particular kind of practice, and that the use of aluminum, under certain conditions, may produce a most harmful effect, while under other possible conditions the result would be much less marked. Nothing is more difficult than to isolate one factor in a metallurgical equation, and to discover its real value, when it is always associated with complicating and equally powerful agencies.

SEC. XVIIi.—*Influence of arsenic.*—The effect of arsenic upon steel was quite fully investigated several years ago by Harbord and Tucker.† The conclusions given by them may be summarized as follows:

Arsenic, in percentages not exceeding .17, does not appear to affect the bending properties at ordinary temperatures, but above this percentage cold-shortness begins to appear and rapidly increases. In amounts not exceeding .66 per cent., the tensile strength is raised very considerably. It lowers the elastic limit, and decreases the elongation and reduction of area in a marked degree. It makes the steel harden much more in quenching, and injures its welding power even when only .093 per cent. is present.

These results have been corroborated by J. E. Stead,‡ who found that between .10 and .15 per cent. of arsenic in structural steel has no material effect upon the mechanical properties; the tenacity is but slightly increased, the elongation and reduction of area apparently unaffected. With .20 per cent. of arsenic, the difference is noticeable, while with larger amounts the effect is decisive. When one per cent. is present, the tenacity is increased, and the elongation and reduction of area both reduced. This increase in strength and diminution in toughness continue as the content of

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* *The Manufacture of Open-Hearth Steel in Sweden. Trans. A. I. M. E.*, Vol. XXIV, p. 312.

† *On the Effect of Arsenic on Mild Steel. Journal I. and S. I.*, Vol. I, 1888, p. 183.

‡ *The Effect of Arsenic on Steel. Journal I. and S. I.*, Vol. I, 1895, p. 77.

arsenic is raised to 4 per cent., when the elongation and reduction in area become nil.

These experiments are of considerable practical importance, since a great many steels carry an appreciable proportion of arsenic. Some chemists take little cognizance of this fact, and their phosphorus determinations are often too high on account of the presence of arsenic in the phosphorus precipitate. Other analysts take special precautions to avoid this contamination.

TABLE XVII-L.

The Physical Qualities of Nickel Steel as Compared with Carbon Steel of Similar Tensile Strength.

NOTE.—All steels were made in an acid open-hearth furnace by The Pennsylvania Steel Company.

Kind of steel.	Composition; per cent.				
	C.	Mn.	P.	S.	Ni.
Nickel	.24	0.78	.032	.027	3.25
Hard forging	.30 to .35	.60 to 1.00	.03 to .05	.03 to .05	nil.
Forging	.25 to .30	.60 to .80	.03 to .06	.03 to .07	nil.

Shape of member.	Kind of steel.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elastic ratio; per cent.	Elongation in 8 inches; per cent.	Elongation in 2 inches; per cent.	Reduction of area; per cent.
Rounds,	Nickel	86015	63575	73.9	20.19	34.00	46.3
	Hard forging	87663	58055	66.2	16.70	24.44	30.3
	Forging	78066	51793	66.3	23.94	. . .	52.0
Angles,	Nickel	86960	58553	67.3	21.75	39.67	50.5
	Hard forging	87820	54153	61.7	19.25	34.83	43.3
	Forging	76970	49544	64.4	. . .	. . .	49.6
Universal plates, longitudinal,	Nickel	85773	58410	68.1	21.08	39.25	52.0
	Hard forging	82773	50163	60.6	20.50	37.67	47.0
	Forging	78996	46654	59.1	26.78	. . .	52.1
Universal plates, transverse,	Nickel	86417	58203	67.4	16.50	28.92	36.1
	Hard forging	85173	(50000)*	(58.7)*	18.83	23.17	27.4
	Forging	. . . . .	. . . . .	. . . . .	. . .	. . .	. . .
Sheared plates, longitudinal,	Nickel	85337	58169	68.2	19.00	35.50	48.3
	Hard forging	85012	(50000)*	(58.8)*	22.10	39.40	48,4
	Forging	78918	49128	62.3	22.03	. . .	50.8
Sheared plates, transverse,	Nickel	84377	57260	67.9	17.13	32.50	43.4
	Hard forging	84327	(50000)*	(59.3)*	21.71	37.00	41.3
	Forging	. . . . .	. . .	. . . . .	. . .	. . .	. . .

SEC. XVIIj.—*Influence of nickel, tungsten and chromium.*—The first public presentation of the effect of nickel upon steel was

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* Approximate; could not determine accurately.

a paper by Jas. Riley.[†] Since that time the properties of nickel steel have become widely known through the experiments by the United States Government on the armor plate manufactured by The Bethlehem Iron Company, and by the Carnegie Steel Company. As often happens in the case of a new metal, the tendency is to exaggerate its importance. In a paper read before the American Society of Civil Engineers, in June, 1895, I gave the detailed results found by testing nickel steel when rolled into rounds, angles and plates, and compared them with the records of carbon steel of about the same tensile strength. A condensation of the work will be found in Table XVII-L.

It will be noted that the nickel steel is superior, but in less measure than may be generally supposed. It must be kept in mind, however, that in armor plate, as in many another field, there is sometimes but a very small distance between absolute success and absolute failure, and that it matters little how much margin there is above success, provided there is a margin at all.

There are other elements used to make special alloys with iron, some of these metals being of considerable importance. Tungsten and chromium are both employed to give tool steels extreme hardness, their peculiar characteristic being that no quenching or tempering is required. These alloys, however, do not come under the head of structural material, and will therefore not be considered here.

Sec. XVIIk.—*Influence of oxide of iron.*—The last step in the making of a heat of steel is the addition of the recarburizer to wash the oxygen from the bath, but this action is not perfect, and the exact relation is not generally understood. The amount of oxygen taken from the metal will evidently be measured in a rough way by the amount of manganese and other metalloids that are burned during the reaction. This is particularly true of acid practice. In basic work there is oftentimes a very considerable loss of manganese through the presence of a large amount of free oxygen in the slag. This occasionally occurs in the acid furnace, but less frequently. It was shown in Section Xj that the loss of manganese in recarburization is a function of the quantity which is added. In other words, if there is a reduction in the percentage of manganese which is added to an open-hearth bath at the time of

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[*] *Alloys of Nickel and Steel. Journal I. and S. I.,* Vol. I, 1889, p. 45.

tapping, there will be a reduction in the amount of manganese which will be oxidized, and this proves conclusively that the reaction is not perfect, and that an increasing amount of oxygen must remain in the metal as the content of manganese decreases; but a reasonable proportion of this oxygen can hardly exert any marked deleterious influence, else the fact would long ago have been known in some more definite form than the suppositions and theories which are occasionally founded on exceptional phenomena.

Assuming as certain that high oxygen will more likely be found in steels both low in manganese and in oxidizable metalloids, it may reasonably be expected that any bad effect it may exert will be seen in the softest products of the basic open-hearth and in the purest of acid steel. On the contrary, it is well known that the reverse is true, and that the ductility increases as the condition of pure iron is approached.

TABLE XVII-M.

Individual Records of Heats Composing Group 63 in Table XVII-N.

Heat number.	Carbon by combustion; per cent.	Carbon by color; per cent.	Phosphorus; per cent.	Manganese; per cent.	Sulphur; per cent.	Copper; per cent.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elastic ratio; per cent.
4669	. . .	.04	.007	.02	.024	.10	28420	45620	62.3
4809	. . .	.04	.007	.05	.019	.05	30640	46310	66.2
4930	. . .	.04	.007	.04	.021	.06	24370	46000	53.0
4932	. . .	.04	.011	.04	.029	.04	25810	46480	55.5
4971	. . .	.03	.010	.05	.032	.14	26780	47140	56.8
4972	. . .	.04	.010	.04	.021	.10	27920	47000	59.4
Average,	.025	.04	.009	.04	.024	.08	27323	46425	58.9

Some people imagine that it is not well to take all the impurities out of iron, their thesis having been forcibly, though somewhat inelegantly, expressed in the saying that a shirt can be ruined by too much scrubbing. Unfortunately, the simile is entirely worthless, for the purification of steel is not a process of washing, although often so called. Dephosphorization does not consist in mechanically removing certain foreign ingredients, but in placing the metal in contact with a slag of such a character that the metalloids find in it a more congenial home, and although it is true that over-oxidation assists the purification, it is not at all a necessary adjunct, since the transfer of allegiance may be effected by a slag moderately rich in lime, combined with the normal oxidizing influences.

In a discussion of a paper by Webster, which will be referred to at length in Part II of this chapter, H. D. Hibbard* deduced the fact that oxide of iron reduces the tensile strength of very soft metal by several thousand pounds. I cannot indorse this conclusion, but offer Table XVII-M as evidence to the contrary.

These heats were made in a basic open-hearth furnace, and their regularity both in chemical and physical character shows that we are dealing with a normal and definite metal and not with an accidental product. They were purposely made with the lowest possible content of manganese, and it seems positively certain that the steel must be saturated with oxygen.

These six heats constitute Group 63 in Table XVII-N, and by the most casual inspection, as well as by a glance at Curve *AA* in Fig. XVII-B, it will be plain that these steels are much stronger than would be expected as compared with those containing more carbon. It may be that the first increments of carbon have less strengthening effect than further additions, or it may be that the first increments of manganese have a marked weakening effect, but it is more probable that the oxide of iron increases the ultimate strength.

PART II.

EFFECT OF CERTAIN ELEMENTS AS DETERMINED BY SPECIAL MATHEMATICAL INVESTIGATIONS.

SEC. XVIII.—*Investigations by Webster on the influence of the metalloids.*—A very comprehensive and systematic study of the physical formula of steel has been carried out by W. R. Webster.† He has used the long and laborious method of successive approximations, and by "cutting and trying" has found the effect of each element upon the ultimate strength, as well as the effect of the

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* *Trans. A. I. M. E.*, Vol. XXI, p. 999.

† *Observations on the Relations between the Chemical Constitution and Physical Character of Steel. Trans. A. I. M. E.*, Vol. XXI, p. 766, and Vol. XXIII, p. 113; also *Journal I. and S. I.*, Vol. I, 1894, p. 328.

thickness and finishing temperature. The results are given by him as follows:

.01 per cent. of sulphur increases the tensile strength 500 pounds per square inch.

.01 per cent. of manganese has an effect which varies with each increment as follows, the values being expressed in pounds per square inch:

An increase in percentage	gives an increment of	making a total increase in strength over metal with no manganese of
from .00 to .15	3600	3600
" .15 to .20	1200	4800
" .20 to .25	1100	5900
" .25 to .30	1000	6900
" .30 to .35	900	7800
" .35 to .40	800	8600
" .40 to .45	700	9300
" .45 to .50	600	9900
" .50 to .55	500	10400
" .55 to .60	500	10900
" .60 to .65	500	11400

.01 per cent. of phosphorus has an effect which varies according to the amount of carbon present:

With .08 per cent. of carbon it is 800 pounds per square inch.
" .09 " " " " " " 900 " " " "
" .10 " " " " " " 1000 " " " "
" .11 " " " " " " 1100 " " " "
" .12 " " " " " " 1200 " " " "
" .13 " " " " " " 1300 " " " "
" .14 " " " " " " 1400 " " " "
" .15 " " " " " " 1500 " " " "
" .16 " " " " " " 1500 " " " "
" .17 " " " " " " 1500 " " " "

Carbon is credited with a constant effect of 800 pounds for each .01 per cent.

Mr. Webster has constructed, from these values, a table showing the strength of metal containing different proportions of carbon and phosphorus, from which, as a basis, the strength of a given steel may be found by allowing for the content of manganese and sulphur. This table presents a curious anomaly, as will be shown by the following excerpt:*

Estimated Ultimate Strengths; Pounds per Square Inch; per Webster.

Carbon; per cent.	.07	.08	.09	.10	.11	.12	.13	.14	.15	.16	.17	.18
P = .00 per ct.	40350	41150	41950	42750	43550	44350	45150	45950	46750	47550	48350	49150
P = .03 per ct.	42750	43550	44650	45750	46850	47950	49050	50150	51250	52050	52850	53650
P t	45150	45950	47350	48750	50150	51550	52950	54350	55750	56550	57350	58150
	48350	49150	50950	52750	54550	56350	58150	59950	61750	62550	63350	64150

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* *Journal I. and S. I.*, Vol. I, 1894, p. 338.

An examination of these figures reveals two absolutely irreconcilable conditions, for Mr. Webster takes as his starting point the dictum that carbon is a constant, and proceeds to construct a table in which it is not a constant at all, and in which it is not even constantly irregular. By his own calculation a steel of .06 per cent. phosphorus and .10 per cent. carbon is strengthened 1400 pounds by the addition of .01 per cent. of carbon, while with .10 per cent. phosphorus it is strengthened 1800 pounds by the same addition. Assuredly, this is not a constant effect. Moreover, carbon does not even have a constant effect with the same content of other metalloids, for, with .10 per cent. of phosphorus, an increase in carbon from .07 to .08 per cent. raises the strength 800 pounds, while an increase from .08 to .09 per cent. strengthens it 1800 pounds.

It would be just as correct to conclude from these results that phosphorus is a constant and carbon a variable, as to say that carbon is a constant and phosphorus a variable. The changing values which it would be necessary to assign to carbon to fulfill the first assumption would be no more arbitrary and hypothetical than the changing values assigned to phosphorus by Mr. Webster, or the changing values which he has assigned to manganese. Thus the table which has been given is entirely indecisive, since it can be translated into two diametrically opposite readings, and it must be acknowledged that one empirical formula is as good as another, provided the same answers are obtained from both.

This curious contradiction of the premises by the conclusion can only arise from some erroneous hypothesis in the values assigned to the different elements, for in the construction of such equations it is plain that an error in one factor must be atoned for by an opposite and equal error in another factor. If this reasoning be true, then very little faith can be attached to the formula as an expression of fundamental laws, however accurately the mathematical results may coincide with observations.

It is to be regretted that the earnest endeavor of Mr. Webster to write the physical formula should have been hampered by the necessity of working on sheared plates, which are finished under greater variations of temperature than angles or bars, and furthermore, that these plates were of basic Bessemer steel, a material which would not be chosen for its regularity. By correcting for thickness and finishing temperature, Mr. Webster has shown that about 90 per cent. of the heats investigated came within 5000 pounds per square inch of what his equation calls for.

This is a very satisfactory result, and it is not in a spirit of hypercriticism (for my own results, to be given later, display examples of the same character), but from a strictly scientific point of view, that attention is called to the very unpleasant corollary that one charge out of every ten does not give results within 5000 pounds. Some of these undoubtedly are vitiated by wrong chemical determinations, for the carbon was determined by color, and this gives only approximate results; on others there might well be an error in estimating the finishing temperature; on others there would be mistakes in measuring and testing; while some pieces, perhaps, did actually show those peculiarities which we call abnormal, which are ascribed sometimes to oxide of iron, sometimes to nitrogen, and not infrequently to the devil, but which grow less numerous as we learn more of our art.

I cannot believe that the complicated formula of Mr. Webster represents actual conditions, and the remainder of this chapter will attempt to show that a reasonably accurate empirical equation of steel may be written without the introduction of such manifold variations, and by the use of constant values for each element within the limits usually obtaining in structural metal. It will also be shown that the first increments of manganese do not add greatly to the strength of steel, since low-manganese metal is stronger than would be indicated by a formula that applies to steels containing higher percentages of this element.

INTRODUCTORY NOTE.

The remainder of Part II of this chapter may be omitted by the general reader. It discusses the first investigation made upon a series of steels by the method of least squares, but the results which are given later on a second series shed much light on points that are not made clear by the first investigations and give authority for more positive statements. This increased knowledge does not arise from any superiority of the second investigation, but simply from the fact that the basis of work was doubled and the validity of the results correspondingly enhanced.

The careful student will find it necessary to read all that is written to understand the steps involved, and to know why certain elements have been omitted from the formula, but those less curious may pass to Part III, which embraces the latest investigations on both series, while Section XVIIw gives a synopsis of the whole argument and the conclusions drawn therefrom.

SEC. XVIIm.—*Investigation on Pennsylvania Steel Company steels by the method of averaging groups of preliminary tests.*—I believe that the true way to investigate the influence of the metalloids upon the physical qualities of steel is to make groups of heats so as to avoid the determinative errors in any one charge. It is essential that the components of each group should be very nearly alike in chemical composition, or the whole purpose of the investigation may be frustrated by the intermingling and the integration of factors which should be differentiated and equated. If, however, the members of each group are as nearly uniform as possible, we may thereby reduce the effect of determinative errors and render possible an accurate determination of carbon, for it is out of the question to make a combustion on each separate charge, and I do not consider a color determination as any fit ground for scientific work.

The method of forming the groups in the following investigation is of such importance that it is necessary to give a full description. It is the custom at Steelton to make a preliminary test of every open-hearth heat, and it is found that this test is almost invariably a reliable exponent of the charge from which it comes. In the rolling of plates, angles and miscellaneous shapes, the thickness of the piece and the finishing temperature have a great effect upon the result, but in this test-piece the conditions of heating and working are so constant that the results as shown by the testing machine reflect only the influence of variations in the chemical equation.

Having preserved the broken bars for a considerable time, there were at hand 575 pieces of acid steel below 80,000 pounds ultimate strength, 1160 pieces of basic steel below 70,000 pounds, and 145 pieces of acid steel above 80,000 pounds. In addition to the ultimate strength, the content of manganese, sulphur and phosphorus was on record for each piece.

Taking the low-acid steels as one basis of work, a further separation was made according to the tensile strength; for example, in the case of the low-acid steels there were 148 heats between 58,000 and 60,000 pounds, and these were considered a sub-division. This was again divided, the heats being arranged according to their chemical composition. Thus there were 18 heats which showed lower manganese than the rest, and these were averaged to give Group 8 in Table XVII-N. There were 13 heats showing high manganese, and these gave Group 16. The low-sulphur heats gave Group 24, the high-sulphur Group 17. The low-phosphorus gave Group 25, the high-phosphorus Group 19, while there were 72 heats which did not show a high content of any element, and these form Group 15.

Oftentimes it would happen that a charge which contained high manganese would show either a low or a high percentage of some other element, and hence would appear in two or more groups, so that the total number of heats in the table is larger than the number of test-pieces.

After forming these groups, the average manganese, sulphur, phosphorus and ultimate strength of each were calculated from the records, while the average carbon, silicon and copper were determined by weighing an equal quantity of drillings from each bar and making a chemical analysis, the carbon being determined by combustion. Since each member of a group contained nearly the same percentage of carbon, it is evident that very little error is introduced by this system of average, while it assuredly tends to hide the idiosyncrasies of any one heat.

By this system of combination the low-acid steels gave 47 groups, which are given in Division I, Table XVII-N, and are plotted in Curve *AA*, Fig. XVII-A. The high-acid steels gave 15 groups, which are given in Division II, and are plotted in Curve *BB*, Fig. XVII-A. The basic steels gave 75 groups, which are given in Division III, and are plotted in Curve *AA*, Fig. XVII-B. In these graphic representations the ordinates are the ultimate strength per square inch, and the abscissas the percentage of carbon, the latter element being selected because it is universally recognized as the controlling component.

SEC. XVIIn.—*Quantitative valuation of the elements by the method of least squares.*—It is certain that carbon increases the strength of steel when present in small proportions, but that after a certain content is reached (say about 1.00 per cent.) there is no increase in cohesive power from a further addition. It will also be granted that this point is not a sudden break in the line, but

TABLE XVII-N.

List of Groups Used in Determining the Effect of Certain Elements upon the Tensile Strength of Steel, together with the Formulæ Obtained therefrom by the Method of Least Squares.

NOTE.—All figures relating to ultimate strength are expressed in pounds per square inch.

Number of formula.	Kind of steel.	Effect of .001 per cent. upon the ultimate strength.			
		Carbon.	Manganese.	Phosphorus.	Iron.
1	Acid,	+152.9212	—3.902156	+131.6955	+0.3432669
2	Basic,	+103.4560	+5.298315	+ 94.08509	+0.3899613

	Number of group.	Number of heats in group.	Composition; per cent.							Average ultimate strength of group.	Formula No. 1.		
			Carbon, by combustion.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Copper.	Iron, by difference.		Ult. strength as calculated from formula.	Diff. bet. actual and calculated ultimate strength.	Calculated str. from iron and carbon only.
Division I. Low acid open-hearth steel.	1	6	.082	.006	.290	.034	.034	.120	99.434	52090	50018	—2072	46672
	2	12	.105	.009	.380	.059	.074	.180	99.193	57375	58369	+ 994	50106
	3	11	.109	.008	.310	.036	.066	.140	99.331	57310	58248	+ 938	50765
	4	12	.109	.007	.380	.048	.082	.150	99.224	57430	60045	+2615	50729
	5	38	.113	.009	.430	.038	.061	.130	99.219	57140	57694	+ 554	51339
	6	11	.113	.007	.480	.046	.096	.180	99.078	62870	62060	— 810	51290
	7	5	.115	.007	.490	.029	.037	.090	99.232	55450	54610	— 840	51649
	8	18	.115	.013	.300	.043	.069	.170	99.290	58780	59585	+ 805	51669
	9	12	.116	.005	.590	.025	.034	.100	99.130	56830	53942	—2888	51767
	10	19	.116	.015	.500	.069	.082	.190	99.028	60870	60580	— 290	51732
	11	9	.116	.013	.470	.057	.089	.170	99.085	62610	61638	— 972	51752
	12	18	.117	.018	.330	.039	.073	.200	99.223	61190	60278	— 912	51952
	13	17	.117	.005	.450	.049	.099	.160	99.120	61430	63198	+1768	51916
	14	19	.118	.005	.590	.030	.035	.100	99.122	56990	54377	—2613	52070
	15	72	.118	.007	.420	.045	.075	.140	99.195	59110	60333	+1223	52095
	16	13	.118	.008	.560	.044	.063	.140	99.067	59350	58163	—1187	52051
	17	15	.118	.007	.450	.064	.081	.170	99.110	59260	60977	+1717	52066
	18	15	.118	.014	.570	.056	.076	.180	98.986	60900	59808	—1092	52023
	19	21	.119	.009	.420	.051	.090	.140	99.171	59310	62453	+3143	52240
	20	15	.119	.017	.430	.028	.065	.160	99.181	61020	59125	—1895	52243
	21	96	.119	.009	.440	.043	.077	.160	99.152	61130	60657	— 473	52233
	22	19	.123	.014	.440	.030	.063	.160	99.170	59110	59431	+ 321	52851
	23	6	.129	.008	.490	.050	.118	.160	99.045	65020	67354	+2334	53726
	24	11	.131	.012	.470	.033	.051	.130	99.173	60690	58958	—1732	54075
	25	13	.134	.015	.480	.035	.045	.150	99.141	58820	58577	— 243	54523
	26	12	.138	.021	.360	.041	.077	.140	99.223	62940	63899	+ 959	55163
	27	38	.140	.016	.480	.042	.077	.180	99.065	62890	63682	+ 792	55415
	28	10	.143	.006	.390	.045	.086	.200	99.130	64880	65700	+ 820	55891
	29	10	.147	.012	.540	.024	.056	.160	99.061	63210	61752	—1458	56484
	30	12	.151	.012	.640	.033	.051	.130	98.983	62650	61288	—1362	57069
	31	7	.151	.005	.490	.055	.088	.160	99.051	64950	66769	+1819	57092
	32	12	.156	.008	.570	.035	.070	.170	98.991	65180	64830	— 350	57836
	33	8	.171	.011	.630	.026	.036	.100	99.023	62850	62425	— 425	60142
	34	4	.178	.008	1.000	.043	.076	.140	98.555	71930	67157	—4773	61051
	35	8	.183	.014	.680	.030	.027	.100	98.966	65100	62859	—2241	61956
	36	9	.185	.008	.760	.028	.038	.130	98.851	65590	64261	—1329	62223
	37	6	.193	.009	.670	.020	.036	.100	98.972	65280	65614	+ 334	63488
	38	5	.198	.013	.610	.032	.060	.140	98.947	69970	69765	— 205	64244
	39	8	.207	.012	.790	.045	.067	.150	98.729	71210	71286	+ 76	65545
	40	8	.212	.010	.820	.039	.073	.140	98.706	71870	72716	+ 846	66302
	41	4	.213	.012	.700	.019	.046	.140	98.870	69750	69837	+ 87	66511
	42	5	.225	.015	.990	.048	.077	.220	98.425	78700	74471	—4229	68193
	43	5	.235	.016	.750	.027	.037	.140	98.795	71170	71796	+ 626	69850
	44	12	.240	.009	.760	.030	.054	.140	98.767	72320	74754	+2434	70605
	45	7	.242	.010	.860	.049	.076	.190	98.573	78020	77497	— 523	70844
	46	6	.282	.009	.660	.033	.053	.160	98.803	76830	81444	+4614	77040
	47	6	.282	.010	.770	.023	.043	.140	98.732	76940	79673	+2733	77015

TABLE XVII-N (Continued).

			Composition; per cent.								Formula No. 1.		
	Number of group.	Number of heats in group.	Carbon, by combustion.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Copper.	Iron, by difference.	Average ultimate strength of group.	Ult. strength as calculated from formula.	Diff. bet. actual and calculated ultimate strength.	Calculated str. from iron and carbon only.
Division II. High acid open-hearth steel.	48	7	.306	.010	.790	.034	.050	.090	98.720	82680	84183	+1503	80681
	49	7	.333	.220	.650	.026	.041	.080	98.650	87410	87649	+ 239	84786
	50	11	.341	.020	.850	.034	.045	.110	98.600	86980	88602	+1622	85992
	51	8	.374	.030	.830	.035	.057	.120	98.554	90750	95291	+4541	91023
	52	14	.390	.220	.680	.023	.034	.080	98.573	92630	95300	+2670	93476
	53	6	.427	.028	.860	.026	.027	.100	98.532	99300	99320	+ 20	99120
	54	17	.428	.220	.650	.023	.036	.080	98.563	97270	101488	+4218	99284
	55	16	.438	.220	.690	.026	.033	.130	98.463	102900	102432	— 468	100779
	56	14	.477	.240	.690	.025	.030	.080	98.458	107300	107999	+ 699	106741
	57	20	.480	.230	.690	.022	.032	.060	98.486	111740	108731	—3009	107209
	58	13	.480	.090	1.120	.044	.106	.190	97.970	121210	116621	—4589	107032
	59	18	.507	.061	1.185	.047	.110	.180	97.910	126800	121003	—5797	111140
	60	10	.527	.250	.720	.027	.032	.070	98.374	116980	115763	—1217	114358
	61	10	.554	.230	.680	.022	.032	.090	98.392	122950	120054	—2896	118493
	62	9	.555	.090	1.130	.042	.109	.190	97.884	123620	128417	+4797	118472
											Formula No. 2.		
Division III. Basic open-hearth steel.	63	6	.025	.005	.040	.024	.009	.080	99.817	46420	42570	—3850	41511
	64	4	.045	.006	.270	.045	.010	.110	99.514	47550	45834	—1716	43462
	65	4	.050	.009	.330	.026	.007	.190	99.388	47060	46337	— 723	43930
	66	4	.050	.005	.360	.031	.022	.150	99.382	47610	47905	+ 295	43928
	67	16	.052	.012	.350	.054	.019	.140	99.373	49010	47773	—1237	44131
	68	6	.055	.015	.340	.019	.008	.100	99.463	47130	47031	— 99	44477
	69	7	.055	.005	.220	.030	.012	.140	99.538	47570	46801	— 769	44506
	70	12	.058	.005	.340	.029	.011	.140	99.417	47010	47606	+ 596	44769
	71	8	.061	.006	.460	.025	.016	.140	99.292	47300	48973	+1673	45031
	72	18	.062	.008	.210	.036	.015	.120	99.549	48980	47758	—1222	45235
	73	6	.065	.008	.360	.080	.014	.180	99.293	49770	48670	—1100	45445
	74	17	.070	.013	.350	.034	.031	.140	99.362	49250	50760	+1510	45989
	75	22	.074	.005	.360	.023	.007	.130	99.401	48830	48984	+ 154	46418
	76	19	.074	.009	.390	.018	.013	.100	99.396	49150	49706	+ 556	46416
	77	13	.076	.011	.410	.062	.018	.180	99.243	50880	50429	— 451	46564
	78	94	.078	.003	.380	.031	.016	.110	99.382	49090	50343	+1253	46825
	79	15	.081	.005	.540	.031	.016	.130	99.197	49220	51429	+2209	47063
	80	17	.083	.005	.420	.029	.008	.130	99.325	50910	50298	— 612	47320
	81	16	.083	.006	.570	.035	.017	.110	99.179	51060	51882	+ 822	47263
	82	26	.084	.009	.250	.033	.021	.140	99.463	50900	50777	— 123	47477
	83	23	.085	.014	.380	.032	.036	.140	99.313	51140	52922	+1782	47522
	84	21	.090	.006	.400	.018	.015	.100	99.371	51200	51592	+ 392	48062
	85	121	.093	.006	.400	.032	.019	.130	99.320	51030	52259	+1229	48352
	86	17	.093	.006	.400	.038	.040	.160	99.263	53020	54213	+1193	48330
	87	21	.094	.011	.430	.036	.046	.180	99.203	54800	55016	+ 216	48410
	88	14	.096	.007	.440	.065	.023	.160	99.209	53000	53115	+ 115	48619
	89	19	.099	.012	.280	.035	.029	.160	99.385	52950	53210	+ 260	48998
	90	14	.100	.009	.660	.029	.019	.150	99.033	53380	54249	+ 869	48965
	91	5	.102	.010	.470	.087	.027	.150	99.154	53600	54249	+ 649	49219
	92	15	.103	.013	.440	.064	.027	.130	99.223	54950	54221	— 729	49349
	93	15	.108	.008	.420	.019	.018	.110	99.317	52910	53822	+ 912	49903
	94	125	.109	.010	.430	.031	.021	.120	99.279	52980	54246	+1266	49992
	95	103	.112	.005	.420	.034	.025	.160	99.244	54880	54866	— 14	50288
	96	23	.115	.009	.430	.031	.009	.130	99.276	52750	53736	+ 986	50611
	97	13	.117	.007	.460	.035	.053	.130	99.198	57210	58211	+1001	50788
	98	15	.118	.014	.490	.057	.033	.140	99.148	56980	56573	— 407	50872
	99	18	.120	.004	.430	.018	.020	.120	99.288	54860	55293	+ 433	51133
	100	7	.121	.008	.540	.032	.056	.140	99.103	60580	59294	—1286	51165
	101	11	.125	.012	.670	.038	.025	.130	99.000	56680	57440	+ 760	51538
	102	10	.125	.019	.540	.060	.036	.110	99.110	58790	57829	— 961	51581
	103	16	.126	.008	.620	.028	.024	.140	99.054	55090	57206	+2116	51663
	104	19	.131	.008	.300	.029	.022	.130	99.380	54690	55966	+1276	52307
	105	20	.132	.006	.390	.027	.009	.130	99.306	54890	55295	+ 405	52382
	106	63	.132	.010	.470	.033	.028	.190	99.137	56870	57440	+ 570	52316
	107	9	.134	.016	.510	.036	.055	.110	99.139	59110	60400	+1290	52523
	108	15	.136	.009	.310	.029	.024	.130	99.362	57010	56718	— 292	52817

TABLE XVII-N (Continued).

	Number of group.	Number of heats in group.	Composition; per cent.							Average ultimate strength of group.	Formula No. 2.		
			Carbon, by combustion.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Copper.	Iron, by difference.		Ult. strength as calculated from formula.	Diff. bet. actual and calculated ultimate strength.	Calculated str. from iron and carbon only.
Division III. Basic open-hearth steel.	109	11	.137	.020	.720	.037	.033	.180	98.873	59110	59650	+ 540	52730
	110	6	.142	.017	.530	.058	.029	.120	99.104	60570	58874	—1696	53337
	111	10	.144	.008	.500	.020	.026	.120	99.182	58860	58670	— 190	53575
	112	37	.144	.015	.520	.034	.028	.130	99.129	58970	58944	— 26	53554
	113	14	.146	.015	.440	.019	.023	.110	99.247	57030	58302	+1272	53807
	114	21	.147	.005	.430	.027	.011	.100	99.280	57060	57237	+ 177	53923
	115	7	.151	.016	.680	.029	.024	.180	98.920	60870	60058	— 812	54197
	116	9	.152	.008	.640	.034	.045	.170	98.951	63480	61937	—1543	54312
	117	10	.153	.011	.460	.027	.012	.100	99.237	58970	58094	— 876	54527
	118	13	.153	.008	.530	.034	.030	.160	99.085	60770	60099	— 671	54468
	119	12	.155	.012	.390	.029	.020	.120	99.274	59110	58697	— 413	54749
	120	6	.158	.012	.820	.032	.027	.170	98.781	63400	61752	—1648	54867
	121	8	.164	.018	.570	.046	.031	.160	99.011	63740	61514	—2226	55577
	122	7	.173	.009	.530	.021	.021	.110	99.136	60810	61341	+ 531	56557
	123	11	.180	.012	.560	.029	.026	.150	99.043	63110	62658	— 452	57245
	124	10	.181	.006	.480	.031	.011	.100	99.191	60740	60984	+ 244	57406
	125	8	.181	.011	.370	.028	.019	.070	99.321	60870	61205	+ 335	57457
	126	5	.185	.039	.720	.049	.043	.110	98.854	67570	65549	—2021	57689
	127	5	.190	.008	.720	.037	.047	.170	98.828	66480	66433	— 47	58196
	128	5	.196	.025	.860	.032	.029	.170	98.688	67480	66047	—1433	58762
	129	10	.199	.012	.620	.030	.025	.120	98.994	66820	64829	—1991	59192
	130	7	.204	.007	.450	.028	.010	.120	99.181	63600	63107	— 493	59782
	131	8	.210	.010	.530	.020	.018	.130	99.082	63740	64866	+1126	60364
	132	6	.215	.005	.420	.024	.011	.160	99.165	63470	64174	+ 704	60914
	133	6	.231	.029	.360	.025	.012	.120	99.223	67530	65628	—1902	62591
	134	5	.233	.008	.490	.020	.021	.130	99.098	67560	67322	— 238	62750
	135	5	.260	.060	.310	.025	.014	.100	99.231	68470	68554	+ 84	65595
	136	5	.311	.080	.440	.029	.020	.070	99.050	73010	75013	+2003	70800
	137	5	.338	.025	.620	.026	.017	.100	98.874	77950	78410	+ 460	73525

that the effect of each unit of carbon decreases as it is approached. If this relation holds good throughout the whole series of alloys, then each successive increment of carbon will have a less effect from the starting point of pure iron.

It is also possible for the same reasons that every other metalloid will follow the same rule, so that the influence of each separate alloyed element will be represented by a curve. This may be an arc of a circle, or a parabola, or a cycloid, or a broken line; it may be different in degree or different in nature in the case of each element; and it may vary in degree or even in nature with changes in the proportions of the associated elements; but it will be assumed in this investigation that within the narrow limits of the divisions of the table, the effect of a regular increase in the percentage of each metalloid would be represented by a straight line. In other words, that an increase of carbon from .20 to .21 per cent. gives the same increment in strength as an increase from .10 to .11 per cent.

If this last assumption be true, then the seemingly erratic deviations of the curves in Fig. XVII-A and Fig. XVII-B from a straight line are due to variations in the associated percentages of silicon, manganese, sulphur, phosphorus and copper. It seems possible to find the effect of these elements by the method of least squares. Each group may be regarded as an equation containing seven unknown quantities, the combined effect of which produces a certain ultimate strength. If A is written for the effect of .001 per cent. of carbon upon the ultimate strength, B for silicon, C for manganese, D for sulphur, E for phosphorus, F for copper, and G for iron, then Group I will take the following form:

$$82\ A+6\ B+290\ C+34\ D+34\ E+120\ F+99{,}434\ G=52{,}090.$$

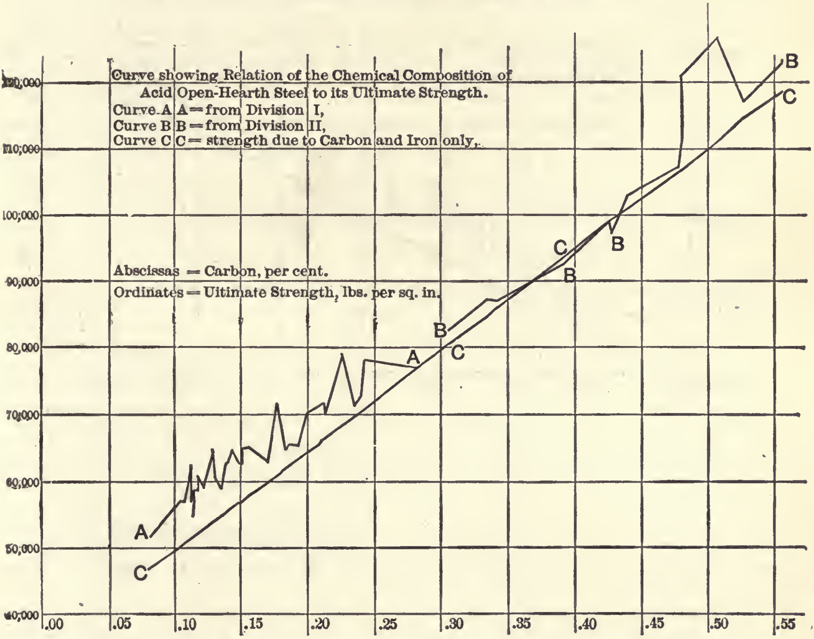

FIG. XVII-A.—CURVES SHOWING RELATION OF THE CHEMICAL COMPOSITION OF ACID OPEN-HEARTH STEEL TO THE ULTIMATE STRENGTH, AS SHOWN IN TABLE XVII-N.

Similarly the 47 groups of low-acid steels furnish 47 equations of condition, as they are called, and from these may be deduced seven normal equations containing seven unknown quantities. These normal equations being solved by ordinary algebraic methods give the values of *A, B, C, D, E, F* and *G,* which will most nearly fit the original equations of condition. The method by which the normal equations are deduced is explained in the following formula:

Multiply each equation by the coefficient of A in that equation, then add together the resulting equations for a new equation; then multiply each equation by the coefficient of B in that equation, and, as before, form the sum of the resulting equations. Continue the process with the coefficients of each of the unknown quantities. The number of resulting normal equations will be equal to that of the unknown quantities, and the values of the unknown quantities deduced therefrom will, as above stated, be the most probable values.

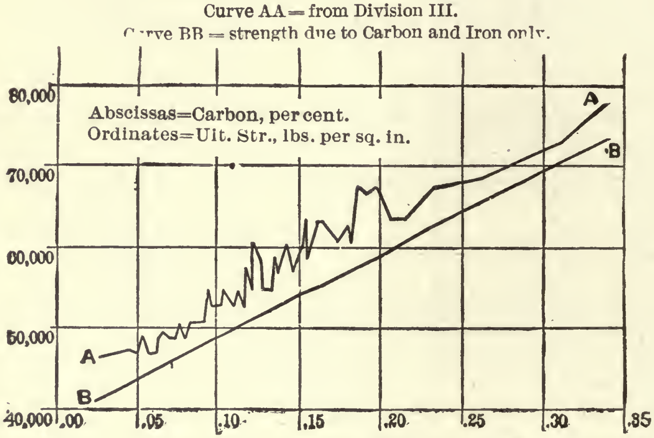

FIG. XVII-B.—CURVES SHOWING RELATION OF THE CHEMICAL COMPOSITION OF BASIC OPEN-HEARTH STEEL TO THE ULTIMATE STRENGTH, AS SHOWN IN TABLE XVII-N.

NORMAL EQUATIONS FROM LOW ACID OPEN-HEARTH HEATS.

Equation from A; 1,210,191 A + 76,504 B + 4,298,830 C + 272,436 D + 450,670 E + 1,074,560 F + 710,516,809 G = 471,142,035.

Equation from B; 76,504 A + 5,845 B + 274,330 C + 19,254 D + 31,696 E + 75,260 F + 48,817,111 G = 31,631,465.

Equation from C; 4,298,830 A + 274,330 B + 15,861,200 C + 1,002,980 D + 1,644,430 E + 3,887,300 F + 2,581,030,930 G = 1,697,750,700.

Equation from D; 272,436 A + 19,254 B + 1,002,980 C + 78,962 D + 128,102 E + 286,420 F + 183,011,846 G = 117,362,985.

Equation from E; 450,670 A + 31,696 B + 1,644,430 C + 128,102 D + 215,997 E + 474,310 F + 300,954,795 G = 194,090,210.

Equation from F; 1,074,560 A + 75,260 B + 3,887,300 C + 286,420 D + 474,310 E + 1,093,400 F + 697,108,750 G = 450,996,700.

Equation from G; 710,516,809 A + 48,817,111 B + 2,581,030,930 C + 183,011,846 D + 300,954,795 E + 697,108,750 F + 460,910,659,759 G = 296,665,604,300.

These equations have been worked out without the use of logarithms and are absolutely accurate, since the conditions of the problem render possible a perfect proof. The iron being determined by difference, it follows that the sum of the coefficients in each equation of condition is 100,000, and since each coefficient in each equation is successively multiplied by every other one in the same equation to form new coefficients, it follows that the sum of the resultant coefficients for each equation of condition must be the square of 100,000, while the sum of all the equations derived from the 47 equations of condition will be 47 times this number, or 470,000,000,000, and this is exactly the sum of all the coefficients in the above seven normal equations.

In the subsequent work of finding values of the unknown quantities it is out of the question to sustain this strict accuracy, as by the continual combination of terms the final step would involve the multiplication of two numbers, each of which would contain nearly 150 integers. Seven-place logarithm tables have therefore been used, and seven integers have been kept in all corresponding numbers. This care is necessary in determining seven unknown quantities, since the number of operations is so great that the accumulated logarithmic error is of considerable importance.

It is necessary also to keep in mind that the iron is determined by difference, so that it must bear all the inaccuracies that occur in the determination of the other elements. Moreover, it is a false assumption that this "difference" is entirely made up of pure iron, for there are certain appreciable portions of oxygen and arsenic, with traces of other elements like nickel, cobalt, nitrogen, etc. It is difficult to say how much this fact impairs the value of the results.

Following is the result of the solution for the low acid open-hearth heats, the number in each case expressing the effect of .001 per cent. of the element upon the tensile strength, in pounds per square inch.

Carbon=+135.6419; Silicon=+71.75700.
Manganese=−2.066168; Sulphur=−37.77523.
Phosphorus=+117.6217; Copper=+7.389871.
Iron=+0.3655429.

The values are given in each case to seven figures, although at first sight this may seem an absurd refinement. It must be remembered, however, that although the *original groups* contain large determinative errors, the *normal equations* constitute an accurate mathematical problem, and that the figures just given should be such that they satisfy the original equations of condition more nearly than any other possible set of values. This is equivalent to saying that if they be substituted in the 47 groups of Division I, Table XVII-N, the sum total of the errors should be zero.

The formula actually used is not the formula just given, since for reasons to be explained later, I have discarded the results of operating upon seven variables, and taken cognizance of only four elements. I have, however, made the trial of applying the above values to the groups in Division I and find that the sum of the plus and minus errors is 29 pounds, being an average error of only one-half a pound to each group, which is very close to mathematical accuracy.

The true way of proving the correctness of values deduced from such a series of equations is first to eliminate in the order *G, F, E, D, C, B, A* and then in the order *A, B, C, D, E, F, G,* to see if the two sets of answers agree; but as each such double solution, when every step of the work is proven to avoid error, consumes nearly two weeks of steady work, this reverse process has not been carried out in every one of the cases herein recorded. It has, however, been used to corroborate the following less tedious method of proof which is described for the benefit of future investigators.

The process of elimination is performed according to the following chart, where each figure represents an equation, and each bracket the combination of two equations by multiplication and subtraction.

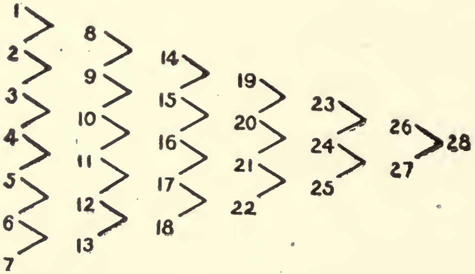

Chart Showing Method of Determining Seven Unknown Quantities in Seven Equations.

After the determination of the final factor in equation No. 28, the value of each element is successively determined by substitution in Nos. 26, 23, 19, 14, 8 and 1. After the last unknown is thus found the values are substituted in No. 7, and if it is then found that the results agree to the seventh or even to the sixth logarithmic place, it may confidently be asserted that the values are correct to the third and sometimes to the fourth integer, and this is amply sufficient for the work in hand.

Notwithstanding such methods of proof and the reasonable, although in some respects the unexpected, nature of the results just given from Division I, it is with no little disappointment that I am forced to confess that further investigation throws grave doubts on the validity of this method of least squares when applied to such a number of unknown quantities, and when any one of these quantities is of very little importance. The reasons for this conclusion will appear in the results shown in Table XVII-O, which were obtained from the normal equations derived from the groups composing Division II.

TABLE XVII-O.

Effect of Certain Elements upon the Strength of Steel as Determined from Division II in Table XVII-N.

Order of solution.	Effect of .001 per cent.						Strength of pure iron.
	C.	Si.	Mn.	S.	P.	Cu.	
Forward . . .	+148.403	+36.030	+29.069	+367.923	—34.340	—29.110	42347
Backward . .	+148.402	+36.012	+29.056	+367.467	—34.203	—29.088	42530

NORMAL EQUATIONS FROM THE HIGH ACID OPEN-HEARTH HEATS, CONSTITUTING DIVISION II OF TABLE XVII-N

Equation from A; $3,008,187\ A + 990,763\ B + 5,453,335\ C + 202,211\ D + 351,674\ E + 743,270\ F + 650,950,560\ G = 708,894,410.$

Equation from B; $990,763\ A + 441,605\ B + 1,596,765\ C + 57,835\ D + 91,526\ E + 207,280\ F + 212,514,226\ G = 230,460,700.$

Equation from C; $5,453,335\ A + 1,596,765\ B + 10,427.125\ C + 391,865\ D + 704,040\ E + 1,447,300\ F + 1,201,479,570\ G = 1,298,675,100.$

Equation from D; $202,211\ A + 57,835\ B + 391,865\ C + 14,854\ D + 26,895\ E + 54,730\ F + 44,851,610\ G = 48,331,270.$

Equation from E; $351,674\ A + 91,526\ B + 704,040\ C + 26,895\ D + 52,914\ E + 102,250\ F + 76,070,701\ G = 84,275,880.$

Equation from F; $743,270\ A + 207,280\ B + 1,447,300\ C + 54,730\ D + 102,250\ E + 208,300\ F + 162.236,870\ G = 177,275,000.$

Equation from G; $650,950.560\ A + 212,514,226\ B + 1,201,479,570\ C + 44,851,610\ D + 76,070,701\ E + 162,236,870\ F + 145,264,796,433\ G = 154,504,087,640.$

After laborious attempts to find any mathematical error, I am certain that the discrepancies between the results found by solving in reverse order are due solely to logarithmic errors, and could only be lessened by using logarithm tables of more than seven places. But these errors are of no importance, and it is certain that the values are approximately correct, mathematically speaking, although they are absurd from a practical point of view.

If .001 per cent. of sulphur did actually cause an increase of 367 pounds, then .06 per cent., which is a very common content, would increase the strength 22,000 pounds, when in reality its effect is very slight, if it is even appreciable. Phosphorus is shown as a minus quantity, which is entirely wrong, and copper is given at — 29 pounds, which is equivalent to saying that one-half of one per cent. would reduce the strength 14,500 pounds, when, in fact, a content of even one per cent. does not seem to have any effect at all.

These ridiculous values place in question the validity of the method of least squares, by which they were determined, and the next section will attempt to survey the territory over which it has jurisdiction.

SEC. XVIIo.—*Application of the method of least squares as limited by the conditions of the problem.*—The fundamental difficulty in the solution of Division II is the fact that the iron is not self-determining. The highest percentage of iron in any group of the division is 98.720, and the lowest is 97.884, being a ratio of less than 101 to 100. It is true that the ratios in Divisions I and III are very little higher than this, but in both these cases there is a determining condition in the fact that there are a number of groups which are nearly pure iron, and it will evidently be less probable that a wrong result will be found under such circumstances.

The only way, therefore, of obtaining an intelligent result for Division II is to make the iron self-determining, and since this cannot be done within the limits of the division, it is necessary to combine it with Division I. This combination may be regarded as unjustifiable, since the effect of carbon decreases after a certain point is passed, but it can be answered that the curve in Fig. XVII-A gives no sign of falling, and that the value of carbon just found for Division II is greater than for Division I. Moreover, it will be shown in Table XVII-P that the value of carbon as found by the combination of I and II is higher than for I alone, so that there is good warrant for the union of the two.

This conjunction will tend to prevent an absurd result in the case of iron, and will give a better value for carbon; but it will not prevent a wrong estimation of an element like copper, which has very little influence upon the tensile strength. It is certain that the equations of condition are not absolutely accurate, owing to the limitations of chemical research and the variations in the rolled test-bars. These errors are incorporated into the normal equations, and are distributed in the final solution so as to give the best mathematical result.

It does not follow that the values so found will accurately represent the actual practical state of affairs, for a purely fanciful result is not an unusual phenomenon in mathematics; thus, in the solution of every quadratic equation, two values are always produced by the plus and minus roots, and one of these values is often inapplicable to the original conditions. This occurred in the derivation of the curves given in Fig. XVI-B, for there were two possible conic sections discovered in each case. One of them fitted the problem, while the other was a reverse curve exactly similar to the first, but situated for the most part in *minus* territory, and having an existence only as a mirage of the true solution.

To prevent such a purely mathematical answer to the present practical problem it is necessary to discard two sets of variables:

(1) Those which are known to have very little effect.

(2) Those which are present in very nearly constant proportion.

If an element has no effect, then it cannot be self-determining, but may be forced to bear all the results of analytical errors. If it is present in nearly constant quantity, then the slight variations can have very little determining effect.

From one point of view these limitations beg the question, for it becomes necessary to know in a general way the influence of an element before its value can be quantitatively determined. The ultimate logical consequences of such a provision need not be discussed, for, in the problem under consideration, it is known that copper has scarcely any influence upon the tensile strength, and that the same is true of sulphur when present in ordinary proportions.

In the case of silicon there is a chance for greater hesitation, but it will be noticed that in only eight groups is the content of this metalloid above .20 per cent., while in only three other groups, or 11 in all, is it over .03 per cent. Within the limits of .00 and .03 per cent., which thus includes five-sixths of the groups, the power of silicon is not enough to disturb the calculations.

Sec. XVIIp.—*Effect of carbon, manganese, phosphorus and iron* *upon the ultimate strength.*—Having thus decided to neglect the effect of silicon, sulphur and copper, the equations of condition are simplified so that they take the following form:

EQUATIONS OF CONDITION.

From Group I; 82 A + 290 C + 34 E + 99434 G = 52090.
From Group II; 105 A + 380 C + 74 E + 99193 G = 57375.

From these may be deduced the following normal equations:

NORMAL EQUATIONS, DIVISION I.

Equation from A; 1,210,191 A + 4,298,830 C + 450,670 E + 710,516,809 G = 471,142,635.

Equation from C; 4,298,830 A + 15,861,200 C + 1,644,430 E + 2,581,030,930 G = 1,697,750,700.

Equation from E; 450,670 A + 1,644,430 C + 215,997 E + 300,954,795 G = 194,090,210.

Equation from G; 710,516,809 A + 2,581,030,930 C + 300,954,795 E + 460,910,659,759 G = 296,665,604,300.

NORMAL EQUATIONS, DIVISION II.

Equation from A; 3,008,187 A + 5,453,335 C + 351,674 E + 650,950,560 G = 708,894,410.

Equation from C; 5,453,335 A + 10,427,125 C + 704,040 E + 1,201,479,570 G = 1,298,675,100.

Equation from E; 351,674 A + 704,040 C + 52,914 E + 76,070,701 G = 84,275,880.

Equation from G; 650,950,560 A + 1.201,479,570 C + 76,070,701 E + 145,264,796,463 G = 154,504,087,640.

NORMAL EQUATIONS, DIVISION III.

Equation from A; 1,505,996 A + 4,700,050 C + 225,664 E + 954,850,000 G = 574,293,000.

Equation from C; 470,005 A + 1,723,710 C + 83,790 E + 340,994,800 G = 198,609,150.

Equation from E; 225,664 A + 837,900 C + 48,942 E + 169,769,400 G = 98,593,980.

Equation from G; 9,548,500 A + 34,099,480 C + 1,697,694 E + 7,382,138,000 G = 4,206,995,000.

NORMAL EQUATIONS, DIVISIONS I AND II COMBINED.

Equation from A; 4,218,378 A + 9,752,165 C + 802,344 E + 1,361,467,000 G = 1,180,037,000.

Equation from C; 9,752,165 A + 26,288,330 C + 2,348,470 E + 3,782,511,000 G = 2,996,426,000.

Equation from E; 802,344 A + 2,348,470 C + 268,911 E + 377,025,500 G = 278,366,090.

Equation from G; 13,614,670 A + 37,825,110 C + 3,770,255 E + 6,061,755,000 G = 4,511,697,000.

These equations, when solved, give the values shown in Table XVII-P. In two cases the elimination has been performed in the order *G, E, C, A,* and has then been repeated "backward" in the order *A, C, E, G.* The comparison of results shows the degree of accuracy obtained. In the other two cases the work was not repeated in this manner, but the table gives two values of iron. These two determinations are the result of substitution in the extreme equations, as shown by the chart on page 494, and the almost perfect agreement of the two proves that the work is correct within the limits of logarithmic error.

TABLE XVII-P.

Effect of Carbon, Manganese and Phosphorus upon the Strength of Iron, as Determined from Table XVII-N by the Method of Least Squares.

NOTE.—All values are in pounds per square inch.

No. of division. (See Table XVII-N.)	Order of solution.	Effect of .001 per cent.			Strength of pure iron.
		Carbon.	Manganese.	Phosphorus	
Division I.	Forward,	+141.4929	—3.086216	+109.3771	37139.65 37139.67
Division II.	Forward,	+166.8914	+3.921577	+ 97.28167	23236.27
	Backward,	+166.8939	+3.928512	+ 97.24250	23231.43
Divisions I and II combined.	Forward,	+152.9212	—3.902156	+131.6955	34326.69
	Backward,	+152.9203	—3.901182	+131.6965	34326.22
Division III.	Forward,	+103.4560	+5.298315	+ 94.08509	38996.13 38996.14

The values are given for Division I in order that they may be compared with those found by combining Divisions I and II. They are given also for Division II separately, in order to corroborate what was said in Sections XVIIn and XVIIo on the worthlessness of any solution of this division by itself. The value of 23,236 pounds for the strength of pure iron is absurd, and, of course, this renders worthless all the other factors, but the coincidence of the results when the equations were worked in opposite directions proves conclusively the accuracy of the work.

Moreover, I have applied these values to the separate groups of Division II, and the greatest discrepancy in any one group between the actual and the calculated strength is 6784 pounds, while the sum of the plus and minus errors is only 4.2 pounds, being an average error of only 0.28 pounds for each group. This shows again, what has been insisted upon elsewhere, that perfectly correct mathematical results may be inapplicable to the practical conditions unless the factors are self-determining.

The values found by the combination of Divisions I and II, and the values given for Division III, are those which have been applied to the groups in Table XVII-N under the titles of Formulæ No. 1 and No. 2. The antepenultimate column gives the tensile strength as calculated from the formula, while the penultimate shows the error, or the difference between this calculated value and the result found by the testing machine.

The accuracy of the formulæ may be judged from the fact that the sum of the plus and minus quantities for the acid steels, comprising Divisions I and II, is 29 pounds, being an error of half a pound for each group. In the case of the basic steels the error is only 5 pounds, or only one-fifteenth of a pound for each group.

Sec. XVIIq.—*Value of carbon and phosphorus when manganese is neglected.*—In the preceding section it has been shown that manganese is a plus quantity in basic steels, and a minus quantity in acid metal. These contradictory values may seem improbable, although they are by no means impossible. In order to get a little more light on the subject, I have arbitrarily divided the list of groups, given in Table XVII-N, into two sets, and have determined the most probable values of carbon, manganese and phosphorus for each set. It would naturally be expected that the results from one-half the number of groups would be less valid and less uniform than from the complete list, but they may nevertheless be of use as corroborative evidence.

The method of dividing the list was to take the odd numbers for one set and the even numbers for the other. Inasmuch as the original arrangement is on the basis of carbon content alone, it will be evident that this insures a fair division without any chance of selection in aid of any preconceived theory. It would have been much better if a calculation could have been made on those groups showing low manganese, and those with high manganese, but as the low steels did not offer any examples of a high content of this element, and the high steels did not offer any examples of a low content, the result would have been of no value.

In the case of acid steel a mistake was made in taking for this arbitrary division the original list of groups, which, of course, was made up before the determinations of carbon were made by combustion. On comparing the numbers on this original list with the new arrangement, it was found that the two sets of so-called "odd" and "even" numbers really embraced the following groups, as given in Table XVII-N, after they had been renumbered:

Odd numbers: Groups, 1, 2, 3, 8, 9, 10, 13, 15, 18, 22, 23, 25, 26, 27, 29, 31, 33, 36, 38, 41, 42, 43, 44 and 45.

Even numbers: Groups 4, 5, 6, 7, 11, 12, 14, 16, 17, 19, 20, 21, 24, 28, 30, 32, 34, 35, 37, 39, 40, 46, and 47.

Inasmuch as one arbitrary division seems to be as good as another and as the calculation is very laborious, it was deemed unnecessary to repeat the work simply for the sake of uniformity, but this explanation is made for the sake of any mathematician who might wish to test the accuracy of the solution. In the case of the basic steel, the odd and even figures were taken as they stand in Table XVII-N. The results are given in Table XVII-Q.

TABLE XVII-Q.

Values of Carbon, Manganese, Phosphorus, and Iron, obtained by Arbitrarily Dividing the List in Table XVII-N According to Odd and Even Numbers and Solving Each Division by the Method of Least Squares.

Factor.	Kind of steel.	Value in pounds per sq. inch.		
		Odd.	Even.	Combined.
.01 per cent. of carbon	Acid,	+1554	+1502	+1529
	Basic,	+1069	+ 992	+1035
.01 per cent. of manganese	Acid,	— 0.18	— 107	— 39
	Basic,	+20	+ 85	+ 53
.01 per cent. of phosphorus	Acid,	+1451	+1032	+1317
	Basic,	+ 799	+1100	+ 941
Pure iron	Acid,	30824	40519	34327
	Basic,	40303	37749	38996

It will also be seen that in each case the "combined" value, which is the original value given in Table XVII-N, is very close to an average of the odd and even. This is by no means a foregone conclusion, and would not follow if the factors were not self-determining to a great extent.

It will also be seen that there are variations in the values of each one of the factors, but that manganese shows the widest range. In the acid steel the figure for the even numbers is—107, while in the odd numbers it is only a small fraction. The variations in phosphorus are very small when compared with this, while those of carbon are insignificant. The value of iron must necessarily change with the other elements, since it is less self-determining than carbon or phosphorus.

The great differences found in the values of phosphorus in the odd and even subdivisions of the basic heats are easily explained. An examination of the table will show that of the odd numbers there are only four groups showing more than .04 per cent. of phosphorus, and only three groups in the even numbers. There is therefore too little variation for the phosphorus to have an overpowering self-determining effect. The combined figures are subject to the same criticism, but the larger number of groups gives the results a greater validity.

Taking into consideration the fact that manganese is indicated as positive in basic and negative in acid steels, and that it gives wide differences in value between the odd and even lists, it would seem reasonable to suppose that it has very little effect at all when present in usual proportions, since the method of least squares should give a reliable result for an element which has a strong and positive action, when such an element is present in widely varying proportion.

Accepting such a conclusion, it remains to be seen whether a true formula can be deduced by omitting manganese altogether, and ascribing all the variations in tensile strength to the carbon, phosphorus, and iron. On this new basis the following normal equations are formed, the solutions of which are given in Table XVII-R.

NORMAL EQUATIONS, OMITTING B, C, D, AND F.
DIVISIONS I AND II COMBINED.

Equation from A; $4{,}218{,}378\ A + 802{,}344\ E + 1{,}361{,}467{,}000\ G = 1{,}180{,}037{,}000.$
Equation from E; $802{,}344\ A + 268{,}911\ E + 377{,}025{,}500\ G = 278{,}366{,}090.$
Equation from G; $13{,}614{,}670\ A + 3{,}770{,}255\ E + 6{,}061{,}755{,}000\ G = 4{,}511{,}697{,}000.$

DIVISION III.

Equation from A; $1{,}505{,}996\ A + 225{,}664\ E + 954{,}850{,}000\ G = 574{,}293{,}000.$
Equation from E; $225{,}664\ A + 48{,}942\ E + 169{,}769{,}400\ G = 98{,}593{,}980.$
Equation from G; $9{,}548{,}500\ A + 1{,}697{,}694\ E + 7{,}382{,}138{,}000\ G = 4{,}206{,}995{,}000.$

The data in Table XVII-R may be expressed in simple formulæ, an allowance being made for the fact that there is never quite 100 per cent. of iron in any steel. In Table XVII-S these formulæ are applied to the groups of metals given in Table XVII-N.

In order to see whether these formulæ satisfy all the classes of steels under consideration, the results in Table XVII-S may be analyzed by the following method:

Silicon: Referring to the acid steels in Table XVII-N, it will be found that there are eight groups containing .22 per cent. or over of silicon. Four of these, 49, 55, 56, and 60, show an error in Table XVII-S of less than 2000 pounds. There are two groups, 52 and 54, having an aggregate plus error of 6390 pounds, and two groups, 57 and 61, with an aggregate minus error of 7080 pounds. Thus there is no evidence that silicon influences the result.

TABLE XVII-R.

Effect of Carbon and Phosphorus upon the Strength of Iron.

NOTE.—All values are expressed in pounds per square inch.

Kind of steel.	Effect of .001 per cent.		Strength of pure iron.
	Carbon.	Phosphorus.	
Acid steel; Divs. I and II,	148.495	126.449	33212.2
Basic steel; Division III,	108.542	119.707	40196.5

Sulphur: There are six groups in the acid steel, 2, 10, 11, 17, 18, and 31, which contain .055 per cent. or more of sulphur, and none of these shows an error in Table XVII-S of over 2000 pounds, In the basic steels there are eight groups, 73, 77, 88, 91, 92, 98, 102, and 110, showing over .055 per cent., and the greatest error in any of them in Table XVII-S is 1680 pounds. Thus the sulphur does not seem to affect the situation.

Manganese: There are sixteen acid groups containing .75 per cent. or more of manganese. Of these there are six, 36, 39, 40, 43, 45, and 53, which have an error in Table XVII-S of less than 2000 pounds, while group 48 is only 60 pounds above this figure. Of the remainder there are five groups, 44, 47, 50, 51, and 62, giving an aggregate plus error of 19310 pounds, and four groups, 34, 42, 58, and 59, with an aggregate minus error of 13720 pounds. This would indicate, if it indicates anything, that manganese has a minus value in the acid steels, which is in accordance with the mathematical deductions of the last section.

Among the basic groups there are only two, 120 and 128, which contain more than .75 per cent. of manganese. These two show an aggregate minus error in Table XVII-S of 5750 pounds. There are six other groups with a content of manganese between .65 and .75 per cent. Five of these, 90, 101, 109, 115, and 127, show an error under 2000 pounds, while the remaining group gives a minus error of 2340 pounds. There is, therefore, a slight indication that manganese strengthens basic steel, as was discovered in the last section.

TABLE XVII-S.

Ultimate Strength of the Steels Given in Table XVII-N as Compared with the Results Obtained from the Following Formulæ.

Formula for Acid Steel; 33,000+1485 C+1260 P = Ultimate Strength.
Formula for Basic Steel; 40,000+1085 C+1200 P = Ultimate Strength.

	Number of group.	Ultimate strength.			Number of group.	Ultimate strength.			Number of group.	Ultimate strength.		
		Actual.	Calculated from formula.	Diff. between actual and calculated strengths.		Actual.	Calculated from formula.	Diff. between actual and calculated strengths.		Actual.	Calculated from formula.	Diff. between actual and calculated strengths.
Acid steel.	1	52090	49460	—2630	22	59110	59200	+ 90	43	71170	72560	+1390
	2	57375	57920	+ 545	23	65020	67030	+2010	44	72320	75440	+3120
	3	57310	57500	+ 190	24	60690	58880	—1810	45	78020	78510	+ 490
	4	57430	59520	+2090	25	58820	58570	— 250	46	76830	81560	+4730
	5	57140	57470	+ 330	26	62940	63200	+ 260	47	76940	80300	+3360
	6	62870	61880	— 990	27	62890	63490	+ 600	48	82680	84740	+2060
	7	55450	54740	— 710	28	64880	65070	+ 190	49	87410	87620	+ 210
	8	58780	58770	— 10	29	63210	61890	—1320	50	86980	89310	+2330
	9	56830	54510	—2320	30	62650	61850	— 800	51	90750	95720	+4970
	10	60870	60560	— 310	31	64950	66510	+1560	52	92630	95200	+2570
	11	62610	61440	—1170	32	65180	64990	— 190	53	99300	99810	+ 510
	12	61190	59570	—1620	33	62850	62930	+ 80	54	97270	101090	+3820
	13	61430	62850	+1420	34	71930	69010	—2920	55	102900	102200	— 700
	14	56990	54930	—2060	35	65100	63580	—1520	56	107300	107620	+ 320
	15	59110	59970	+ 860	36	65590	65260	— 330	57	111740	108310	—3430
	16	59350	58460	— 890	37	65280	66200	+ 920	58	121210	117640	—3570
	17	59260	60730	+1470	38	69970	69960	— 10	59	126800	122150	—4650
	18	60900	60100	— 800	39	71210	72180	+ 970	60	116980	115290	—1690
	19	59310	62010	+2700	40	71870	73680	+1810	61	122950	119300	—3650
	20	61020	58860	—2160	41	69750	70430	+ 680	62	123620	129150	+5530
	21	61130	60370	— 760	42	78700	76120	—2580	. .	. . . .	. . . .	. . . .
Basic steel.	63	46420	43790	—2630	88	53000	53180	+ 180	113	57030	58600	+1570
	64	47550	46080	—1470	89	52950	54220	+1270	114	57060	57270	+ 210
	65	47060	46270	— 790	90	53380	53130	— 250	115	60870	59260	—1610
	66	47610	48070	+ 460	91	53600	54310	+ 710	116	63480	61890	—1590
	67	49010	47920	—1090	92	54950	54420	— 530	117	58970	58040	— 930
	68	47130	46930	— 200	93	52910	53880	+ 970	118	60770	60200	— 570
	69	47570	47410	— 160	94	52980	54350	+1370	119	59110	59220	+ 110
	70	47010	47610	+ 600	95	54880	55150	+ 270	120	63400	60380	—3020
	71	47300	48540	+1240	96	52750	53560	+ 810	121	63740	61510	—2230
	72	48980	48530	— 450	97	57210	59050	+1840	122	60810	61290	+ 480
	73	49770	48730	—1040	98	56980	56760	— 220	123	63110	62650	— 460
	74	49250	51320	+2070	99	54860	55420	+ 560	124	60740	60960	+ 220
	75	48830	48870	+ 40	100	60580	59850	— 730	125	60870	61920	+1050
	76	49150	49590	+ 440	101	56680	56560	— 120	126	67570	65230	—2340
	77	50880	50410	— 470	102	58790	57880	— 910	127	66480	66260	— 220
	78	49090	50380	+1290	103	55090	56550	+1460	128	67480	64750	—2730
	79	49220	50710	+1490	104	54690	56850	+2160	129	66820	64590	—2230
	80	50910	49970	— 940	105	54890	55400	+ 510	130	63600	63330	— 270
	81	51060	51050	— 10	106	56870	57680	+ 810	131	63740	64940	+1200
	82	50900	51630	+ 730	107	59110	61140	+2030	132	63470	64650	+1180
	83	51140	53540	+2400	108	57010	57640	+ 630	133	67530	66500	—1030
	84	51200	51570	+ 370	109	59110	58830	— 280	134	67560	67800	+ 240
	85	51030	52370	+1340	110	60570	58890	—1680	135	68470	69890	+1420
	86	53020	54890	+1870	111	58860	58740	— 120	136	73010	76140	+3130
	87	[illegible]	55720	+ 920	112	58970	58980	+ 10	137	77950	78710	+ 760

Phosphorus: There are thirteen acid groups containing .08 per cent. of phosphorus or more, and seven of these, 6, 10, 11, 13, 17, 28, and 31, have an error in Table XVII-S of less than 2000 pounds. Of the remainder, four groups, 4, 19, 23 and 62, give an aggregate plus error of 12,330 pounds, and two groups, 58 and 59, give a minus error of 8220 pounds. This would indicate that the value of phosphorus in the acid steels is nearly correct but that it may be a trifle too high. The basic metals contain no examples of high phosphorus, and hence the value found cannot be corroborated.

It will be found that these deductions must be materially modified on account of the investigations chronicled in Part III. In the later work the value of iron is nearly the same in acid and basic metal. This assuredly seems more in accord with reason, and gives greater force to the values found for the metalloids. The above calculation will be of interest to show how nearly an arbitrary equation can fit the case.

PART III.

EFFECT OF CARBON, MANGANESE, AND PHOSPHORUS UPON THE TENSILE STRENGTH OF IRON, AS DETERMINED BY SPECIAL MATHEMATICAL INVESTIGATIONS.

INTRODUCTORY NOTE.—A general synopsis of the argument and conclusions of both Parts II and III is given in Section XVIIw.

SEC. XVIIr.—*Values of carbon, manganese, phosphorus, and iron in a new series of acid steels.*—In the introductory note to Part II of this chapter it was stated that a second series of steels had been investigated. The method employed in the formation of the groups was the same as described in Section XVIIm, and all the details of the work were performed by the same men that conducted the previous examination. The two series, which we may call the "old" and the "new," are therefore of equal force and virtue, and the testimony of the one must always be considered in connection with the testimony of the other.

It was proven in Section XVIIo that the influence of silicon in small proportions was so slight that it did not make a satisfactory working factor for the method of least squares. The same was found true of sulphur and copper. In plotting the records of acid steel of the new series, however, it was found that the groups that contained high silicon seemed to show a greater tensile strength than steels of low silicon with the same content of carbon. As this was not the case in the old series, the groups were all put together in the former calculation, but in the light of this new evidence it would seem proper to separate them on the basis of their silicon content. This is easily done, since in both cases the high-silicon heats were put together in separate groups. In the low-silicon groups neither the total content nor the variations in this element seem sufficient to materially disturb the result.

The normal acid steels of the new series are shown in Division I of Table XVII-U, and the normal acid steels of the old series in Division II. They are both combined to give the line *AA* in Figure XVII-C.

The high-silicon steels of the new series are given in Division III, and those of the old series in Division IV. They are both combined to give the line *BB* in Figure XVII-C.

The high-manganese and high-phosphorus steels of the old series are placed in Division V, but are not shown in the diagram.

Considering only the normal acid steels of both the old and the new series, as enumerated in Divisions I and II, a calculation was made by the method of least squares to find the values for carbon, manganese, phosphorus, and iron, which would most nearly satisfy the conditions of the problem. The results are shown in Table XVII-T.

TABLE XVII-T.

Values of Carbon, Manganese, Phosphorus, and Iron, as Determined by the Method of Least Squares from the Normal Acid Steels in Divisions I and II in Tables XVII-U.

Series.	Influence of .01 per cent. in pounds per sq. inch.			
	Carbon.	Manganese.	Phosphorus.	Iron.
New series, Division I	+1126	+ 3	+ 716	+4.0439
Old series, Division II	+1368	−23	+1068	+3.7544

In the old series as originally formed, including the abnormal steels, the value of .01 per cent. of manganese was — 39 pounds. In the revised series, after omitting these groups, it is — 23 pounds, while in the new series the value deduced is + 3. It would appear, therefore, that manganese does not make a satisfactory working factor in the calculations on acid steels, while the values obtained for it, in addition to being contradictory, show that it does not have a very important influence. In the following section, therefore, I have computed a formula from carbon, phosphorus, and iron alone, and have then compared the ultimate strengths as calculated from this formula with the actual tensile tests.

SEC. XVIIs.—*Values of carbon, phosphorus, and iron in acid steel when manganese is neglected, as determined from the normal steels of the old and the new series combined.*—Considering only the normal steels as given in Table XVII-U, and omitting manganese from the problem, we shall have by the method of least squares the following equations, in which A = the influence of .001 per cent. of carbon, expressed in pounds per square inch, B = the influence of .001 per cent. of phosphorus, and C = the influence of .001 per cent. of iron.

ACID STEELS;* DIVISIONS I AND II IN TABLE XVII-U.

Equation from A; 3,227,256 A+1,065,433 B+1,676,848,333 C=1,130,441,335.
Equation from B; 1,065,433 A+488,892 B+689,328,873 C=441,177,250.
Equation from C; 1,676,848,333 A+689,328,872 B+1,043,135,334,268 C =670,977,073,970.

The solution of these equations gives the following values:

	Lbs. per sq. in.
Effect of .001 per cent. of carbon................	+ 121.6
Effect of .001 per cent. of phosphorus............	+ 88.9
Strength of pure iron..........................	38,908

There is never quite 100 per cent. of iron in any steel, so that it would not be right to take the above determination of iron as a starting point. Theoretically it would be necessary to calculate the value of iron for each separate metal, and this was done in Table XVII-N; but for practical purposes it will be assumed that structural steel contains 99.2 per cent. of iron, which by the above determination should confer a strength of 38,600 pounds per square inch for acid metal.

It then becomes practicable to write the following formula by which the strength of acid steel may be calculated when the percentages of carbon and phosphorus are known, the answer being expressed in pounds per square inch.

Acid Steel; 38600+121 Carbon+89 Phosphorus+R=Ultimate Strength.

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* The sum total of the coefficients in these equations is not quite 1,060,000,000,000, as it should be theoretically, because the factors in the old series relating to silicon, sulphur and copper have been omitted.

The unit for carbon and phosphorus is .001 per cent. The factor *R* represents an allowance for the conditions under which the piece is rolled, whether finished hot or cold. In the present series of groups it is zero.

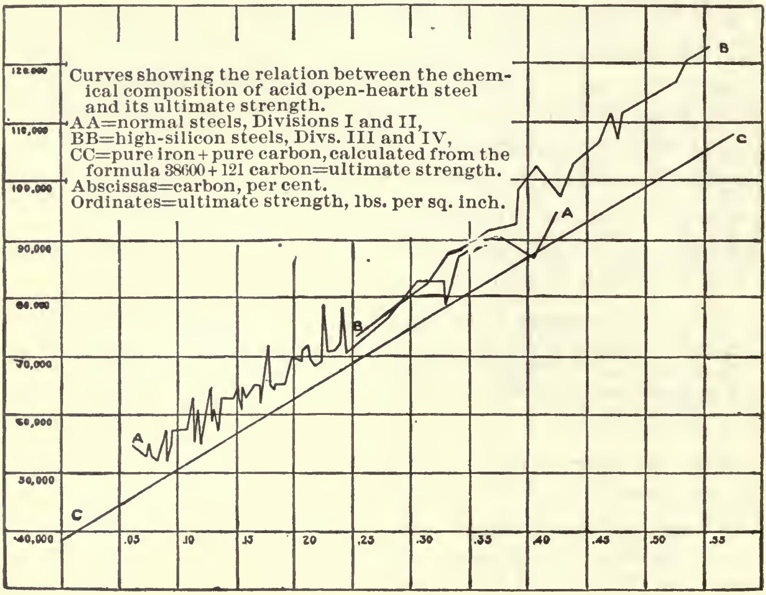

FIG. XVII-C.—CURVES SHOWING RELATION BETWEEN THE CHEMICAL COMPOSITION OF ACID OPEN-HEARTH STEEL AND ITS ULTIMATE STRENGTH AS GIVEN IN TABLE XVII-U.

In Table XVII-U this formula has been applied to all the steels, both normal and abnormal, and the differences between the actual and the calculated ultimate strength have been placed in the last column. This difference will sometimes be spoken of as the "error" in subsequent remarks, as being the discrepancy between the recorded results and those obtained by calculation. An examination of this column reveals several notable points.

First: Group 54 is entirely abnormal. It is almost identical in composition with Group 53, and yet differs from it by 4200 pounds in strength. The fact that No. 53 is an average of twelve heats and conforms to the formula, while No. 54 is an average of only four heats, points to the latter as an erratic member which has some bar-sinister in its history. Out of numerous possibilities it is only necessary to mention that one of the test-bars might have been wrongly marked. This group will be neglected in the following observations.

Second: There is a decided difference between the old and the new series. The sum of all the plus values in Division I of Table XVII-U, after omitting Group 54, is 49,310 pounds, while the sum of the plus values in Division II is only 7290 pounds. The sum of the minus values in Division I is 10,930 pounds, while in Division II it is 57,780 pounds. The individual records corroborate these totals, for in Division I there are 39 groups where the error is plus, and only 16 groups where it is minus. On the other hand, Division II furnishes only 11 groups where the error is plus, while it has 38 groups where it is minus.

This seems too decided a record to be the result of chance, yet, as before stated, the two investigations relate to steels which were made in the same furnaces and handled by the same men, while the physical and chemical determinations were made on the same apparatus and by the same operators. In the light of this evidence it is not remarkable that results from different sources are sometimes inconsistent.

Third: There are seven groups among the normal acid steels where the actual strength is more than 2000 pounds *below* the calculated, and six of the seven, Nos. 29, 36, 45, 46, 49, and 50, show no striking peculiarity. The other group, No. 55, is low in phosphorus and sulphur, and rather high in manganese.

On the other hand, there are ten groups where the actual strength is more than 2000 pounds *above* the calculated, and six of these, Nos. 90, 94, 98, 101, 104, and 105, show a high content of manganese. Of the others, No. 1 is low in manganese and high in sulphur, No. 62 is high in phosphorus, No. 67 is normal, and No. 76 is low in sulphur. Thus the only point that is gained by a review of those heats that display a difference of more than 2000 pounds between the calculated and actual strengths, is that high manganese seems to increase the tenacity. The figure 2000 pounds is chosen arbitrarily, since this seems a sufficiently close approximation to attain by any formula.

Fourth: The influence of manganese may be investigated by putting together the groups that show a similar content of this element. Thus there are twenty-nine groups that hold from .30 to .39 per

TABLE XVII-U.

List of Groups of Acid Open-Hearth Steel of Old and New Series, Used in Determining the effect of Certain Elements upon the Tensile Strength of Steel, Together with the Formula Obtained Therefrom by the Method of Least Squares.

NOTE.—All figures relating to ultimate strength are expressed in pounds per square inch.

Formula; the unit for carbon and phosphorus being .001 per cent., and the result being expressed in pounds per square inch.

38600+121 Carbon+89 Phosphorus=Ultimate Strength.

	No. of group.	No. of heats in group.	Composition; per cent.						Average ultimate strength of group.	Ultimate strength as calculated from formula.	Difference between actual and calculated ultimate strength.
			Carbon, by combustion.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Copper.			
Division I. Normal acid open-hearth steels. New series.	1	5	.061	.007	.29	.071	.069	.34	54700	52120	—2580
	2	4	.073	.009	.24	.034	.050	.18	52850	51880	— 970
	3	7	.075	.005	.27	.054	.070	.21	54880	53910	— 970
	4	5	.076	.003	.31	.052	.080	.16	55190	54920	— 270
	5	6	.078	.006	.31	.036	.057	.22	53020	53110	+ 90
	6	7	.087	.008	.33	.043	.060	.15	55470	54470	—1000
	7	9	.090	.017	.33	.062	.088	.16	57310	57320	+ 10
	8	4	.091	.006	.31	.024	.035	.08	52180	52730	+ 550
	9	5	.091	.006	.36	.027	.059	.15	54760	54860	+ 100
	10	7	.095	.005	.39	.036	.051	.18	54960	54630	— 330
	11	8	.096	.011	.25	.060	.075	.22	57200	56890	— 310
	12	11	.103	.007	.35	.077	.074	.26	57260	57650	+ 390
	13	35	.106	.007	.35	.052	.070	.20	57140	57660	+ 520
	14	18	.116	.009	.29	.055	.070	.15	58860	58870	+ 10
	15	15	.116	.005	.32	.051	.075	.18	60770	59310	—1460
	16	9	.117	.007	.39	.028	.056	.08	56950	57740	+ 790
	17	14	.117	.006	.36	.057	.090	.11	58860	60770	+1910
	18	5	.119	.005	.38	.030	.041	.14	55030	56650	+1620
	19	11	.120	.006	.37	.080	.071	.24	58920	59440	+ 520
	20	12	.121	.008	.41	.026	.065	.06	58820	59030	+ 210
	21	11	.125	.007	.41	.032	.047	.08	56960	57910	+ 950
	22	15	.125	.016	.39	.080	.076	.24	61080	60490	— 590
	23	15	.126	.005	.48	.039	.063	.26	59060	59450	+ 390
	24	49	.127	.013	.39	.055	.075	.14	60850	60640	— 210
	25	11	.128	.006	.39	.057	.095	.13	61110	62540	+1430
	26	16	.130	.009	.40	.042	.053	.10	59170	59050	— 120
	27	69	.131	.007	.38	.051	.072	.18	58940	60860	+1920
	28	14	.132	.009	.47	.053	.076	.10	61260	61340	+ 80
	29	12	.134	.009	.44	.042	.058	.05	57080	59980	+2900
	30	14	.140	.007	.41	.074	.087	.20	62910	63280	+ 370
	31	10	.143	.006	.39	.065	.099	.14	62830	64710	+1880
	32	11	.148	.006	.49	.051	.071	.13	62860	62830	— 30
	33	16	.151	.003	.40	.045	.060	.21	60920	62210	+1290
	34	12	.151	.006	.33	.055	.084	.18	63030	64350	+1320
	35	12	.152	.007	.41	.029	.072	.13	62910	63400	+ 490
	36	16	.155	.012	.41	.034	.069	.09	60940	63500	+2560
	37	40	.155	.003	.41	.051	.073	.19	62910	63850	+ 940
	38	12	.159	.011	.40	.045	.056	.17	62930	62820	— 110
	39	8	.166	.007	.42	.048	.094	.18	65430	67050	+1620
	40	8	.170	.011	.46	.035	.070	.14	64640	65400	+ 760
	41	18	.170	.012	.43	.046	.074	.17	64840	65760	+ 920
	42	8	.171	.007	.41	.065	.078	.24	65260	66230	+ 970
	43	7	.180	.004	.53	.044	.072	.12	65320	66790	+1470
	44	9	.181	.008	.45	.049	.059	.19	64830	65750	+ 920
	45	10	.184	.009	.36	.051	.073	.22	64570	67360	+2790
	46	7	.207	.009	.41	.047	.088	.12	69410	71480	+2070
	47	5	.207	.011	.57	.042	.066	.14	69950	69520	— 430

TABLE XVII-U.—Continued.

	No. of group.	No. of heats in group.	Composition; per cent.						Average ultimate strength of group.	Ultimate strength as calculated from formula.	Difference between actual and calculated ultimate strength.
			Carbon, by combustion.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Copper.			
Division I.—Contin'd. Normal acid open-hearth steels. New series.	48	5	.214	.013	.47	.068	.077	.18	69700	71350	+1650
	49	7	.218	.009	.43	.049	.070	.17	68410	71210	+2800
	50	7	.224	.008	.37	.045	.079	.09	69440	72730	+3290
	51	5	.229	.011	.50	.032	.065	.07	70810	72090	+1280
	52	5	.244	.008	.46	.038	.044	.15	70360	72040	+1680
	53	12	.330	.035	.52	.029	.039	.05	82810	82000	— 810
	54	4	.331	.018	.51	.032	.039	.03	78610	82120	+3510
	55	11	.406	.060	.54	.030	.035	.07	86990	90840	+3850
	56	4	.424	.060	.57	.031	.043	.05	94470	93730	— 740
Division II. Normal acid open-hearth steels. Old series.	57	6	.082	.006	.29	.034	.034	.12	52090	51550	— 540
	58	12	.105	.009	.38	.059	.074	.18	57380	57890	+ 510
	59	11	.109	.008	.31	.036	.066	.14	57310	57660	+ 350
	60	12	.109	.007	.38	.048	.082	.15	57430	59090	+1660
	61	38	.113	.009	.43	.038	.061	.13	57140	57700	+ 560
	62	11	.113	.007	.48	.046	.096	.18	62870	60820	—2050
	63	5	.115	.007	.49	.029	.037	.09	55450	55810	+ 360
	64	18	.115	.013	.30	.043	.069	.17	58780	58660	— 120
	65	12	.116	.005	.59	.025	.034	.10	56830	55660	—1170
	66	19	.116	.015	.50	.069	.082	.19	60870	59930	— 940
	67	9	.116	.013	.47	.057	.089	.17	62610	60560	—2050
	68	18	.117	.018	.33	.039	.073	.20	61190	59250	—1940
	69	17	.117	.005	.45	.049	.099	.16	61430	61570	+ 140
	70	19	.118	.005	.59	.030	.035	.10	56990	55990	—1000
	71	72	.118	.007	.42	.045	.075	.14	59110	59550	+ 440
	72	13	.118	.008	.56	.044	.063	.14	59350	58490	— 860
	73	15	.118	.007	.45	.064	.081	.17	59260	60090	+ 830
	74	15	.118	.014	.57	.056	.076	.18	60900	59640	—1260
	75	21	.119	.009	.42	.051	.090	.14	59310	61010	+1700
	76	15	.119	.017	.43	.028	.065	.16	61020	58780	—2240
	77	96	.119	.009	.44	.043	.077	.16	61130	59850	—1280
	78	19	.123	.014	.44	.030	.063	.16	59110	59090	— 20
	79	6	.129	.008	.49	.050	.118	.16	65020	64710	— 310
	80	11	.131	.012	.47	.033	.051	.13	60690	58990	—1700
	81	13	.134	.015	.48	.035	.045	.15	58820	58820	. . . .
	82	12	.138	.021	.36	.041	.077	.14	62940	62150	— 790
	83	38	.140	.016	.48	.042	.077	.18	62890	62390	— 500
	84	10	.143	.006	.39	.045	.086	.20	64880	63560	—1320
	85	10	.147	.012	.54	.024	.056	.16	63210	61370	—1840
	86	12	.151	.012	.64	.033	.051	.13	62650	61410	—1240
	87	7	.151	.005	.49	.055	.083	.16	64950	64700	— 250
	88	12	.156	.003	.57	.035	.070	.17	65180	63710	—1470
	89	8	.171	.011	.63	.026	.036	.10	62850	62500	— 350
	90	4	.178	.008	1.00	.043	.076	.14	71930	66900	—5030
	91	8	.183	.014	.68	.030	.027	.10	65100	63150	—1950
	92	9	.185	.008	.76	.028	.038	.13	65590	64370	—1220
	93	6	.193	.009	.67	.020	.036	.10	65280	65160	— 120
	94	5	.198	.013	.61	.032	.060	.14	69970	67900	—2070
	95	8	.207	.012	.79	.045	.067	.15	71210	69610	—1600
	96	8	.212	.010	.82	.039	.073	.14	71870	70750	—1120
	97	4	.213	.012	.70	.019	.046	.14	69750	68470	—1280
	98	5	.225	.015	.99	.048	.077	.22	78700	72680	—6020
	99	5	.235	.016	.75	.027	.037	.14	71170	70330	— 840
	100	12	.240	.009	.76	.030	.054	.14	72320	72450	+ 130
	101	7	.242	.010	.86	.049	.076	.19	78020	74650	—3370
	102	6	.282	.009	.66	.033	.053	.16	76830	77440	+ 610
	103	6	.282	.010	.77	.023	.043	.14	76940	76550	— 390
	104	7	.306	.010	.79	.034	.050	.09	82680	80080	—2600
	105	11	.341	.020	.85	.034	.045	.11	86980	83870	—3110
	106	8	.374	.030	.83	.035	.057	.12	90750	88930	—1820

TABLE XVII-U.—Continued.

	No. of group.	No. of heats in group.	Composition; per cent.						Average ultimate strength of group.	Ultimate strength as calculated from formula.	Difference between actual and calculated ultimate strength.
			Carbon, by combustion.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Copper.			
Division III. High-silicon acid open-hearth steels. New series.	107	14	.253	.150	.55	.026	.033	.03	73710	72150	— 1560
	108	7	.316	.200	.65	.025	.033	.06	82240	79770	— 2470
	109	7	.342	.190	.61	.020	.029	.04	87860	82560	— 5300
	110	7	.366	.170	.60	.022	.028	.04	91580	85380	— 6200
	111	9	.392	.210	.63	.022	.029	.06	98180	88610	— 9570
	112	9	.408	.230	.70	.021	.029	.04	102430	90550	—11880
	113	9	.461	.230	.64	.021	.029	.05	106560	96960	— 9600
	114	7	.470	.230	.65	.021	.031	.07	111830	98230	—13600
	115	7	.535	.200	.72	.022	.030	.07	120590	106010	—14580
Division IV. High-silicon acid open-hearth steels. Old series.	116	7	.333	.220	.65	.026	.041	.08	87410	82540	— 4870
	117	14	.390	.220	.68	.023	.034	.08	92630	88820	— 3810
	118	17	.428	.220	.65	.023	.036	.08	97270	93590	— 3680
	119	16	.438	.220	.69	.026	.033	.13	102900	94540	— 8360
	120	14	.477	.240	.69	.025	.030	.08	107300	98990	— 8310
	121	20	.480	.230	.69	.022	.032	.06	111740	99530	—12210
	122	10	.527	.250	.72	.027	.032	.07	116980	105220	—11760
	123	10	.554	.230	.68	.022	.032	.09	122950	108480	—14470
Div. V. High-manganese and high-phosphorus acid open-hearth steels. Old series.	124	13	.480	.090	1.12	.044	.106	.19	121210	106110	—15100
	125	18	.507	.061	1.19	.047	.110	.18	126800	109740	—17060
	126	9	.555	.090	1.13	.042	.109	.19	123620	115460	— 8160

cent. Nineteen of these have a plus error with a total of 21,650 pounds, while ten groups have a minus error with a total of 8,030 pounds. The difference between these totals, or rather their algebraic sum, is + 13,620, which, divided by twenty-nine, gives the average error for one group. Table XVII-V has been constructed by this process of differential synthesis for each increment of manganese, Group No. 54 being omitted for reasons given above.

TABLE XVII-V.

Average Error of Groups in Table XVII-U Arranged According to their Manganese Content.

Manganese; per cent.		No of heats	Total minus error.	Total plus error	Net error.	Average error
Limits.	Average.					
.20 to .29	.27	6	— 5370	+ 10	— 5360	— 893
.30 to .39	.36	29	— 8030	+21650	+13620	+ 470
.40 to .49	.44	38	—10660	+27600	+16940	+ 446
.50 to .59	.55	13	—10520	+ 6600	— 3920	— 301
.60 to .69	.65	6	— 5730	+ 610	— 5120	— 853
.70 to .79	.76	7	— 7930	+ 130	— 7800	—1114
.80 to .89	.84	4	— 9420	. . . . . .	— 9420	—2355
.99 to 1.00	1.00	2	—11050	. . . . . .	—11050	—5525

It should be noted that most of the groups that contain high manganese are in Division II, and it has been remarked that there is some occult cause why the actual strengths of this division are slightly above the formula. The error arising from this condition is not sufficient to invalidate the records, but when most of the members of the division are slightly above the formula it is not extraordinary if the high-manganese groups follow the rule.

Passing over this reasoning, the table teaches that in steels containing about .25 per cent. of manganese, the actual ultimate strength is 893 pounds *greater* than would be indicated by the formula. With an increase in the content to .36 per cent. the actual strength is 470 pounds *less* than the formula, and with .44 per cent. it is 446 pounds *less*. From this point an increase in manganese gives an increase in strength.

It is important to notice that the figures + 446 for .44 per cent. of manganese, and+470 for .36 per cent., are consistent with the minus values for the higher percentages, since manganese was entirely omitted in the derivation of the formula, and the result may therefore be looked upon as strictly applicable only to the average content of an element which it neglects; and if such an element does have an effect, it should make itself evident in a plus error on one side of the average and a minus error on the other.

This reasoning, however, is inconsistent with the fact that manganese did not make a good working factor in the method of least squares. This inconsistency is explained by the values obtained in the first three lines of Table XVII-V. With a content of .27 per cent., the actual strength is more than the calculated, and this is directly opposed to the law of higher strength with higher manganese. Moreover, the figure for .36 per cent. is practically the same as that for .44 per cent., being + 470 in one case and + 446 in the other. Considering the fact that three-quarters of all groups were below .50 per cent. in manganese, and that the results on such metal were indecisive, it is not strange that manganese did not form a proper determinative member of the equations.

It is indicated, therefore, that with less than .50 per cent. of manganese the effect is not so uniformly marked as with larger proportions. Whether this is due to the different physical or molecular condition of soft metal, or to the presence of oxide of iron, or whether it arises from abnormality of the steels, or determinative errors in the records, cannot be satisfactorily demonstrated.

The results, as a whole, justify the use of a formula for normal acid steels without any factor representing manganese. With contents above .60 per cent. of this element, it is necessary to make allowance for an increased strength, while above .80 per cent. the tenacity will rapidly increase.

It may also be necessary to allow for a very low content of manganese, since it was found in Table XVII-V that when there is less than .30 per cent. the actual strength was 893 pounds more than was indicated by the formula. This fact will be considered in Section XVIIv in connection with other information from the basic steels.

Fifth: The high-silicon steels all show a much greater strength than is given by the formula. The natural inference would be that silicon strengthens steel, but it is necessary to notice a curious and important fact, *viz.*, that the differences between the calculated and actual strength vary in proportion to the content of carbon, and not in proportion to the content of silicon.

In the new series, as given in Division III, the lowest carbon is .253 per cent., and the error is 1560 pounds. As the carbon increases to .316 per cent., the error rises to 2470 pounds, and with .342 per cent. it is 5300 pounds. The old series starts at .333 per cent. as the lowest carbon, and the error is 4870 pounds, so that the two series agree perfectly at the starting point. They also agree at their highest point, for the maximum carbon is .535 per cent. in the new series, and .554 in the old, the error being 14,580 pounds in one case and 14,470 in the other. Between these two extremes there are considerable variations, but in the main the law holds good that the error steadily rises with higher carbon.

A glance at the table will show that the content of silicon is practically constant throughout both series, and hence it is mathematically impossible to find any constant value for this element which will account for the variations in ultimate strength. In explanation of this it may be urged that the formula by which the strength is calculated gives a wrong value to carbon.

The answer to this criticism will be found in the line *CC* in Figure XVII-C. The most casual inspection will show that this line is very nearly parallel to the trend of the line *AA*. It is impossible to decide exactly what that trend is, but the line *CC* seems to follow the average direction as near as it can be estimated. If any criticism were to be made, it would be that the tangent of *CC* was too great rather than too small. Bearing in mind that the carbon determines the tangent of these lines, and that the linear distance between them represents the effect of the other metalloids, it will be seen that the graphic delineation bears almost conclusive proof of the mathematical deductions.

The general trend of the line *BB* in Figure XVII-C, which represents the high-silicon steels, forms a decidedly greater tangent to the horizontal axis than the line *AA* or its counterpart *CC*, and it would be impossible to draw a line which would be parallel to the trend of *BB*, and which at the same time would be parallel to the trend of *CC*, and since it has been remarked that the tangent of *CC* is fully as great as it can be to fall parallel to *AA*, and is possibly a step beyond, it will be evident that a different law is indicated for the metals with high silicon.

This law may be stated in two different ways:

First: That a constant percentage of silicon exerts a greater effect with each increment of carbon.

Second: That when a constant percentage of silicon is present, each increment of carbon exerts a greater influence.

It will be granted that this law has an upper limit, since the ultimate strength does not increase after a certain content of carbon is attained. It also appears that there is a lower limit, for, by referring again to Figure XVII-C, it will be seen that the line *BB* joins *AA* at a point corresponding to about .25 per cent. of carbon, and it is therefore indicated that silicon has very little effect below this point, even when present in considerable proportions.

These high-silicon groups were all composed of heats made for steel castings, and it seems possible that the different conditions of casting temperature might exert an influence on the result. If this were true, it would also seem as if soft steel, made for castings, should show different physical properties from heats made in the ordinary way. Such does not seem to be the case, for Groups 9, 16, 20, 23, 85, 86, 89, 91, 92, 93, and 99, were composed almost entirely of casting heats, and yet conform very closely to the formula.

Sixth: The influence of sulphur has not been taken into account in the formula, and accordingly an investigation was made on the steels of Divisions I and II of Table XVII-U by the same process of synthetical differentiation that was used to discover the effect of manganese in Table XVII-V, Group No. 54 being omitted as before. The results are given herewith, it being evident that no law is indicated.

16	groups bet.	.019	and	.03	per cent.	sulphur	gave an	average	error of	—485	lbs.
30	"	.03	"	.04	"	"	"	"	"	—260	"
27	"	.04	"	.05	"	"	"	"	"	—188	"
20	"	.05	"	.06	"	"	"	"	"	+319	"
7	"	.06	"	.07	"	"	"	"	"	+584	"
5	"	.07	"	.081	"	"	"	"	"	—378	"

Seventh: A similar table, which is given on the following page, shows the average error for the different percentages of phosphorus. As there seems to be no law of error, the value given to phosphorus is probably approximately true.

The foregoing conclusions are summarized in Section XVIIw in connection with a similar study of basic steel.

1	group bet.	.02	and	.03	per cent.	phosphorus	gave an	av.	error of	—1950	lbs.
11	"	.03	"	.04	"	"	"	"	"	— 117	"
8	"	.04	"	.05	"	"	"	"	"	— 159	"
16	"	.05	"	.06	"	"	"	"	"	— 324	"
16	"	.06	"	.07	"	"	"	"	"	— 268	"
34	"	.07	"	.08	"	"	"	"	"	— 173	"
11	"	.08	"	.09	"	"	"	"	"	+ 130	"
7	"	.09	"	.10	"	"	"	"	"	+ 947	"
1	"	.11	"	.12	"	"	"	"	"	— 310	"

SEC. XVIIt.—*Values of carbon, manganese, phosphorus, and iron in a new series of basic steels.*—The steels considered in Sections XVIIr and XVIIs were all made by the acid process, but at the same time that they were under investigation, similar series of basic steels were being studied. The groups were formed in the same way as described in Section XVIIm, and a list of them is given in Division I of Table XVII-N, while the old series of basic steels is shown in Division II. The numbers given to the groups are continuous with those in Tables XVII-U to avoid confusion in references. The members of both series are combined to give Curve *AA* in Fgure XVII-D.

TABLE XVII-W.

Values of Carbon, Manganese, Phosphorus, and Iron, as Determined by the Method of Least Squares from the Basic Steels in Divisions I and II of Table XVII-X.

Series.	Influence of .01 per cent. in pounds per square inch.			
	Carbon.	Manganese.	Phosphorus.	Iron.
New series, Division I,	+ 935	+114	+939	+3.6335
Old series, Division II,	+1035	+ 53	+941	+3.8996

The solution of the new series by the method of least squares is given in the first column of Table XVII-W, while the second column shows, for comparison, the determinations on the old series of basic steels as given in Table XVII-N.

The results indicate that manganese has a decided strengthening effect upon basic steel, although it was found that in the case of acid steel no positive relation could be proven. This conclusion is corroborated by a calculation which was made by combining the old and new series, and solving the resultant equations by the method of least squares, without taking any account of manganese as a factor. In the case of acid steel this process gave a satisfactory formula, but in the basic steel it gave the following results:

.01 per cent. of carbon=+998 pounds.
.01 per cent. of phosphorus=+1444 pounds.
Pure iron=39,987 pounds.

This value of phosphorus is not sustained by any other evidence. Referring to Table XVII-W, it will be seen that the corresponding figure was + 939 for the new series, and + 941 for the old series. Thinking that there might be a clerical error, the solution was repeated in reverse order, as described on page 494, but the answers were found to be mathematically correct to five places.

This high value of phosphorus, when manganese is omitted, may be explained in the following way:

(1) It has been shown that carbon is self-determining in every series investigated, and that it gives fairly accurate results.

(2) The iron is less self-determining, but with basic metal, where some groups are so nearly pure iron, the chance for variations in this factor is less than in the case of acid steel.

(3) It is evident, therefore, that if manganese is a positive factor, and if it is neglected, its effect must be forced upon some other factor by the method of least squares, and phosphorus is the only factor available.

(4) The responsibility falls on phosphorus rather than on carbon, because the variations in phosphorus are very small and it is therefore less self-determining than carbon, and less than in acid steel where it is present in large proportions.

SEC. XVIIu.—*Values of carbon, manganese, phosphorus, and iron in basic steel, as determined from the old and the new series combined.* Accepting as proven the conclusion of the foregoing section that manganese has a decided influence upon the tensile

TABLE XVII-X.

List of Groups of Basic Open-Hearth Steels of Old and New Series, used in Determining the Effect of Certain Elements upon the Tensile Strength of Steel, Together with the Formula obtained therefrom by the Method of Least Squares.

NOTE.—All figures relating to ultimate strength are expressed in pounds per square inch. The group numbers are made continuous with those of Table XVII-U to avoid confusion in references.

Formula: the unit for carbon, manganese, and phosphorus being .001 per cent., and the result being expressed in pounds per square inch.

37430+95 Carbon+8.5 Manganese+105 Phosphorus = Ultimate Strength.

	Number of group.	Number of heats in group.	Composition, per cent.						Average ultimate strength of group.	Ultimate strength as calculated from formula.	Difference between actual and calculated ultimate strength.
			Carbon, by combustion.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Copper.			
Division I; new series.	127	6	.051	.008	.25	.027	.008	.06	46630	45240	—1390
	128	13	.058	.007	.26	.036	.012	.10	48900	46410	—2490
	129	11	.062	.007	.38	.059	.019	.05	50640	48550	—2090
	130	10	.063	.017	.41	.046	.032	.06	50860	50260	— 600
	131	15	.069	.003	.39	.053	.013	.08	49030	48660	— 370
	132	6	.070	.006	.36	.050	.009	.08	47360	48090	+ 730
	133	7	.071	.008	.44	.038	.009	.08	47720	48860	+1140
	134	14	.071	.003	.50	.037	.012	.06	49060	49680	+ 620
	135	7	.072	.003	.34	.021	.008	.07	46670	48000	+1330
	136	42	.072	.005	.38	.037	.011	.08	48990	48660	— 330
	137	14	.074	.007	.38	.034	.021	.07	49280	49900	+ 620
	138	11	.079	.007	.33	.030	.007	.05	46950	48470	+1520
	139	17	.081	.006	.37	.035	.011	.08	47320	49420	+2100
	140	12	.081	.004	.42	.032	.007	.07	49070	49430	+ 360
	141	15	.082	.007	.38	.020	.011	.11	49150	49600	+ 450
	142	33	.082	.004	.43	.028	.014	.08	50770	50350	— 420
	143	13	.087	.006	.53	.036	.017	.10	51010	51980	+ 970
	144	12	.087	.006	.28	.030	.015	.08	51290	49650	—1640
	145	13	.101	.005	.40	.027	.007	.08	50710	51160	+ 450
	146	9	.102	.005	.37	.018	.010	.12	51090	51310	+ 220
	147	10	.105	.020	.53	.032	.012	.07	52970	53170	+ 200
	148	8	.106	.019	.41	.036	.036	.06	53130	54760	+1630
	149	9	.118	.008	.41	.048	.014	.10	52990	53590	+ 600
	150	17	.119	.005	.36	.034	.015	.09	52930	53370	+ 440
	151	10	.125	.009	.38	.030	.008	.10	52750	53380	+ 630
	152	10	.127	.009	.43	.019	.010	.06	52980	54200	+1220
	153	8	.128	.006	.28	.035	.017	.07	53070	53760	+ 690
	154	12	.128	.012	.51	.035	.022	.08	54930	56230	+1300
	155	9	.131	.014	.41	.039	.033	.08	54870	56830	+1960
	156	13	.136	.003	.40	.040	.031	.09	57000	57000	+ . .
	157	12	.144	.004	.30	.037	.013	.10	55260	55030	— 230
	158	12	.147	.004	.38	.055	.019	.08	55100	56620	+1520
	159	24	.155	.006	.37	.034	.015	.08	55000	56870	+1870
	160	13	.162	.010	.30	.029	.017	.12	57060	57160	+ 100
	161	38	.164	.032	.38	.034	.015	.08	57020	57810	+ 790
	162	12	.165	.009	.41	.051	.021	.11	57220	58800	+1580
	163	9	.166	.007	.39	.032	.008	.07	55080	57360	+2280
	164	13	.169	.002	.51	.036	.018	.07	57070	59710	+2640
	165	13	.170	.008	.36	.019	.013	.09	55250	58000	+2750
	166	12	.170	.003	.36	.019	.012	.13	57210	57900	+ 690
	167	13	.170	.003	.42	.043	.040	.07	61070	61770	+ 700
	168	10	.175	.007	.41	.041	.029	.08	59060	60580	+1520
	169	11	.176	.009	.38	.052	.024	.10	58970	59900	+ 930
	170	10	.177	.008	.48	.034	.019	.08	59280	60320	+1040
	171	43	.179	.014	.38	.032	.014	.10	58970	59140	+ 170

TABLE XVII-X.—Continued.

	Number of group.	Number of heats in group.	Composition; per cent.						Average ultimate strength of group.	Ultimate strength as calculated from formula.	Difference between actual and calculated ultimate strength.
			Carbon, by combustion.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Copper.			
Division I, continued; new series.	172	13	.183	.004	.36	.030	.008	.13	57350	58710	+1360
	173	13	.187	.004	.46	.054	.030	.07	60940	62250	+1310
	174	13	.188	.013	.30	.031	.015	.10	58900	59420	+ 520
	175	15	.192	.004	.39	.020	.013	.08	58900	60350	+1450
	176	13	.194	.004	.39	.019	.014	.09	60860	60640	— 220
	177	13	.194	.007	.51	.040	.023	.06	61340	62610	+1270
	178	8	.195	.004	.38	.024	.008	.08	59000	60020	+1020
	179	38	.202	.010	.42	.033	.016	.09	60740	61870	+1130
	180	10	.204	.006	.54	.039	.025	.11	63700	64020	+ 320
	181	15	.208	.005	.47	.038	.035	.07	63530	64860	+1330
	182	13	.209	.007	.47	.053	.024	.06	63220	63800	+ 580
	183	17	.214	.007	.42	.030	.008	.07	60860	62170	+1310
	184	38	.214	.004	.43	.031	.017	.11	63130	63200	+ 70
	185	7	.217	.009	.59	.039	.025	.07	68140	65680	—2460
	186	11	.219	.007	.32	.027	.016	.10	60790	62630	+1840
	187	12	.220	.006	.40	.018	.015	.08	63560	63300	— 260
	188	7	.229	.007	.49	.039	.043	.07	67770	67870	+ 100
	189	10	.233	.009	.47	.032	.007	.09	66330	64300	—2030
	190	9	.234	.007	.40	.030	.008	.08	63400	63900	+ 500
	191	10	.245	.009	.33	.028	.019	.13	63290	65500	+2210
	192	8	.248	.006	.40	.033	.018	.08	66220	66280	+ 60
	193	8	.252	.006	.50	.050	.026	.08	67090	68350	+1260
	194	20	.255	.010	.50	.035	.020	.10	67340	68000	+ 660
	195	10	.257	.007	.45	.019	.015	.08	66920	67250	+ 330
	196	5	.297	.007	.50	.037	.021	.07	71360	72100	+ 740
	197	6	.301	.005	.65	.029	.017	.08	76890	73340	—3550
Division II; old series.	198	6	.025	.005	.04	.024	.009	.08	46420	41090	—5330
	199	4	.045	.006	.27	.045	.010	.11	47550	45050	—2500
	200	4	.050	.009	.33	.026	.007	.19	47060	45720	—1340
	201	4	.050	.005	.36	.031	.022	.15	47610	47550	— 60
	202	16	.052	.012	.35	.054	.019	.14	49010	47340	—1670
	203	6	.055	.015	.34	.019	.008	.10	47130	46380	— 750
	204	7	.055	.005	.22	.030	.012	.14	47570	45790	—1780
	205	12	.058	.005	.34	.029	.011	.14	47010	46980	— 30
	206	8	.061	.006	.46	.025	.016	.14	47300	48820	+1520
	207	18	.062	.008	.21	.036	.015	.12	48980	46680	—2300
	208	6	.065	.008	.36	.080	.014	.18	49770	48130	—1640
	209	17	.070	.013	.35	.034	.031	.14	49250	50310	+1060
	210	22	.074	.005	.36	.023	.007	.13	48830	48260	— 570
	211	19	.074	.009	.39	.018	.013	.10	49150	49140	— 10
	212	13	.076	.011	.41	.062	.018	.18	50880	50030	— 850
	213	94	.078	.003	.38	.031	.016	.11	49090	49750	+ 660
	214	15	.081	.005	.54	.031	.016	.13	49220	51400	+2180
	215	17	.083	.005	.42	.029	.008	.13	50910	49720	—1190
	216	16	.083	.006	.57	.035	.017	.11	51060	51950	+ 890
	217	26	.084	.009	.25	.033	.021	.14	50900	49740	—1160
	218	23	.085	.014	.38	.032	.036	.14	51140	52520	+1380
	219	21	.090	.006	.40	.018	.015	.10	51200	50950	— 250
	220	121	.093	.006	.40	.032	.019	.13	51030	51660	+ 630
	221	17	.093	.006	.40	.038	.040	.16	53020	53860	+ 840
	222	21	.094	.011	.43	.036	.046	.18	54800	54840	+ 40
	223	14	.096	.007	.44	.065	.023	.16	53000	52700	— 300
	224	19	.099	.012	.28	.035	.029	.16	52950	52260	— 690
	225	14	.100	.009	.66	.029	.019	.15	53380	54540	+1160
	226	5	.102	.010	.47	.087	.027	.15	53600	53950	+ 350
	227	15	.103	.013	.44	.064	.027	.13	54950	53790	—1160
	228	15	.108	.008	.42	.019	.018	.11	52910	53150	+ 240
	229	125	.109	.010	.43	.031	.021	.12	52980	53640	+ 660
	230	103	.112	.005	.42	.034	.025	.16	54880	54260	— 620
	231	23	.115	.009	.43	.031	.009	.13	52750	52960	+ 210
	232	13	.117	.007	.46	.035	.053	.13	57210	58020	+ 810
	233	15	.118	.014	.49	.057	.033	.14	56980	56270	— 710
	234	18	.120	.004	.43	.018	.020	.12	54860	54590	— 270

TABLE XVII-X.—Continued.

	Number of group.	Number of heats in group.	Composition, per cent.						Average ultimate strength of group.	Ultimate strength as calculated from formula.	Difference between actual and calculated ultimate strength.
			Carbon, by combustion.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Copper.			
Division II, continued; old series.	235	7	.121	.008	.54	.032	.056	.14	60580	59400	—1180
	236	11	.125	.012	.67	.038	.025	.13	56680	57620	+ 940
	237	10	.125	.019	.54	.060	.036	.11	58790	57680	—1110
	238	16	.126	.008	.62	.028	.024	.14	55090	57190	+2100
	239	19	.131	.908	.30	.029	.022	.13	54690	54730	+ 40
	240	20	.132	.006	.39	.027	.009	.13	54890	54230	— 660
	241	63	.132	.010	.47	.033	.028	.19	56870	56900	+ 30
	242	9	.134	.016	.51	.036	.055	.11	59110	60270	+1160
	243	15	.136	.009	.31	.029	.024	.13	57010	55500	—1510
	244	11	.137	.020	.72	.037	.033	.18	59110	60030	+ 920
	245	6	.142	.017	.53	.058	.029	.12	60570	58470	—2100
	246	10	.144	.008	.50	.020	.026	.12	58860	58090	— 770
	247	37	.144	.015	.52	.034	.028	.13	58970	58470	— 500
	248	14	.146	.015	.44	.019	.023	.11	57030	57460	+ 430
	249	21	.147	.005	.43	.027	.011	.10	57060	56200	— 860
	250	7	.151	.016	.68	.029	.024	.18	60870	60080	— 790
	251	9	.152	.008	.64	.034	.045	.17	63480	62040	—1440
	252	10	.153	.011	.46	.027	.012	.10	58970	57130	—1840
	253	13	.153	.008	.53	.034	.030	.16	60770	59620	—1150
	254	12	.155	.012	.39	.029	.026	.12	59110	57570	—1540
	255	6	.158	.012	.82	.032	.027	.17	63400	62250	—1150
	256	8	.164	.018	.57	.046	.031	.16	63740	61110	—2630
	257	7	.173	.009	.53	.021	.021	.11	60810	60570	— 240
	258	11	.180	.012	.56	.029	.026	.15	63110	62020	—1090
	259	10	.181	.006	.48	.031	.011	.10	60740	59860	— 880
	260	8	.181	.011	.37	.028	.019	.07	60870	59770	—1100
	261	5	.185	.039	.72	.049	.043	.11	67570	65640	—1930
	262	5	.190	.008	.72	.037	.047	.17	66480	66530	+ 50
	263	5	.196	.025	.86	.032	.029	.17	67480	66400	—1080
	264	10	.199	.012	.62	.030	.025	.12	66820	64230	—2590
	265	7	.204	.007	.45	.028	.010	.12	63600	61690	—1910
	266	8	.210	.010	.53	.020	.018	.13	63740	63770	+ 30
	267	6	.215	.005	.42	.024	.011	.16	63470	62580	— 890
	268	6	.231	.029	.36	.025	.012	.12	67530	63700	—3830
	269	5	.233	.008	.49	.020	.021	.13	67560	65940	—1620
	270	5	.260	.060	.31	.025	.014	.10	68470	66230	—2240
	271	5	.311	.080	.44	.029	.020	.07	73010	72820	— 190
	272	5	.338	.025	.62	.026	.017	.10	77950	76600	—1350

BASIC STEELS;* DIVISIONS I AND II, TABLE XVII-X

Equation from carbon; 3,503,736 A + 9,353,710 B + 423,710 C + 2,049,800,569 D = 1,230,544,020.

Equation from manganese; 9,353,710 A + 29,555,000 B + 1,350,180 C + 6,301,464,560 D = 3,660,255,100.

Equation from phosphorus; 423,710 A + 1,350,180 B + 74,634 C + 290,433,400 D = 169,202,400.

Equation from iron; 2,049,800,569 A + 6,301,464,560 B + 290,433,410 C + 1,439,974,511,304 D = 822,329,462,810.

The solution of these equations gives the following values:

	Lbs. per sq. in.
Effect of .001 per cent. of carbon	+ 94.9
Effect of .001 per cent. of manganese	+ 8.5
Effect of .001 per cent. of phosphorus	+ 105.4
Strength of pure iron	37733

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* The sum total of the coefficients in these equations is not quite 1,460,000,000,000, as it should be theoretically, because the factors in the old series relating to silicon, sulphur, and copper, have been omitted.

strength of basic steel, the groups of both the new and the old series as given in Division I and II of Table XVII-X were combined, the resultant equations being given at the foot of page 519, in which $A =$ the influence of .001 per cent. of carbon, $B =$ the influence of .001 per cent. of manganese, $C =$ the influence of .001 per cent. of phosphorus, and $D =$ the influence of .001 per cent. of iron.

Following the same line of argument as in acid steels, it is necessary to make allowance for the fact that there is never 100 per cent. of iron in any steel. The figure 99.2 per cent. was taken as a basis in Section XVIIs, and it will also be taken in the present case. It is true that the phosphorus is generally lower in basic steel, but, on the other hand, the carbon is usually higher. On this assumption the strength given by the iron itself in an average basic steel will be 37,430 pounds per square inch.

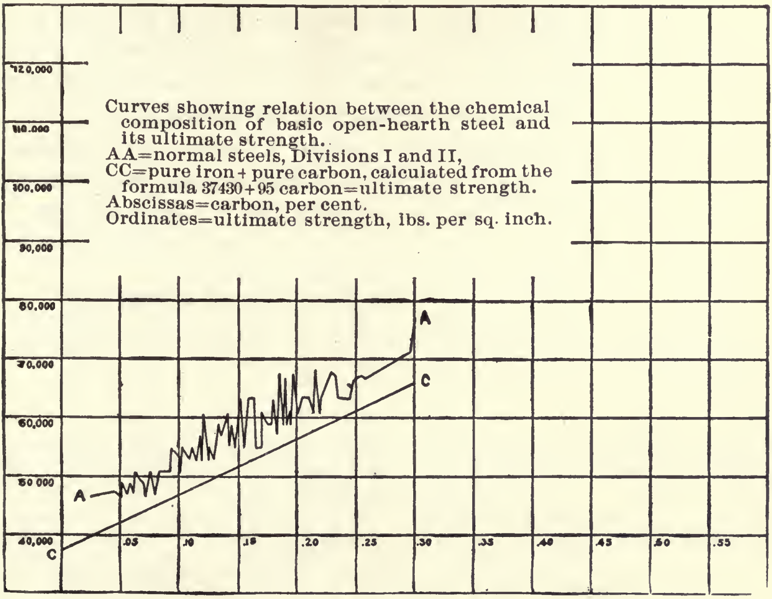

FIG. XVII-D.—CURVES SHOWING RELATION BETWEEN THE CHEMICAL COMPOSITION OF BASIC OPEN-HEARTH STEEL AND ITS ULTIMATE STRENGTH AS SHOWN IN TABLE XVII-X.

Constructing a formula in the same way as for acid metal, we have the following, the answer being expressed in pounds per square inch.

37,430+95 Carbon+8.5 Manganese+105 Phosphorus+R=Ultimate Strength.

The factor *R* represents an allowance for the conditions under which the piece is rolled, whether finished hot or cold. In the present series of groups it is zero. In each case the unit is .001 per cent., but since manganese is seldom determined beyond two decimal points, it will be convenient in calculation to use a unit of .01 per cent, and a value of 85 pounds per unit, but it would be very confusing to so write the formula.

In Table XVII-X this formula has been applied to the basic steels of the old and the new series, and the differences between the actual and the calculated ultimate strengths have been placed in the last column. An inspection of these differences or "errors" as they have been called, brings to light one or two points of interest.

First: The difference, which was found between the two series of normal acid steels, exists also between the two series of basic products. In Division I there are fifty-six groups that give a plus error, with a total of 57,130 pounds, while there are only fourteen groups that are minus, with a total of 18,080 pounds.

On the other hand, Division II offers only 24 groups having a plus error, with a total of 18,330 pounds, while it has 51 groups with a total minus error of 65,350 pounds. The net error of Division I is +39,050 pounds, and that of Division II is —47,020 pounds. The reason for this difference is unknown.

Second: An investigation was made into the effect of manganese in the same way as was done for acid steel in Table XVII-V, and the results are shown in Table XVII-Y.

TABLE XVII-Y.

Average Error of Groups in Table XVII-X, Arranged According to their Manganese Content.

Manganese; per cent.		Number of heats.	Total minus error.	Total plus error.	Net error.	Average error.
Limits.	Average.					
.20 to .29	.26	9	—13950	+ 690	—13260	—1473
.30 to .39	.36	47	—20190	+30680	+10490	+ 223
.40 to .49	.43	52	—16850	+24680	+ 7830	+ 151
.50 to .59	.53	24	—13230	+14240	+ 1010	+ 42
.60 to .69	.65	8	— 9720	+ 4200	— 5520	— 690
.70 to .79	.72	3	— 1930	+ 970	— 960	— 320
.80 to .89	.84	2	— 2230	....	— 2230	—1115

There is no such regular progression as was shown in the former case. This is readily explained by the fact that manganese is given a value as part of the formula, and it is indicated that the value determined must be a very close approximation to the truth.

In the case of the steels containing between .20 and .29 per cent. manganese, the actual strength is 1473 pounds above the calculated. This will be again referred to in Section XVIIv.

Third: The influence of sulphur was investigated in the same way as manganese. The results, given herewith, agree with those found from acid steel, in showing that sulphur exerts no regular influence upon the tensile strength.

13	groups	bet.	.01	and	.02	per cent.	sulphur	gave an	av.	error of	+ 317	lbs.
37	"	"	.02	"	.03	"	"	"	"	"	— 598	"
69	"	"	.03	"	.04	"	"	"	"	"	+ 251	"
9	"	"	.04	"	.05	"	"	"	"	"	— 397	"
12	"	"	.05	"	.06	"	"	"	"	"	+ 81	"
4	"	"	.06	"	.07	"	"	"	"	"	— 855	"
2	"	"	.08	"	.09	"	"	"	"	"	— 645	"

Fourth: A similar table, which is here given, shows the average error for the different percentages of phosphorus. This is done as corroborative evidence that the value of phosphorus in the formula is correct, for it may be assumed that if the value was too high or too low, the fact would be made manifest by a large error in the groups containing either high or low phosphorus. The fact that no regular relation exists seems to indicate that the deduced value is practically correct.

21	groups bet.	.00	and	.01	per cent.	phosphorus	gave an	av.	error of	— 20	lbs.
63	"	.01	"	.02	"	"	"	"	"	— 56	"
39	"	.02	"	.03	"	"	"	"	"	— 168	"
13	"	.03	"	.04	"	"	"	"	"	+ 261	"
7	"	.04	"	.05	"	"	"	"	"	— 234	"
3	"	.05	"	.06	"	"	"	"	"	+ 263	"

SEC. XVIIv.—*Meaning of the term "pure iron."*—In the foregoing investigation, a slightly different value was found for "pure iron" as derived from acid steels, and "pure iron" as derived from basic metal. This contradiction is solely a matter of words. Absolutely pure iron never has been, and, in all probability never will be made. The steels given in Table XVII-M are about as near to pure iron as can be found. Heat No. 4932 in that table contains .011 per cent. of phosphorus, .04 per cent. of manganese, .029 per cent. of sulphur, and .04 per cent. of copper. The carbon was not determined by combustion, but it must have been about the same as the average sample of the six heats, which was .025 per cent. This would leave a total content of impurities of 00.145 per cent. If copper is omitted from the total, as having no appreciable effect, the total will be 00.105 per cent.

Notwithstanding this purity, the tensile strength of this heat is 46,480 pounds, which is practically the same as the average of the group. The great strength of this metal, as compared with steel containing a larger proportion of impurity, has already been discussed in Section XVII-R, but must again be considered here.

It is easy to imagine that oxide of iron is present in this decarburized and dephosphorized product, and that it may confer an abnormal cohesive power. This supposition is corroborated by Tables XVII-V and XVII-Y, which indicate that both acid and basic steels, when low in manganese, are somewhat stronger than would be accounted for by their content of carbon and phosphorus, and it will be acknowledged that such steel holds a considerable quantity of oxygen.

It is true that these abnormal metals may contain unusual proportions of certain substances like hydrogen, nitrogen, or carbonic oxide, but since the effect of these constituents is entirely hypothetical, the most reasonable assumption is that oxide of iron increases the ultimate strength.

Whether this theory is perfectly true or not is of little importance so far as the present investigation is concerned, for the results obtained from absolutely pure iron would be utterly valueless as a guide in creating a proper formula. From one point of view there is no more real necessity of knowing the strength of pure iron than of knowing the strength of pure carbon or pure phosphorus. There may be no connection at all between the tensile strength of a carbide or phosphide of iron and the tensile strength of its separate components, since a chemical compound often has nothing in common with its parents.

In the foregoing pages, therefore, the term "pure iron" is arbitrary, and is intended to express simply the datum plane from which it is most convenient to start in order to find the strength of steel by a simple formula.

SEC. XVIIw.—*Synopsis of the argument and conclusions in the foregoing investigations.*—The argument involved in the foregoing calculations is so complicated, and the conclusions are so scattered throughout the text, that it will be convenient to give a general synopsis of Parts II and III of this chapter. As far as the conclusions are concerned, it is conceded that no one series of experiments can make a valid foundation for universal generalizations, but it has been deemed proper to put the discovered relations into the form of statements, which are to be accepted subject to the limitations of the premises.

Basis of the investigation.—The object of the investigation was to discover the influence upon the tensile strength of open-hearth steel, of the metalloids that are usually found therein. Both acid and basic metals were investigated, but the two kinds were kept separate throughout the work.

The preliminary tests of several hundred heats of each kind of steel were at hand, with a record of the ultimate strength of each, together with the content of sulphur, phosphorus, and manganese. These tests were made into several divisions on the basis of their ultimate strength, and these divisions were again subdivided so as to produce groups that would show high and low phosphorus, high and low sulphur, and high and low manganese. These groups were analyzed by taking an equal quantity of drillings from each bar, and determining the carbon by combustion, and also the silicon and the copper. The iron was calculated by difference.

Each one of these groups was then considered as a unit, and an equation was constructed from its chemical composition. On one side of the equation were the carbon, silicon, manganese, sulphur, phosphorus, copper and iron, and on the other side was the ultimate strength. The coefficients of the factors were the percentages found by analysis, while the factors themselves were the unknown quantities whose values were to be sought.

Mathematical calculations.—The only method which seemed to meet the case was the method of least squares, but the first application of this very complicated and laborious mathematical agent gave results which were palpably incorrect. It was demonstrated that the error arose from using silicon, sulphur, and copper as factors in the equations, when, as a matter of fact, they exerted no controlling influence.

Neglecting these elements, a solution was made by which values were found for carbon, manganese, phosphorus, and iron. Differences existed between the basic and acid steels in the values of all these factors, but the most striking variation was in manganese, it being found that it was a minus quantity in acid, and a plus quantity in basic steel.

After completing these calculations, the same line of work was repeated on an entirely new series of acid and basic steels. The results corroborated the former records in most respects, but the value of manganese was found to be very nearly zero in the case of the acid steel. Certain computations showed that this element gave very discordant results when the acid steels were separated into two arbitrary divisions, while the figures for the other metalloids preserved their general character, and the conclusions were drawn that manganese was an unsatisfactory factor in acid metal, that its effect upon the tensile strength was very small when present in ordinary proportions, and that a working formula could be constructed without it.

Finally the old and the new series of steels were put together and a solution was made of the combined list to find the most probable values of the metalloids. Manganese was neglected in the case of the acid steel, but it was found to have a decided influence upon basic metal.

From the values so determined, formulæ were constructed, and these were applied in Tables XVII-U and XVII-X to the groups from which they were derived. Against each group is placed the strength as given by the formula, as well as the difference between this figure and the actual strength.

This column of differences was then analyzed in the case of both acid and basic steels, and it was sought to find whether there was any law of error; for instance, whether high-sulphur groups would always give a plus difference and low sulphur groups would always give a minus difference, thus indicating that the formula did not fit the facts, and that the values were not correct.

From this series of steps the following conclusions were drawn:

Conclusions.—(1) The strength of pure iron, as far as it can be determined from the strength of steel, is about 38,000 or 39,000 pounds per square inch.

(2) An increase of .01 per cent. of carbon raises the tensile strength of acid steel about 1210 pounds per square inch, and of basic steel about 950 pounds. This difference between the effect of carbon upon acid and basic steels, as found by mathematical analysis, is corroborated by the graphic records in Figures XVII-C and XVII-D.

(3) An increase of .01 per cent. of manganese has very little effect upon acid steel unless the content exceeds .60 per cent., but it raises the strength of basic steel about 85 pounds per square inch.

(4) An increase of .01 per cent. of phosphorus raises the tensile strength of acid steel about 890 pounds per square inch, and of basic steel about 1050 pounds.

(5) The following formulæ will give the ultimate strength of ordinary open-hearth steel in pounds per square inch, the carbon, manganese, and phosphorus being expressed in units of .001 per cent., and a value being assigned to *R* in accordance with the conditions of rolling and the thickness of the piece.

FORMULA FOR ACID STEEL.

38,600+121 Carbon+89 Phosphorus+R=Ultimate Strength.

FORMULA FOR BASIC STEEL.

37,430+95 Carbon+8.5 Manganese+105 Phosphorus+R=Ultimate Strength.

(6) The metals, from which these data were derived, were ordinary structural steels ranging from .02 to .35 per cent. of carbon, and it is not expected that the formulæ are applicable to higher steels or to special alloys.

(7) A considerable difference may be found between steels which apparently are of the same composition, and which, as far as known, have been made under the same conditions.

(8) In the case of acid steel, an increase in manganese above .60 per cent. will raise the tensile strength above the amount indicated by the formula, the increment being quite marked when a content of .80 per cent. is exceeded.

(9) In steels containing from .30 to .50 per cent. of carbon, the value of the metalloids is fully as great as with lower steels, while the presence of silicon in such metal in proportions greater than .15 per cent. seems to enhance the strengthening effect of carbon.

(10) In steels containing less than .25 per cent. of carbon the effect of small proportions of silicon upon the ultimate strength is inappreciable.

(11) Sulphur, in ordinary proportions, exerts no appreciable influence upon the tensile strength.

(12) Both acid and basic steels containing less than .30 per cent. of manganese give an actual strength greater than is shown by the formula, and when this is taken in connection with the abnormal strength of the unusually pure metal shown in Group 198 of Table

XVII-X, it is indicated that oxide of iron raises the ultimate strength.

NOTE. Several years have elapsed since the foregoing formulæ were deduced. During that time every open-hearth heat made at Steelton has been calculated according to formula and almost every one, acid and basic, has come out within 2500 pounds of the actual strength as determined by the breaking test, except the steels containing manganese in excess of .60 per cent. Usually the calculated strength is within 1000 or 1500 pounds of the actual. Our experience proves that the formula represents something and it is used as a check and as a guide in the practical and commercial disposition of hundreds of thousands of tons of steel.

The exception noted in the case of high-manganese contents is in exact accordance with conclusion No. 8, just given. It was not possible for the mathematical method to give a correct answer for this kind of metal, because such steels were not represented in sufficient proportion in the groups taken and because no simple formula of this kind so determined, could express a varying function.

I have more than once met with the objection that these formulæ do not allow for the variations in thickness and finishing temperature. This criticism is unfounded. The only way in which these can be allowed for is by adding a certain sum for thin pieces and cold finishing, or subtracting for heavy pieces and hot finishing. This was explained in the conclusions given and the factor *R* covers this ground, as it may be either plus or minus. Mention is made of this because it does not seem to have been made sufficiently prominent.

CHAPTER XVIII.

CLASSIFICATION OF STRUCTURAL STEELS.

SECTION XVIIIa.—*Influence of the method of manufacture on the properties of steel.*—The first problem in the writing of specifications for structural steel is the advisability of prescribing the method by which it shall be manufactured. Some engineers, with commendable fairness, hold that the way in which a bar or plate is made is a matter entirely beyond their dominion. Logically this position is impregnable, but it is not so practically, for although there is no essential difference in the results obtained from open-hearth and Bessemer steel in the ordinary testing machine, there is good testimony to show that the product of the converter is an inferior metal which gives way in a treacherous manner under shock.

It is granted that in a strict sense there is no such thing as treachery or mystery, but these are convenient terms to cover an undiscovered law. The evidence concerning the unreliability of Bessemer steel is made up for the most part of scattered individual opinions, many of which have been made on insufficient evidence, but they are too numerous to be entirely ignored, and they are fortified by the carefully considered statements of men whose words are weighed, and who are absolutely disinterested in their decisions. Thus A. E. Hunt, whose long experience as the chief of The Pittsburg Testing Laboratory gives much force to his opinion, wrote as follows:* "Numerous cases have come under our observation of angles and plates which broke off short in punching, but although makers of Bessemer steel claim that this is just as likely to occur in open-hearth metal, we have as yet never seen an instance of failure of this kind in open-hearth steel."

Mr. Hunt also quotes (*loc. cit.*) from a paper by Wailes before the British Association to the effect that "these mysterious failures

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* *The Inspection of Materials of Construction in the United States. Journal I. and S. I.*, Vol. II, 1890, p. 316.

occur in steel of one class, *viz.*, soft steel made by the Bessemer process."

There is also the testimony of W. H. White, Director of Naval Construction, Royal Navy.* "With converter steel riveted samples have given less average strength, greater variations in strength, and much more irregularity in modes of fracture than similar samples of open-hearth steel."

My own experience leads me to think that Bessemer steel requires more work for the attainment of a proper structure than open-hearth metal, so that a thick bar is more apt to have a coarse crystalline fracture. This may be ascribed in any particular case to improper heat treatment, but if it is true that open-hearth metal would not be injured under a similar exposure, then it is proven that there is a difference between the metals, and, if this be acknowledged, then there is no necessity for further argument.

It is true that Bessemer metal has been used for rails, and that these are exposed to great stress and shock, but it also true that a large number of rails break in service, and that the use of ordinary rail steel for bridges was long ago given up as dangerous. Moreover, it is quite probable that the number of broken rails would be considerably reduced if they were made of open-hearth steel.

The question therefore arises why rails are not made of this material, and railroad engineers occasionally come forward with inquiries to that end. It may be well to say therefore that the making of open-hearth rails is purely a commercial question, but it involves immense sums of money. All rails made to-day in America are made by the Bessemer process, and each rail-making plant must be regarded as a unit. The converting department is one factor of this unit, its capacity and whole scheme of operation being designed for the one purpose of supplying the blooming mill with just the right quantity of ingots of just exactly the right size. It may be that at a given rail-making works there is no open-hearth furnace plant at all. In such a case if open-hearth rails are wanted they can be made only by some such changes as the following:

(1) Bring cold blooms from other works, entailing much expense and the erection of a mammoth plant of bloom heating furnaces.

(2) Bring cold ingots from other works, with the same necessity for heating furnace equipment. In both cases the extra fuel consumption and waste in heating would be very serious matters.

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* *Experiments with Basic Steels. Journal I. and S. I.*, Vol. 1, 1892, p. 35.

(3) The foregoing propositions are merely temporary on their face and the only true solution is an open-hearth plant. This calls for a very large amount of capital, and when the plant gets into operation the Bessemer plant will become a scrap heap of no value whatever, for in order that it shall be of any value it must run, and in order that it may run, it would be necessary to build a complete plant of rolling mills to handle its product, and this would seldom be desirable even if it were feasible at all in some cases.

(4) Having written off the value of the Bessemer outfit as a dead loss, it is necessary to guarantee business to the open-hearth department in sufficient quantity to keep it in steady operation at a price in proportion to the increased cost. It is out of the question to operate the open-hearth plant on certain orders for open-hearth rails at a slightly higher price, and then start up the Bessemer plant on other orders and let the open-hearth lie idle. Such a proposition is clearly out of the argument.

(5) It may seem possible to have a number of mills and have the open-hearth and Bessemer plants both operating continuously and distributing their product as orders demand. One or two works in the country are able to do this to a greater or less extent, but it is impossible to do it and maintain the proper coördination of dependent factors and keep the operating costs in each department at a minimum.

We may conclude therefore that small lots of open-hearth rails may be made, but their production on a large scale means a plant laid out with that end in view, and if this plant is not guaranteed a regular line of business extending over many years at an increased price, it will be a losing venture. Such an innovation is hardly justified by the present knowledge of the rail business. Within the last few years it has been clearly shown that a great improvement may be made by certain modes of heat treatment. Much care is now taken to finish the rails colder than formerly and to do a great deal of work upon them while they are at a moderately low heat. By so doing a much better grain is attained, and this renders possible the use of a higher content of carbon than was formerly thought advisable. This question of finishing temperature and all the associated problems of wear and toughness are being thoroughly threshed out, and it may be well to await the results of experiments now under way before starting out into untried fields.

In the case of structural shapes there is no difficulty in obtaining at moderate cost all needed sections in open-hearth steel, and it would seem to be the safer way to prescribe that it shall be used in all structures, like railroad bridges, where the metal is under constant shock, and where life and death are in the balance. In this connection it should be stated that the method by which the steel is made cannot be discovered by ordinary chemical analysis. Certain experiments indicate that there is a difference between Bessemer and open-hearth steel in the character of the occluded gases, but this system of analysis is never resorted to in practice, and no provision is made for it in laboratories. Moreover, it is doubtful if any expert would risk his reputation by asserting positively, from any such evidence, that a certain steel was made by either one or the other process. Consequently, when open-hearth metal is specified, a careful watch should be kept in the steel works that there is no substitution of the inferior material.

Sec. XVIIIb.—*Chemical specifications.*—Another point concerning which there is room for discussion is the propriety of limiting the chemical composition. Some engineers contend that as long as the physical tests are fulfilled, the making of the metal is an entirely foreign matter. This position is untenable, for it would be possible to make a steel with 0.25 per cent. of phosphorus which would satisfy the ordinary tests of strength and ductility, and although such a content could usually be detected in the shops, a considerable proportion of the bars might be able to pass muster.

It is impossible to fix a limit of phosphorus below which there is no danger of treacherous breakage, but it is quite certain that, as the content is reduced, the danger of such disaster disappears. On this account it becomes not only the province but the duty of the engineer to specify the chemical composition of the metal that he buys.

In the construction of ordinary roof-trusses and similar work there is no necessity for stringency, and Bessemer steel with a maximum content of .10 per cent. of phosphorus may be allowed; but in railroad bridges, traveling cranes, and other structures where the steel is exposed to moving loads and continued shock, and where the consequence of failure may not be measured in money, the specifications should require the use of open-hearth steel with a maximum phosphorus of .06 per cent. The common limit at the present day is .08 per cent., but the time has come for another step in advance, since the difference in the cost of the purer metal has been reduced to an unimportant figure.

In addition to thus limiting the chemical content of phosphorus, it is necessary to specify the manner in which the sample shall be taken for analysis. There are four methods of doing this of which only one is correct, and this correct one is seldom or never used. Taking for illustration a rolled billet of steel three inches square, its cross-section may be mentally divided into nine equal squares, each having an area of one square inch. Eight of these squares are next to the surface, while only one is in the interior. This central square will include almost all the segregated portion of the mass.

Ordinarily a sample of such a billet would be taken by drilling to a depth of half an inch, but it is evident that this does not take cognizance of the interior core, and that the chemical determinations on the drillings will show too low a content of certain segregrating metalloids.

Another method is to drill all the way to the center, and to take all the drillings that are made. Two-thirds of these drillings will come from the outside square and one-third from the inside, or a ratio of two from the outside and one from the interior, while the true ratio is eight to one; hence the content of segregating metalloids found by this method is higher than the true average.

A third method which is sometimes used, although manifestly inaccurate, is to take only those drillings that come from the central portion, but this will give a very much higher content of certain elements than will be found throughout the bar.

The fourth way is to plane the entire surface and thus get a true average, but, as before stated, this practice is seldom carried out.

In the case of angles, a very fair sample can be obtained by drilling into the bar as far as the center, the results so obtained being only slightly higher than the true values. In plates it is much more difficult to take a fair sample, since the segregated portion is in the body of the sheet, and it is usually impracticable to drill a hole without injuring the strength of the member.

It is easy to see that great injustice may be done by insisting on unusual methods of sampling. It would be perfectly right to state in the contract that drillings were to be taken from the center of the plate, but it is not right to take them in this way in the absence of a previous understanding. On the other hand, the engineer has an indisputable right to investigate the homogeneity of any plate, and to reject those members that show excessive segregation.

It is necessary, therefore, to take some account of these variations, and in the following specification it is provided that when drillings are taken from the center of plates, the allowable maximum of phosphorus and sulphur shall be raised 25 per cent.; *e. g.,* from .04 to .05 per cent., or .08 to .10 per cent.

The engineer who has been calling for steel containing less than .08 per cent. of phosphorus, may deem it a step backward to allow the center of plates to contain .10 per cent., but it is necessary to consider that the new provision is merely a formal recognition of a fact, and that the higher phosphorus has always existed in the center of plates, particularly if they have been rolled directly from ordinary plate ingots which have not undergone a preliminary "roughing" and "cropping." It is also well to consider that less careful engineers, who have specified a maximum of .10 per cent. of phosphorus, have received many a plate that contained .12 per cent., and even .15 per cent., of this impurity. The fact of non-homogeneity in plates is a strong argument in favor of the further lowering of the allowable maximum, for, when all other conditions are the same, each decrease in the average content diminishes the increment due to segregation.

Usually it is specified that basic metal shall show a still lower phosphorus. There does not seem to be any proof that basic open-hearth steel of a given composition is more unreliable than acid metal of the same character, but in order to meet any possible danger, and because the cost of a little extra purification is not excessive, it is not amiss to require that the best basic steel shall not show over .04 per cent. of phosphorus.

The other elements need not be rigidly limited, for many combinations are possible, and some discretion should be left to the maker in the attainment of definite results. It is not uncommon for engineers of limited knowledge to write specifications that give an upper limit for every element, and require a tensile strength which cannot be obtained by the formula. The carbon should always be left open, so that if the maker wishes to reduce the phosphorus he may use carbon to get strength.

Manganese may be limited to .60 per cent. on the steels under

64,000 pounds per square inch, and to .80 per cent. on harder metal. This will ensure a safe material, and will not be a burden on the manufacturer. Silicon is of little importance, but the maximum may be placed at .04 per cent. for soft steel, this proportion being seldom, if ever, exceeded.

Sulphur, in most cases, concerns the manufacturer more than the engineer, for if it is too high the bar will crack in rolling and be imperfect, while it seems to have no marked effect on the ductility of the finished piece. In material for eye-bars, however, there is danger that high sulphur may cause coarse crystallization during the heating necessary to form the eye.

Copper may be entirely neglected, for no ill effect upon the cold properties of low steel has ever been traced to its action, while thousands of tons of excellent metal have been made with a content of .75 per cent.

Rivet steel, like eye-bar flats, stands on an entirely different footing from other structural metal, for this must be heated and worked after leaving the place of manufacture. Only the very best of material should be used, and it should be so soft that it will not be injured by cold working or crystallized by overheating. The phosphorus should not be over .04 per cent., the sulphur not over .05 per cent., and the tensile strength not over 56,000 pounds per square inch. These limits should be insisted upon whether acid or basic open-hearth metal be used.

SEC. XVIIIc.—*Use of soft steel in structural work.*—It is not the intention of this chapter to arbitrarily state just what should or should not be given as the best tensile strength for every purpose, but it is my opinion that a softer metal should be used for bridges than is often employed, because, although a slight sacrifice is made in the ultimate strength, there is a gain in the working strength due to the higher elastic ratio, and a decided increase in toughness and resistance to shock, so that the calculations may be made on the same basis for the working load as with a harder metal.

The fact that the elastic ratio rises as the ultimate strength decreases is not generally recognized, but will be shown in Table XVIII-A. This is constructed by comparing the groups of angles in Table XIV-H, which are made by the same process, and are of the same thickness, and which contain the same percentage of phosphorus. It will be found that in every case the stronger steel gives a lower elastic ratio.

TABLE XVIII-A.

Rise in Elastic Ratio with Decrease in Ultimate Strength. Comparison of the Angles Given in Table XIV-H which are Made by the Same Process, of the Same Thickness, and with the Same Content of Phosphorus.

Kind of steel.	Content of phosphorus; per cent.	Thickness of angle, in inches.	Harder steels.			Softer steels.			Rise in elastic ratio in softer steels; per cent.
			Av. ultimate strength; pounds per square inch.	Average elastic limit; pounds per square inch.	Average elastic ratio; per cent.	Av. ultimate strength; pounds per square inch.	Average elastic limit; pounds per square inch.	Average elastic ratio; per cent.	
Basic O. H.	below .04	$\frac{5}{16}$ to $\frac{3}{8}$	58865	39692	67.43	52533	36284	69.07	1.64
		$\frac{7}{16}$ to $\frac{1}{2}$	58538	37827	64.62	53171	34891	65.62	1.00
		$\frac{9}{16}$ to $\frac{5}{8}$	59235	37487	63.28	51903	34026	65.56	2.28
		$\frac{11}{16}$ to $\frac{7}{8}$	59125	36035	60.95	51923	32356	62.31	1.36
Acid O. H.	.05 to .07	$\frac{5}{16}$ to $\frac{3}{8}$	65656	43713	66.58	60845	40891	67.21	0.63
		$\frac{7}{16}$ to $\frac{1}{2}$	65631	42191	64.28	60695	39415	64.94	0.66
Acid O. H.	.07 to .10	$\frac{5}{16}$ to $\frac{3}{8}$	66365	44486	67.03	60064	41143	68.50	1.47
		$\frac{7}{16}$ to $\frac{1}{2}$	65777	42817	65.09	60583	40170	66.30	1.21
Acid Bess.	.07 to .10	$\frac{5}{16}$ to $\frac{3}{8}$	66277	46422	70.04	60659	43417	71.58	1.54
		$\frac{7}{16}$ to $\frac{1}{2}$	65940	45280	68.66	59882	42518	71.00	2.34

The tendency in the first epoch of steel structures was toward a hard alloy, but later practice has been a continual progress toward toughness. There was a halt in this movement at a tensile strength of 60,000 pounds, not entirely on account of any magic virtue in the figure, but because the ordinary mild steels gave that result, and a much higher price was charged for a softer metal. The conditions to-day are somewhat different, for the reduced cost of low-phosphorus pig-iron, and the introduction of the basic hearth, have altered the economic situation. A steel with a tensile strength of 50,000 to 58,000 pounds per square inch is a most attractive material, possessing all the good characteristics of wrought-iron with greater strength and toughness.

With this recommendation for the adoption of softer metal, certain classes are proposed from which the engineer can choose. In some cases the option is given between acid and basic open-hearth steel, but it must not be forgotten that it costs more to make low-phosphorus metal by the acid than by the basic process, so that the terms of the specification should be enforced after the contract is awarded, out of justice to the other bidders who have based their calculations on the letter of the law. In steel above .08 per cent.

of phosphorus, this difference in cost disappears and there is no economy in the use of the basic hearth.

The option is sometimes given between open-hearth and Bessemer metal, but it will be understood that whenever the former is specified the latter is not admissible, although as a matter of course the manufacturer may supply open-hearth in place of Bessemer, if for any reason he wishes to use the better and more expensive material.

SEC. XVIIId.—*Tests on plates.*—In the specifications for plates it will be noticed that a variation of 10,000 pounds per square inch is allowed, and that concessions are made for thick and wide sections. All this may seem to some engineers to be a step backward, but in reality these provisions have been in force for many years. The engineer who writes a new specification calling for a better elongation, never knows that he receives exactly the same steel that has been made before. The plate rollers have been driven to expedients which are not dishonest, but which are dangerously near the line of deception. Thus, if it is required that a test must be cut from one plate out of every ten, the manufacturer will leave a coupon on every plate and test strips are cut from immediately next to them; after finding which plates fill the requirements, the coupons are cut from the others and the inspector is told that the pile is ready for him.

If every plate is to be tested, then a coupon is left upon each corner and a contiguous strip is privately tested by the maker. After finding which corner gives the best results, the other coupons are cut off and the plate submitted to the inspector. This is not dishonest, for any one corner represents the plate just as much as any other corner, and it would manifestly be absurd to designate from which corner the test is to be taken.

It is also quite certain that no one corner represents the center of the plate, for the edges are always finished colder than the center, and it is just as certain that in a plate rolled direct from an ingot with only the usual amount of scrap, the corners in no way represent the part of the plate which corresponds to the segregated portion of the ingot.

It is by care in the preliminary testing rather than by improvement in the quality of material that advances have been made, and it is time that the fact be made known to engineers. The mill managers have been aided by the inspectors for most of these men (to their credit be it said) are anxious to pass material which they know to be good. They allow the manufacturer to put part of a heat into thick plates and part into thin, and make the tests on three-eighths or one-half inch gauge; they pass over the sheets that are 100 inches wide, and cut the coupons from plates that are less than 70 inches. These concessions have been tacitly made in the past; I have merely put them into print.

On the other hand, I have called for higher tests on plates under 42 inches wide. This is because they can be made on a universal mill, and since better results can be had in this way, it is right to demand what there is a perfectly simple way of obtaining.

It will be seen that no allowance is made for a variation in tensile strength for different shapes, while concessions are made for differences in thickness. This inconsistency arises from the fact that it is generally known beforehand whether a certain heat of steel is to be rolled into angles, or plates, or eye-bars, and it is seldom that it is necessary to put part of a heat into one shape and part into another. On the other hand, it is almost always necessary to roll a charge into more than one thickness and more than one size of angles, plates, etc., and it is evidently an onerous restriction if proper allowance be not made for the normal variations due to different thickness.

SEC. XVIIIe.—*Standard size of test-pieces.*—In all the tensile tests a length of eight inches is taken as the standard for all sections, allowance being made for variations in shape and size. For several years there have been conferences held in foreign lands to establish uniform methods of testing, and it has been officially recommended that in the case of rounds the length of the test-piece shall be proportional to the square root of the sectional area, the formula being given as follows: $l = 12.0\sqrt{f}$ when $l =$ the length in inches and $f =$ the sectional area in square inches. In Table XVIII-B I have calculated from this formula the proper length for rounds from one-half inch to 1¼ inches in diameter. It will be seen that the length is greatly reduced as the diameter grows less, and this, of course, is equivalent to demanding less elongation, while on larger sizes the length is increased, this being the same thing as demanding more elongation.

It is rather difficult to compare this system, in which the elongation is constant and the length varies, with the system wherein the length is constant and the required elongation varies; but an attempt is made to do this by obtaining the proportional elongation for the different lengths from Curve *AA* in Figure XVI-A. The results are given in the last column of the table, and it will be found that the allowances for changes in sectional area, given in the following pages, are in line with the formula just mentioned. A long time has been spent in arriving at the general adoption of an international standard length of eight inches, and it would be very unfortunate if a complicated substitute were introduced. Such a change, however, is very unlikely from present indications.

TABLE XVIII-B.

Calculation of 12.0 $\sqrt{f}$ for Different Diameters, together with the Proportional Elongation for the Given Lengths as Determined by Curve AA in Figure XVI-A.

Diameter, in inches.	f, or area in square inches.	$\sqrt{f}$	12.0 $\sqrt{f}$ = length in inches of test-piece.	Per cent. of elongation for lengths in preceding column; from Curve AA, Fig. XVI-A
½	.1963	.443	5.32	33.2
⅝	.3067	.554	6.65	31.5
¾	.4417	.665	7.98	30.2
⅞	.6013	.775	9.30	29.3
1	.7854	.886	10.63	28.7
1⅛	.9940	.997	11.96	27.8
1¼	1.2271	1.108	13.30	27.1

It is understood in these specifications, as well as throughout this book, that the elastic limit is determined by the drop of the beam, for this is the universal method in American steel works and rolling mills. I have no sympathy with that group of agitators who are trying to introduce new meanings to old terms, and to apply old terms to new factors. It matters not whether the drop of the beam does or does not mark the spot where the elongation ceases to be exactly proportionate to the load. It is certain that it represents a critical point of failure, and this is acknowledged by the agitators before mentioned, who recommend its determination on all tensile test-pieces.

Moreover, it is shown in Section XVIm that this is a definite point which can be determined more accurately than the reduction of area, and nearly as accurately as the elongation. If a new point is desired, such as is shown by an autographic device, then this new point should be given a new name. The term "elastic limit" has been preëmpted by general use, as part of a system of trade nomenclature, to designate the point where the beam drops.

Upon this determination all specifications and contracts are based, and any attempt to ascertain the elastic limit in any other way is a change in the contract requirements which would not be sustained in a court of equity. All calculations upon factors of safety in existing bridges are based upon this "drop of the beam," and there seems to be no good reason why one arbitrary point should be substituted for another and no reason why future work should not be carried on under the present established and well-understood system.

SEC. XVIIIf.—*The quench-test.*—In these specifications there is nothing said about a quench-test, for I am of the opinion that it is an absurdity when applied to ordinary structural material. It was defended by Mr. Hunt* on the ground that it would guard against material that would be injured by careless heating and cooling in the mill or shops, but this suggests the query why such carelessness should be tolerated. It is assumed that the work is done by mills and shops that understand their business, and the steel should be made to fit the work in hand and not the ignorance of middlemen.

It is right to make the most severe tests on the cold properties, for the derailment of a train will subject certain members to great deformation; such an accident is always a possibility which human foresight seems powerless to avoid, but the carelessness in the shop stands on a different footing, for it is caused by positive and unnecessary acts in error.

Moreover, the quench-test depends very much upon slight differences in the methods of heating and cooling, differences which are almost imperceptible and unexplainable, and the same steel may be made to pass or fail under modes of treatment which seem to be inherently identical. It would appear, therefore, that no warrant exists for the imposition of this test upon the material for a railroad bridge, which is not calculated to withstand a conflagration followed by a flood. This position is being taken by a very large number of engineers, and a quench-test is rapidly becoming a thing of the past.

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* *The Inspection of Materials of Construction in the United States. Journal I. and S. I.,* Vol. II, 1890, p. 312.

SEC. XVIIIg.—*Classes of Steel Proposed.*—In the former edition of this work I included several general provisions concerning methods of testing. They are omitted here, not because of any change of views, but because they appear in the American Standard Specifications. I may retain my own views regarding some minor points of special metallurgy, but there should be agreement by vote on the method of testing materials. I also recommended several classes of steel for different purposes, and gave the specifications which they should be called upon to meet. I have seen no reason to change any views or any figures in the tables, save that I have specified that manganese in rivet steels shall not fall below a certain minimum.

I do not offer these specifications for general adoption and never considered that they would be adopted. The specifications drawn up by the American Society for Testing Materials will be given later, and these are already the recognized standard and should be used, but I offer these tables as detailed data representing what changes take place in the physical qualities as the chemical composition changes and as the thickness or shape of the rolled member varies. These pages have been of use to engineers and authors in the past in obtaining such information. They do not represent random guesses, but the condensation of many experiments and much work, albeit they are too complicated for the demands of those who wish to read as they run.

CLASS I.

Extra Dead Soft; for Common Rivets, Wire Cables, and other Purposes where Exceptional Toughness is Required.

Method of manufacture.—Basic open-hearth process.
Chemical composition, in per cent.—P below .04; S below .06; Si below .04; Mn .35 to .50.
Physical requirements as follows:

Shape.	Diameter in inches.	Ultimate strength; pounds per square inch.		Elastic ratio.	Elongation in 8 inches; per cent.	Reduction of area; per cent.
		Minimum.	Maximum.			
Rivet rods,	⅝	46000	55000	64.0	28.0	52
"	¾	46000	54000	63.0	29.0	58
"	⅞	45000	54000	61.5	29.25	56
"	1	45000	54000	60.0	29.50	54
"	1⅛	44000	54000	58.5	29 75	52
"	1¼	44000	54000	57.0	30.00	50

A rolled round about three-quarters inch in diameter, after being nicked about one-quarter way through, shall bend completely double without fracture, with the nick on the outer curve of the bend.

Heats rolled into bars less than five-eighths inch in diameter may be tested in trial rods of three-quarters inch.

If any bar fails to pass the physical tests, four more pieces shall be taken from the same heat, and the average of all five bars shall be considered the true record.

Rivets, when cut out of the work into which they have been put, shall show a tough silky structure, with no crystalline appearance.

Class II.

Bridge Rivets; for Rivets in Railroad Bridges.

Method of manufacture.—Acid or basic open-hearth process.

Chemical composition, in per cent.—P below .04 in acid steel; below .03 in basic; S below .05; Si below .04; Mn .35 to .50.

Physical requirements as follows:

Shape.	Diameter in inches.	Ultimate strength; pounds per square inch.		Elastic ratio.	Elongation in 8 inches; per cent.		Average reduction of area; per cent.
		Minimum.	Maximum.		Average.	Minimum.	
Rivet rods,	5/8	48000	57000	66.0	29.0	27.0	60
"	3/4	48000	56000	65.0	30.0	28.0	60
"	7/8	47000	56000	63.5	30.5	28.5	58
"	1	47000	56000	62.0	31.0	29.0	56
"	1 1/8	46000	56000	60.5	31.0	29.0	54
"	1 1/4	46000	56000	59.0	31.0	29.0	52

Two tons of bars from the same heat shall constitute a lot, and two specimens, each from a different bar, shall be tested from each lot. The above table gives the average required of these two bars, and the minimum below which no bar shall fall. If the average elongation or reduction of area on any one lot shall fall below the requirement, two additional bars shall be cut from the same lot, and the average of the four pieces shall be considered the average of the lot, provided that no concession be made in the minimum. Heats rolled into sizes less than five-eighths inch may be tested in trial rods of three-quarters inch.

A rolled round about three-quarters inch in diameter, after being nicked one-quarter way through, shall bend completely double without fracture, with the nick on the outer curve of the bend. A piece of three-quarter-inch rod cut one-half inch long shall be upset while cold into a disc one-eighth inch thick, without developing extensive flaws or showing signs of cold shortness.

Rivets, when cut out of the work into which they have been put, shall show a tough silky structure, with no crystalline appearance.

CLASS III.

Hard Bridge Rivets; a Substitute for Class II, Giving Greater Strength with Less Toughness.

Method of manufacture.—Acid or basic open-hearth process.
Chemical composition, in per cent.—P below .04 in acid steel; below .03 in basic; S. below .05; Si below .04; Mn .35 to .60.
Physical requirements as follows:

Shape.	Diameter in inches.	Ultimate strength; pounds per square inch.		Elastic ratio.	Elongation in 8 inches; per cent.		Average reduction of area; per cent.
		Minimum.	Maximum.		Average.	Minimum.	
Rivet rods.	⅝	54000	63000	61.0	28.0	26.0	55
"	¾	54000	62000	60.0	29.0	27.5	55
"	⅞	53000	62000	58.5	29.5	27.5	53
"	1	53000	62000	57.0	30.0	28.0	51
"	1⅛	52000	62000	55.5	30.0	28.0	49
"	1¼	52000	62000	54.0	30.0	28.0	47

Two tons of bars from the same heat shall constitute a lot, and two specimens, each from a different bar, shall be tested from each lot. The above table gives the average required of these two bars, and the minimum below which no bar shall fall. If the average elongation or reduction of area on any one lot shall fall below the requirement, two additional bars shall be cut from the same lot, and the average of the four pieces shall be considered the aver-

CLASS IV.

Common Hard Rivets; for Roof Trusses and other Structures not Exposed to Shock.

Method of manufacture.—Acid or basic open-hearth process.
Chemical composition, in per cent.—P below .06 in acid steel; below .04 in basic; S. below .05; Si below .04; Mn. .35 to .60.
Physical requirements as follows:

Shape.	Diameter in inches.	Ultimate strength; pounds per square inch.		Elastic ratio.	Elongation in 8 inches; per cent.	Reduction of area; per cent.
		Minimum.	Maximum.			
Rivet rods,	⅝	54000	63000	61.0	27.0	55
"	¾	54000	62000	60.0	28.0	55
"	⅞	53000	62000	58.5	28.5	53
"	1	53000	62000	57.0	29.0	51
"	1⅛	52000	62000	55.5	29.0	49
"	1¼	52000	62000	54.0	29.0	47

age of the lot, provided that no concession be made in the minimum. Heats rolled into sizes less than five-eighths inch may be tested in trial rods of three-quarters inch.

Rivets, when cut out of the work into which they have been put, shall show a tough silky structure, with no crystalline appearance.

CLASS V.

Soft Bridge Steel; for Angles, Plates, Bars, etc., for Bridges, Cranes, and Similar Structures Exposed to Shock.

Method of manufacture.—Acid or basic open-hearth process.
Chemical composition, in per cent.—P below .06 in acid steel, below .04 in basic; S below .07 in plates and angles, below .06 in eye-bars; Si below .04; Mn below .50.
Physical requirements as follows:

Shape.	Thickness in inches.	Ult. str.; lbs. per sq. inch.		Elastic ratio.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Remarks.
		Minimum.	Maximum.				
Angles.	3/8	50000	58000	63.0	29.0	55	One piece of 3/4-inch angle must open out flat and another close shut without sign of fracture.
	1/2	50000	58000	61.5	29.0	53	
	5/8	49000	58000	60.0	29 0	51	
	3/4	49000	58000	58.5	29.0	49	
	7/8	48000	58000	57.0	29.0	47	
Plates.	5/16	53000	63000	65.0	23.0	44	On plates under 42 inches wide the required elongation shall be raised 1.5 per cent. and the reduction of area 2.0 per cent. On plates over 70 inches wide the elongation shall be lowered 1.5 per cent. and the reduction of area 2.0 per cent. On tests cut crosswise from the sheet, the minimum tensile strength shall be lowered 3000 pounds, the elongation 3 per cent., and the reduction of area 10 per cent. On universal-mill plates the allowance for transverse tests shall be 5000 pounds, 5 per cent. and 15 per cent. Both longitudinal and transverse strips cut from plates shall bend double flat. When every plate in the heat is tested, the minimum elongation and reduction shall be lowered 5 per cent.
	3/8	51000	61000	63.0	26.0	50	
	1/2	50000	60000	62.0	26.0	50	
	3/4	49000	59000	60.0	25.0	48	
	1	48000	58000	58.0	24.0	46	
	1 1/4	47000	58000	56.0	23.0	44	
Eye-bars, annealed.	3/4	50000	58000	57.0	. . .	. .	The elongation in full length shall be 15 per cent. in bars from 10 to 20 feet long, 14 per cent. in 21 to 25 feet, 13.5 per cent. in 26 to 30 feet, and 13 per cent. in 31 to 35 feet.
	1	50000	58000	56.0	. . .	. .	
	1 1/2	49000	58000	54.0	. . .	. .	
	2	49000	58000	53.0	. . .	. .	
	2 1/2	48000	58000	52.0	. . .	. .	

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 inches wide, with the same allowance for difference in thickness. In tests cut from the flange the minimum tensile strength shall be lowered 3000 pounds, the elongation 3 per cent., and the reduction of area 10 per cent..

Four tests shall be taken from each heat, and the average of these four shall conform to the above table. If the average elongation or reduction of area of any heat shall fall below the requirement, four additional bars may be cut from the same heat, and the average of the eight pieces shall be considered the average of the heat. Heats rolled into sizes less than five-eighths inch may be tested in trial rods of three-quarters inch.

Rivets, when cut out of the work into which they have been put, shall show a tough silky structure, with no crystalline appearance.

Class VI.

Medium Bridge Steel; a Substitute for Class V when Greater Strength and Less Toughness are Required.

Method of manufacture.—Acid or basic open-hearth process.
Chemical composition, in per cent.—P below .06 in acid steel, below .04 in basic; S below .07 in plates and angles, below .06 in eye-bars; Si below .04; Mn below .60.
Physical requirements as follows:

Shape.	Thickness in inches.	Ultimate strength; lbs. per sq. inch.		Elastic ratio.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Remarks.
		Minimum.	Maximum.				
Angles.	⅜	56000	64000	63.0	27.0	50	One piece of angle, not over ½ inch thick, shall open out flat, and another close shut without sign of fracture.
	½	56000	64000	61.5	27.0	48	
	⅝	55000	64000	60.0	27.0	46	
	¾	55000	64000	58.5	27.0	44	
	⅞	54000	64000	57.0	27.0	42	
Plates.	5/16	59000	69000	62.0	22.0	39	On plates under 42 inches wide the required elongation shall be raised 1.5 per cent., and the reduction of area 2.0 per cent. On plates over 70 inches wide, the elongation shall be lowered 1.5 per cent., and the reduction of area 2.0 per cent. On tests cut crosswise from the sheet, the minimum tensile strength shall be lowered 3000 pounds, the elongation 3 per cent., and the reduction of area 10 per cent. On universal-mill plates the allowance for transverse tests shall be 5000 pounds, 5 per cent. and 15 per cent. Longitudinal strips shall bend double flat; transverse strips shall bend through 180 degrees around a pin 1 inch in diameter. When every plate in the heat is tested, the minimum elongation and reduction of area shall be lowered 5 per cent.
	⅝	57000	67000	60.0	25.0	45	
	½	56000	66000	59.0	25.0	45	
	¾	55000	65000	57.0	24.0	43	
	1	54000	64000	55.0	23.0	41	
	1¼	53000	64000	53.0	22.0	39	
Eye-bars, annealed.	¾	56000	64000	56.0	. . .	. .	The elongation in full length shall be 14 per cent. in bars from 10 to 20 feet long, 13 per cent. in 21 to 25 feet, 12.5 per cent. in 26 to 30 feet, and 12 per cent. in 31 to 35 feet.
	1	56000	64000	55.0	. . .	. .	
	1½	55000	64000	53.0	. . .	. .	
	2	55000	64000	52.0	. . .	. .	
	2½	54000	64000	51.0	. . .	. .	

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 inches wide, with the same allowance in thickness. In tests cut from the flange, the minimum tensile strength shall be lowered 3000 pounds, the elongation 3 per cent., and the reduction of area 10 per cent.

NOTE.—The allowable content of phosphorus may be raised to .08 per cent. for acid, and .05 per cent. for basic steel, if the best quality is not required, but other specifications must remain the same.

CLASS VII.

Hard Bridge Steel.

Method of manufacture.—Acid or basic open-hearth process.
Chemical composition, in per cent.—P below .06 in acid steel, below .04 in basic; S below .07 in plates and angles, below .06 in eye-bars; Si below .05; Mn below .80
Physical requirements as follows:

Shape.	Thickness in inches.	Ultimate strength; lbs. per sq. inch. Minimum.	Ultimate strength; lbs. per sq. inch. Maximum.	Elastic ratio.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Remarks.
Angles.	⅜	60000	68000	62.0	26.0	48	One piece of angle, less than ½ inch thick, shall open out flat, and another piece close shut without sign of fracture.
	½	60000	68000	60.5	26.0	46	
	⅝	59000	68000	59.0	26.0	44	
	¾	58000	68000	57.5	26.0	42	
	⅞	57000	68000	56.0	26.0	40	
Plates.	5/16	63000	73000	60.0	20.0	34	On plates under 42 inches wide the required elongation shall be raised 1.5 per cent., and the reduction of area 2.0 per cent. On plates over 70 inches wide, the elongation shall be lowered 1.5 per cent., and the reduction of area 2.0 per cent. On tests cut crosswise from the sheet, the minimum tensile strength shall be lowered 3000 pounds, the elongation 3 per cent., and the reduction of area 10 per cent. On universal-mill plates the allowance for transverse tests shall be 5000 pounds, 5 per cent. and 15 per cent. Longitudinal strips shall bend double flat. Transverse strips shall bend through 180 degrees around a pin 1 inch in diameter. When every plate in the heat is to be tested, the minimum elongation and reduction of area shall be lowered 5 per cent.
	⅜	61000	71000	58.0	23.0	40	
	½	60000	70000	57.0	23.0	40	
	¾	59000	69000	55.0	22.0	38	
	1	58000	68000	53.0	21.0	36	
	1¼	57000	68000	51.0	20.0	34	
Eye-bars, annealed.	¾	60000	68000	55.0	. . .	. .	The elongation in full length shall be 13 per cent. in bars from 10 to 20 feet long, 12.5 per cent. in 21 to 25 feet, 12 per cent. in 26 to 30 feet, and 11.5 per cent. in 31 to 35 feet.
	1	60000	68000	54.0	. . .	. .	
	1½	59000	68000	52.0	. . .	. .	
	2	59000	68000	51.0	. . .	. .	
	2½	58000	68000	50.0	. . .	. .	

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 inches wide, with the same allowance for difference in thickness. In tests cut from the flange, the minimum tensile strength shall be lowered 3000 pounds, the elongation 3 per cent., and the reduction of area 10 per cent.

NOTE.—The allowable content of phosphorus may be raised to .08 per cent. in acid, and .05 per cent. in basic steel, if the best quality is not required, but other specifications must remain the same.

CLASS VIII.

Extra Hard Bridge Steel; for Special Structures where Great Stiffness is Essential.

Method of manufacture.—Acid or basic open-hearth process.

Chemical composition, in per cent.—P below .06 in acid steel, below .04 in basic; S below .07 in plates and angles, below .06 in eye-bars; Si below .10; Mn below .80.

Physical requirements as follows:

Shape.	Thickness in inches.	Ultimate strength; lbs. per sq. inch.		Elastic ratio.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Remarks.
		Minimum.	Maximum.				
Angles.	⅜	64000	72000	61.0	25.0	45	One piece of angle, about ⅜ inch thick, shall open out flat, and another piece close shut without sign of fracture.
	½	64000	72000	59.5	25.0	43	
	⅝	63000	72000	58.0	25.0	41	
	¾	62000	72000	56.5	25.0	39	
	⅞	61000	72000	55.0	25.0	37	
Plates.	5/16	67000	77000	59.0	18.0	32	On plates under 42 inches wide, the required elongation shall be raised 1.5 per cent., and the reduction of area 2.0 per cent. On plates over 70 inches wide, the elongation shall be lowered 1.5 per cent., and the reduction of area 2.0 per cent. On tests cut crosswise from the sheet, the minimum tensile strength shall be lowered 3000 pounds, the elongation 3 per cent., and the reduction of area 10 per cent. On universal-mill plates the allowance for transverse tests shall be 5000 pounds, 5 per cent. and 15 per cent. Longitudinal strips shall bend double flat. When every plate in the heat is to be tested, the minimum elongation and reduction of area shall be lowered 5 per cent.
	⅜	65000	75000	57.0	21.0	38	
	½	64000	74000	56.0	21.0	38	
	¾	63000	73000	54.0	20.0	36	
	1	62000	72000	52.0	19.0	34	
	1¼	61000	72000	50.0	18.0	32	
Eye-bars, annealed.	¾	64000	72000	54.0	. . . .	. .	The elongation in full length shall be 12.5 per cent. in bars from 10 to 20 feet long, 12.0 per cent. in 21 to 25 feet, 11.5 per cent. in 26 to 30 feet, and 11.0 per cent. in 31 to 35 feet.
	1	64000	72000	53.0	. . . .	. .	
	1½	63000	72000	51.0	. . . .	. .	
	2	63000	72000	50.0	. . . .	. .	
	2½	62000	72000	49.0	. . . .	. .	

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 inches wide, with the same allowances for difference in thickness. In tests cut from the flange, the minimum tensile strength shall be lowered 3000 pounds, the elongation 3 per cent., and the reduction of area 10 per cent.

NOTE.—The allowable content of phosphorus may be raised to .08 per cent. for acid steel, and .05 per cent. for basic, if the best quality is not required, but other specifications must remain the same.

Within the last few years a most important step has been taken in the adoption of a set of Standard American Specifications. I am indebted to Mr. A. L. Colby, of Bethlehem, Pa., for a brief but accurate account of the steps leading to this, and I give the text of the specifications in full. It is unnecessary to say that the requirements are far more rigid than those in use in foreign countries, and many foreign manufacturers refuse to accept these specifications, claiming that they cannot be regularly filled by the ordinary product.

AMERICAN STANDARD SPECIFICATIONS AND METHODS OF TESTING IRON AND STEEL.

Historical Introduction.

By A. L. Colby.

The first successful effort in America to standardize specifications for iron and steel was made in August, 1895, by the Association of American Steel Manufacturers, a technical organization formed to discuss matters pertaining to the manufacture and use of steel. These specifications were revised by the Association on July 17, 1896, and October 23, 1896. They included specifications for structural steel, special open-hearth plate and rivet steel, and structural cast iron.

Although these specifications were criticized and referred to by the technical press and engineers as "manufacturers'" specifications, they nevertheless grew in favor among engineers and consumers when it was appreciated that just as good steel for the various purposes intended was furnished on these specifications as on engineers' specifications containing numerous other stipulations unnecessary in the present state of the art of making steel. These specifications also accomplished the important work of convincing engineers and customers that more prompt deliveries, and more close competition among manufacturers, were possible on standard specifications containing only such requirements and tests as were necessary to ascertain that a satisfactory steel was being furnished, and omitting many useless tests which only serve to add to the expense or cause delay in manufacturing operations.

The formation of the American Section of the International Association for Testing Materials on June 16, 1898, gave an excellent opportunity for engineers, consumers, and manufacturers to come together with a view of framing American standard specifications covering all the various kinds of iron and steel, for among the twenty-two problems which were presented by the parent association, Problem No. 1 asked the American section to co-operate in establishing "international rules and specifications for testing and inspecting iron and steel."

Under authorization of the Executive Committee of the American Section the American branch of Committee No. 1 was increased to thirty-four members, half of whom were engineers, professors in technical schools, consumers of steel, or delegates from scientific societies, and half were representatives from the leading American manufacturers of the various kinds of iron and steel. This committee held frequent meetings beginning March 9, 1899. Its sub-committees collected and tabulated the requirements of existing American specifications which were used as a basis in framing the ten proposed American standard specifications indorsed as representative of the best American practice by a letter ballot of the committee and published in May, 1900. These proposed standards have been discussed by some of the leading American technical societies and journals, as well as by the International Congress on Testing Materials of Construction held in Paris in July, 1900, and by the Iron and Steel Institute in September, 1900.

The American Section of I. A. T. M., at its third annual meeting held in October, 1900, after a detailed discussion, referred the ten proposed standard specifications back to Committee No. 1. The committee, after frequent meetings, again presented them with some modifications at the fourth annual meeting of the American Section, June 29, 1901. They were then adopted subject to a letter ballot of the full membership of the section. This letter ballot, canvassed in August, 1901, indorsed the action of the American Section in adopting as American standards the ten revised specificaions, which are given in full herewith.*

NOTE: Since the above was written by Mr. Colby the situation has been somewhat changed. The American members of the International Society have organized a new body, which has been duly incorporated under the laws of Pennsylvania, under the title: The American Society for Testing Materials. Each member of this society, by virtue of his membership, becomes also a member of the International Society.

This movement was made advisable by two conditions:

(1) The American members deem of first importance the construction of a uniform set of specifications for the use of buyer and seller, while the foreign members wish to discuss the refinements in methods of testing, postponing to the future the construction of a set of specifications.

(2) The results thus far obtained in America toward making

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* These specifications have been issued by Mr. Colby in convenient book form.

working specifications render it very desirable that the work be pursued under some definite organization, representing engineers, manufacturers, inspectors and investigators.

The society was definitely organized at Atlantic City, on June 12, 1902, and elected as its secretary Prof. Edgar Marburg, of the University of Pennsylvania, Philadelphia, Pa. The society will continue without interruption the work begun by the so-called American Branch.

AMERICAN STANDARD SPECIFICATIONS

FOR

STRUCTURAL STEEL FOR BRIDGES AND SHIPS.

Process of Manufacture.

1. Steel shall be made by the open-hearth process.

Chemical Properties.

2. Each of the three classes of structural steel for bridges and ships shall conform to the following limits in chemical composition:

	Steel made by the acid process. Per cent.	Steel made by the basic process. Per cent.
Phosphorus shall not exceed..........	0.08	0.06
Sulphur shall not exceed............	0.06	0.06

Physical Properties.

3. There shall be three classes of structural steel for bridges and ships, namely, RIVET STEEL, SOFT STEEL and MEDIUM STEEL, which shall conform to the following physical qualities:

Classes

4.

Tensile Tests	Rivet Steel.	Soft Steel.	Medium Steel.
Tensile strength, pounds per square inch.......	50,000 to 60,000	52,000 to 62,000	60,000 to 70,000
Yield point, in pounds per square inch, shall not be less than.........	1/2 T. S.	1/2 T. S.	1/2 T. S.
Elongation per cent. in eight inches shall not be less than	26	25	22

Modifications in elongation for thin and thick material.

5. For material less than five-sixteenths inch (5/16″), and more than three fourths inch (3/4″) in thickness, the following modifications shall be made in the requirements for elongation:

(*a*) For each increase of one-eighth-inch (⅛″) in thickness above three-fourths inch (3/4″), a deduction of one per cent. (1%) shall be made from the specified elongation.

(*b*) For each decrease of one-sixteenth-inch (1/16″) in thickness below five-sixteenths inch (5/16″), a deduction of two and one-half per cent. (2½%) shall be made from the specified elongation.

(*c*) For pins made from any of the three classes of steel, the required elongation shall be five per cent. (5%) less than that specified in paragraph No. 4, as determined on a test specimen, the center of which shall be one inch (1″) from the surface.

Tensile Tests for eye-bars.

6. Eye-bars shall be of medium steel. Full-sized tests shall show 12½ per cent. elongation in fifteen feet of the body of the eye-bar, and the tensile strength shall not be less than 55,000 pounds per square inch. Eye-bars shall be required to break in the body, but should an eye-bar break in the head, and show twelve and one-half per cent. (12½%) elongation in fifteen feet and the tensile strength specified, it shall not be cause for rejection, provided that not more than one-third (1/3) of the total number of eye-bars tested break in the head.

Bending Tests.

7. The three classes of structural steel for bridges and ships shall conform to the following bending tests; and for this purpose the test specimen shall be one and one-half inches wide, if possible, and for all material three-fourths inch (¾″) or less in thickness the test specimen shall be of the same thickness as that of the finished material from which it is cut, but for material more than three-fourths inch (¾″) thick the bending test specimen may be one-half inch (½″) thick:

Rivet rounds shall be tested of full size as rolled.

(*d*) Rivet steel shall bend cold 180° flat on itself without fracture on the outside of the bent portion.

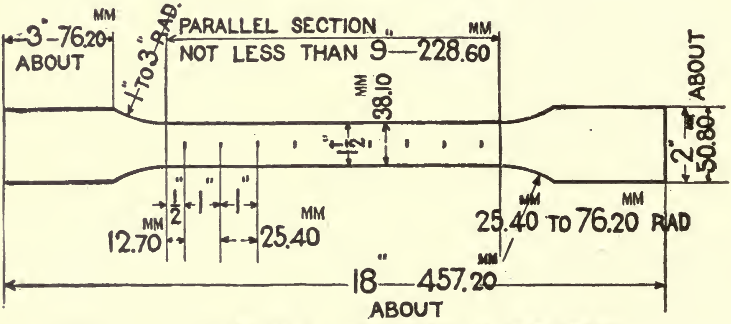
(*e*) Soft steel shall bend cold 180° flat on itself without fracture on the outside of the bent portion.

(*f*) Medium steel shall bend cold 180° around a diameter equal to the thickness of the specimen tested, without fracture on the outside of the bent portion.

Test Pieces and Methods of Testing.

Test Specimen for Tensile Test.

8. The standard test specimen of eight-inch (8″) gauged length, shall be used to determine the physical properties specified in paragraphs Nos. 4 and 5. The standard shape of the test specimen for sheared plates is shown in Fig. XVIII-A. For other material the test specimen may be the same as for sheared plates, or it may be planed or turned parallel throughout its entire length, and in all cases where possible, two opposite sides of the test specimens shall be the rolled surfaces. Rivet rounds and small rolled bars shall be tested of full size as rolled.



PIECE TO BE OF SAME THICKNESS AS THE PLATE.

Fig. XVIII-A.—Eight-inch Test Piece.

Number of Tensile Tests.

9. One tensile test specimen shall be taken from the finished material of each melt, but in case this develops flaws, or breaks outside of the middle third of its gauged length, it may be discarded and another test specimen substituted therefor.

Tests specimen for bending.

10. One test specimen for bending shall be taken from the finished material of each melt as it comes from the rolls, and for material three-fourths inch (¾″) and less in thickness this specimen shall have the natural rolled surface on two opposite sides. The bending test specimen shall be one and one-half inches (1½″) wide, if possible, and for material more than three-fourths inch (¾″) thick the bending test specimen may be one-half inch (½″) thick. The sheared edges of bending test specimens may be milled or planed.

(*g*) The bending test may be made by pressure or by blows.

Annealed Test Specimens

11. Material which is to be used without annealing or further treatment shall be tested for tensile strength in the condition in which it comes from the rolls. Where it is impracticable to secure a test specimen from material which has been annealed or otherwise treated, a full-sized section of tensile test specimen length, shall be similarly treated before cutting the tensile specimen therefrom.

Yield Point.

12. For the purpose of this specification, the yield point shall be determined by the careful observation of the drop of the beam or halt in the gauge of the testing machine.

Sample for Chemical Analysis.

13. In order to determine if the material conforms to the chemical limitations prescribed in paragraph No. 2 herein, analysis shall be made of drillings taken from a small test ingot.

VARIATIONS IN WEIGHT.

14. The variation in cross section or weight of more than 2½ per cent. from that specified will be sufficient cause for rejection, except in the case of sheared plates, which will be covered by the following permissible variations:

(*h*) Plates 12½ pounds per square foot or heavier, up to 100 inches wide, when ordered to weight, shall not average more than 2½ per cent. variation above or 2½ per cent. below the theoretical weight. When 100 inches wide and over, 5 per cent. above or 5 per cent. below the theoretical weight.

(*i*) Plates under 2½ pounds per square foot, when ordered to weight, shall not average a greater variation than the following:

Up to 75 inches wide, 2½ per cent. above or 2½ per cent. below the theoretical weight. 75 inches wide up to 100 inches wide, 5 per cent. above or 3 per cent. below the theoretical weight. When 100 inches wide and over, 10 per cent. above or 3 per cent. below the theoretical weight.

* * * * * * * * * *

(*j*) For all plates ordered to gauge, there will be permitted an average excess of weight over that corresponding to the dimensions on the order equal in amount to that specified in the following table:

TABLE OF ALLOWANCES FOR OVERWEIGHT FOR RECTANGULAR PLATES WHEN ORDERED TO GAUGE.

Plates will be considered up to gauge if measuring not over 1/100 inch less than the ordered gauge.

The weight of 1 cubic inch of rolled steel is assumed to be 0.2833 pound.

PLATES ¼ INCH AND OVER IN THICKNESS.

Thickness of plate.	Width of plate.		
	Up to 75 inches	75 to 100 inches.	Over 100 inches.
Inch.	Per cent.	Per cent.	Per cent.
1/4	10	14	18
5/16	8	12	16
3/8	7	10	13
7/16	6	8	10
1/2	5	7	9
9/16	4½	6½	8½
5/8	4	6	8
Over 5/8	3½	5	6½

PLATES UNDER ¼ INCH IN THICKNESS.

Thickness of plate.	Width of plate.	
	Up to 50 inches.	50 inches and above.
Inch.	Per cent.	Per cent.
1/8 up to 5/32	10	15
5/32 " 3/16	8½	12½
3/16 " 1/4	7	10

FINISH.

15. Finished material must be free from injurious seams, flaws or cracks, and have a workmanlike finish.

BRANDING.

16. Every finished piece of steel shall be stamped with the melt number, and steel for pins shall have the melt number stamped on the ends. Rivets and lacing steel, and small pieces for pin plates and stiffeners, may be shipped in bundles, securely wired together, with the melt number on a metal tag attached.

INSPECTION.

17. The inspector representing the purchaser, shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture, prior to shipment.

AMERICAN STANDARD SPECIFICATIONS

FOR

STRUCTURAL STEEL FOR BUILDINGS.

Process of Manufacture.

1. Steel may be made by either the open-hearth or Bessemer process.

Chemical Properties.

2. Neither of the two classes of structural steel for buildings shall contain more than 0.10 per cent. of phosphorus.

Physical Properties.

Classes.

3. There shall be two classes of structural steel for buildings, namely: RIVET STEEL and MEDIUM STEEL which shall conform to the following physical qualities:

	Rivet Steel.	Medium Steel.
Tensile strength, pounds per square inch.	50,000 to 60,000	60,000 to 70,000
Yield point, in pounds per square inch shall not be less than.....	1/2 T. S.	1/2 T. S.
Elongation, per cent. in eight inches shall not be less than.........	26	22

Modifications in elongation for thin and thick material.

5. For material less than five-sixteenths inch (5/16″), and more than three-fourths inch (¾″) in thickness, the following modifications shall be made in the requirements for elongation:

(*a*) For each increase of one-eighth inch (⅛″) in thickness above three-fourths inch (¾″) a deduction of one per cent. (1%) shall be made from the specified elongation.

(*b*) For each decrease of one-sixteenth inch (1/16″) in thickness below five-sixteenths inch (5/16″) a deduction of two and one-half per cent. (2½%) shall be made from the specified elongation.

(*c*) For pins the required elongation shall be five per cent. (5%) less than that specified in paragraph No. 4, as determined on a test specimen, the center of which shall be one inch (1″) from the surface.

6. The two classes of structural steel for buildings shall conform to the following bending tests; and for this purpose the test specimen shall be one and one-half inches (1½") wide, if possible, and for all material three-fourths inch (¾") or less in thickness the test specimen shall be of the same thickness as that of the finished material from which it is cut, but for material more than three-fourths inch (¾") thick the bending test specimen may be one-half inch (½") thick:

Bending Tests.

Rivet rounds shall be tested of full size as rolled.

(*d*) Rivet steel shall bend cold 180° flat on itself without fracture on the outside of the bent portion.

(*e*) Medium steel shall bend cold 180° around a diameter equal to the thickness of the specimen tested, without fracture on the outside of the bent portion.

TEST PIECES AND METHODS OF TESTING.

7. The standard test specimen of eight-inch (8") gauged length shall be used to determine the physical properties specified in paragraphs Nos. 4 and 5. The standard shape of the test specimen for sheared plates shall be as before shown by Fig. XVIII-A. For other material the test specimen may be the same as for sheared plates, or it may be planed or turned parallel throughout its entire length, and in all cases where possible two opposite sides of the test specimen shall be the rolled surfaces. Rivet rounds and small rolled bars shall be tested of full size as rolled.

Test Specimen for Tensile Tests.

8. One tensile test specimen shall be taken from the finished material of each melt or blow, but in case this develops flaws, or breaks outside of the middle third of its gauged length, it may be discarded and another test specimen substituted therefor.

Number of Tensile Tests.

9. One test specimen for bending shall be taken from the finished material of each melt or blow as it comes from the rolls and for material three-fourths inch (¾") and less in thickness this specimen shall have the natural rolled surface on two opposite sides. The bending test specimen shall be one and one-half inches (1½") wide, if possible, and for material more than three-fourths inch (¾") thick the bending test specimen may be one-half inch (½") thick. The sheared edges of bending test specimens may be milled or planed.

Test Specimen for Bending.

Rivet rounds shall be tested of full size as rolled.

(*f*) The bending test may be made by pressure or by blows.

Annealed Test Specimens.

10. Material which is to be used without annealing or further treatment shall be tested for tensile strength in the condition in which it comes from the rolls. Where it is impracticable to secure a test specimen from material which has been annealed or otherwise treated, a full-sized section of tensile test specimen length shall be similarly treated before cutting the tensile test specimen therefrom.

Yield Point.

11. For the purpose of this specification, the yield point shall be determined by the careful observation of the drop of the beam or halt in the gauge of the testing machine.

Samples for Chemical Analysis.

12. In order to determine if the material conforms to the chemical limitations prescribed in paragraph No. 2 herein, analysis shall be made of drillings taken from a small test ingot.

VARIATION IN WEIGHT.

13. The variation in cross section or weight of more than 2½ per cent.. from that specified will be sufficient cause for rejection, except in the case of sheared plates, which will be covered by the following permissible variations:

(*g*) Plates 12½ pounds per square foot or heavier, up to 100 inches wide, when ordered to weight, shall not average more than 2½ per cent. variation above or 2½ per cent. below the theoretical weight. When 100 inches wide and over, 5 per cent. above or 5 per cent. below the theoretical weight.

(*h*) Plates under 12½ pounds per square foot, when ordered to weight, shall not average a greater variation than the following: Up to 75 inches wide, 2½ per cent. above or 2½ per cent. below the theoretical weight. 75 inches wide up to 100 inches wide, 5 per cent. above or 3 per cent. below the theoretical weight. When 100 inches wide and over, 10 per cent. above or 3 per cent. below the theoretical weight.

* * * * * * * *

(*i*) For all plates ordered to gauge, there will be permitted an average excess of weight over that corresponding to the dimensions on the order equal in amount to that specified in the following table:

TABLE OF ALLOWANCES FOR OVERWEIGHT FOR RECTANGULAR PLATES WHEN ORDERED TO GAUGE.

Plates will be considered up to gauge if measuring not over 1/100 inch less than the ordered gauge.

The weight of 1 cubic inch of rolled steel is assumed to be 0.2833 pound.

PLATES ¼ INCH AND OVER IN THICKNESS.

Thickness of plate.	Width of plate.		
	Up to 50 inches	75 to 100 inches.	Over 100 inches.
Inch.	Per cent.	Per cent.	Per cent.
1/4	10	14	18
5/16	8	12	16
3/8	7	10	13
7/16	6	8	10
1/2	5	7	9
9/16	4½	6½	8½
5/8	4	6	8
Over 5/8	3½	5	6½

PLATES UNDER ¼ INCH IN THICKNESS.

Thickness of plate.	Width of plate.	
	Up to 50 inches	50 inches and above.
Inch.	Per cent.	Per cent.
1/8 up to 5/32	10	15
5/32 " 3/16	8½	12½
3/16 " 1/4	7	10

FINISH.

14. Finished material must be free from injurious seams, flaws or cracks, and have a workmanlike finish.

BRANDING.

15. Every finished piece of steel shall be stamped with the melt or blow number, except that small pieces may be shipped in bundles securely wired together with the melt or blow number on a metal tag attached.

INSPECTION.

16. The inspector representing the purchaser shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture, prior to shipment.

AMERICAN STANDARD SPECIFICATIONS

FOR

OPEN-HEARTH BOILER PLATE AND RIVET STEEL.

PROCESS OF MANUFACTURE.

1. Steel shall be made by the open-hearth process.

CHEMICAL PROPERTIES.

2. There shall be three classes of open-hearth boiler plate and rivet steel, namely: FLANGE OR BOILER STEEL, FIRE BOX STEEL and EXTRA SOFT STEEL, which shall conform to the following limits in chemical composition:

	Flange or Boiler steel. Per cent.	Fire box steel. Per cent.	Extra soft steel. Per cent.
Phosphorus shall not exceed....	Basic 0.04 Acid 0.06	Basic 0.03 Acid 0.04	0.04
Sulphur shall not exceed.......	0.05	0.04	0.04
Manganese	0.30 to 0.60	0.30 to 0.50	0.30 to 0.50

Boiler Rivet Steel. 3. Steel for boiler rivets shall be of the EXTRA SOFT class, as specified in paragraphs Nos. 2 and 4.

PHYSICAL PROPERTIES.

4. The three classes of open-hearth boiler plate and rivet steel, namely: FLANGE OR BOILER STEEL, FIRE BOX STEEL and EXTRA SOFT STEEL, shall conform to the following physical qualities:

	Flange or boiler steel.	Fire box steel.	Extra soft steel.
Tensile strength, pounds per square inch......	55,000 to 65,000	52,000 to 62,000	45,000 to 55,000
Yield point, in pounds per square inch shall not be less than.........	1/2 T. S.	1/2 T. S.	1/2 T. S.
Elongation, per cent. in eight inches shall not be less than	25	26	28

Modifications in elongation for thin and thick material. 5. For material less than five-sixteenths inch (5/16″), and more than three-fourths inch (¾″) in thickness, the following modifications shall be made in the requirements for elongation:

(*a*) For each increase of one-eighth inch (⅛″)

in thickness above three-fourths inch (¾″), a deduction of one per cent. (1%) shall be made from the specified elongation.

(b) For each decrease of one-sixteenth-inch (1/16″) in thickness below five-sixteenths inch (5/16″) a deduction of two and one-half per cent. (2½%) shall be made from the specified elongation.

Bending Tests.

6. The three classes of open-hearth boiler plate and rivet steel shall conform to the following bending tests; and for this purpose the test specimen shall be one and one-half inches (1½″) wide if possible, and for all material three-fourths inch (¾″) or less in thickness the test specimen shall be of the same thickness as that of the finished material from which it is cut; but for material more than three-fourths inch (¾″) thick, the bending test specimen may be one-half inch (½″) thick.

Rivet rounds shall be tested of full size as rolled.

(*c*) Test specimens cut from the rolled material as specified above, shall be subjected to a cold bending test, and also to a quenched bending test. The cold bending test shall be made on the material in the condition in which it is to be used, and prior to the quenched bending test, the specimen shall be heated to a light cherry-red as seen in the dark and quenched in water, the temperature of which is between 80° and 90° Fahrenheit.

(*d*) Flange or boiler steel, fire box steel and rivet steel, both before and after quenching, shall bend cold one hundred and eighty degrees (180°) flat on itself without fracture on the outside of the bent portion.

Homogeneity Tests.

7. For fire box steel a sample taken from a broken tensile test specimen, shall not show any single seam or cavity more than one-fourth inch (¼″) long in either of the three fractures obtained on the test for homogeneity as described below in paragraph 12.

TEST PIECES AND METHODS OF TESTING.

Test Specimen for Tensile Test.

8. The standard test specimen of eight-inch (8″) gauged length shall be used to determine the physical properties specified in paragraphs Nos. 4 and 5. The standard shape of the test specimen for sheared plates shall be as before shown by Fig. XVIII-A. For other material the test specimen may be the same as for sheared plates, or it may

be planed or turned parallel throughout its entire length and in all cases where possible two opposite sides of the test specimens shall be the rolled surfaces. Rivet rounds and small rolled bars shall be tested of full size as rolled.

Number of Tensile Tests.

9. One tensile test specimen will be furnished from each plate as it is rolled, and two tensile test specimens will be furnished from each melt of rivet rounds. In case any one of these develops flaws or breaks outside of the middle third of its gauged length, it may be discarded and another test specimen substituted therefor.

Test Specimens for Bending.

10. For material three-fourths inch (¾″) or less in thickness, the bending test specimen shall have the natural rolled surface on two opposite sides. The bending test specimens cut from plates shall be one and one-half inches (1½″) wide and for material more than three-fourths (¾″) thick the bending test specimens may be one-half inch (½″) thick. The sheared edges of bending test specimens may be milled or planed. The bending test specimens for rivet rounds shall be of full size as rolled. The bending test may be made by pressure or by blows.

Number of Bending Tests.

11. One cold bending specimen and one quenched bending specimen will be furnished from each plate as it is rolled. Two cold bending specimens and two quenched bending specimens will be furnished from each melt of rivet rounds. The homogeneity test for fire box steel shall be made on one of the broken tensile test specimens.

Homogeneity Tests for Fire Box Steel.

12. The homogeneity test for fire box steel is made as follows: A portion of the broken tensile test specimen is either nicked with a chisel or grooved on a machine, transversely about a sixteenth of an inch (1/16″) deep, in three places about two inches (2″) apart. The first groove should be made on one side, two inches (2″) from the square end of the specimen; the second, two inches (2″) from it on the opposite side; and the third, two inches (2″) from the last, and on the opposite side from it. The test specimen is then put in a vise, with the first groove about a quarter of an inch (¼″) above the jaws, care being taken to hold it firmly. The projecting end of the test specimen is then broken off by means of a hammer, a number of light blows being used, and the bending being away from the groove. The specimen is broken at the other two grooves in the same way. The object of this treatment is to open and render

visible to the eye any seams due to failure to weld up, or to foreign interposed matter, or cavities due to gas bubbles in the ingot. After rupture, one side of each fracture is examined, a pocket lens being used if necessary, and the length of the seams and cavities is determined.

Yield Point.

13. For the purposes of this specification, the yield point shall be determined by the careful observation of the drop of the beam or halt in the gauge of the testing machine.

Sample for Chemical Analysis.

14. In order to determine if the material conforms to the chemical limitations prescribed in paragraph No. 2 herein, analysis shall be made of drillings taken from a small test ingot. An additional check analysis may be made from a tensile specimen of each melt used on an order, other than in locomotive fire box steel. In the case of locomotive fire box steel a check analysis may be made from the tensile specimen from each plate as rolled.

VARIATION IN WEIGHT.

15. The variation in cross section or weight of more than 2½ per cent. from that specified will be sufficient cause for rejection, except in the case of sheared plates, which will be covered by the following permissible variations:

(*e*) Plates 12½ pounds per square foot or heavier, up to 100 inches wide, when ordered to weight, shall not average more than 2½ per cent. variation above or 2½ per cent. below the theoretical weight. When 100 inches wide and over, 5 per cent. above or 5 per cent. below the theoretical weight.

(*f*) Plates under 12½ pounds per square foot, when ordered to weight, shall not average a greater variation than the following: Up to 75 inches wide, 2½ per cent. above or 2½ per cent. below the theoretical weight. 75 inches wide up to 100 inches wide, 5 per cent. above or 3 per cent. below the theoretical weight. When 100 inches wide and over, 10 per cent. above or 3 per cent. below the theoretical weight.

* * * * * * * *

(*g*) For all plates ordered to gauge, there will be permitted an average excess of weight over that corresponding to the dimensions on the order equal in amount to that specified in the following table:

TABLE OF ALLOWANCES FOR OVERWEIGHT FOR RECTANGULAR PLATES WHEN ORDERED TO GAUGE.

Plates will be considered up to gauge if measuring not over 1/100 inch less than the ordered gauge.

The weight of 1 cubic inch of rolled steel is assumed to be 0.2833 pound.

PLATES ¼ INCH AND OVER IN THICKNESS.

Thickness of plate.	Width of plate.		
	Up to 75 inches.	75 to 100 inches.	Over 100 inches.
Inch.	Per cent.	Per cent.	Per cent.
1/4	10	14	18
5/16	8	12	16
3/8	7	10	13
7/16	6	8	10
1/2	5	7	9
9/16	4½	6½	8½
5/8	4	6	8
Over 5/8	3½	5	6½

PLATES UNDER ¼ INCH IN THICKNESS.

Thickness of plate.	Width of plate.	
	Up to 50 inches.	50 inches and above.
Inch.	Per cent.	Per cent.
1/8 up to 5/32	10	15
5/32 " 3/16	8½	12½
3/16 " 1/4	7	10

FINISH.

16. All finished material shall be free from injurious surface defects and laminations, and must have a workmanlike finish.

BRANDING.

17. Every finished piece of steel shall be stamped with the melt number, and each plate, and the coupon or test specimen cut from it, shall be stamped with a separate identifying mark or number. Rivet steel may be shipped in bundles securely wired together with the melt number on a metal tag attached.

INSPECTION.

18. The inspector representing the purchaser, shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture, prior to shipment.

AMERICAN STANDARD SPECIFICATIONS

FOR

STEEL RAILS.

PROCESS OF MANUFACTURE.

1. (*a*) Steel may be made by the Bessemer or open-hearth process.

(*b*) The entire process of manufacture and testing shall be in accordance with the best standard current practice, and special care shall be taken to conform to the following instructions.

(*c*) Ingots shall be kept in a vertical position in pit heating furnaces.

(*d*) No bled ingots shall be used.

(*e*) Sufficient material shall be discarded from the top of the ingots to insure sound rails.

CHEMICAL PROPERTIES.

2. Rails of the various weights per yard specified below shall conform to the following limits in chemical composition:

	50 to 59+ pounds. Per cent.	60 to 69+ pounds. Per cent.	70 to 79+ pounds. Per cent.	80 to 89+ pounds. Per cent.	90 to 100 pounds. Per cent.
Carbon	0.35--0.45	0.38--0.48	0.40--0.50	0.43--0.53	0.45--0.55
Phosphorus shall not exceed	0.10	0.10	0.10	0.10	0.10
Silicon shall not exceed	0.20	0.20	0.20	0.20	0.20
Manganese	0.70--1.00	0.70--1.00	0.75--1.05	0.80--1.10	0.80--1.10

PHYSICAL PROPERTIES.

3. One drop test shall be made on a piece of rail not more than six feet long, selected from every fifth blow of steel. The rail shall be placed head upwards on the supports and the various sections shall be subjected to the following impact tests:

Drop Test.

Weight of rail. Pounds per yard.	Height of drop. Feet.
45 to and including 55	15
More than 55 " 65	16
" 65 " 75	17
" 75 " 85	18
" 85 " 100	19

If any rail break when subjected to the drop test, two additional tests will be made of other rails from the same blow of steel, and if either of these latter tests fail all the rails of the blow which they represent will be rejected, but if both of these additional test pieces meet the requirements, all the rails of the blow which they represent will be accepted. If the rails from the tested blow shall be rejected for failure to meet the requirements of the drop test as above specified, two other rails will be subjected to the same tests, one from the blow next preceding, and one from the blow next succeeding the rejected blow. In case the first test taken from the preceding or succeeding blow shall fail, two additional tests shall be taken from the same blow of steel, the acceptance or rejection of which shall also be determined as specified above, and if the rails of the preceding or succeeding blow shall be rejected, similar tests may be taken from the previous or following blows, as the case may be, until the entire group of five blows is tested, if necessary.

The acceptance or rejection of all the rails from any blow will depend upon the result of the tests thereof.

Test Pieces and Methods of Testing.

Drop Testing Machine.

4. The drop test machine shall have a tup of two thousand (2000) pounds weight, the striking face of which shall have a radius of not more than five inches (5″), and the test rail shall be placed head upwards on solid supports three feet (3′) apart. The anvil block shall weigh at least twenty thousand (20,000) pounds, and the supports shall be a part of, or firmly secured to, the anvil. The report of the drop test shall state the atmospheric temperature at the time the tests were made.

Sample for Chemical Analysis.

5. The manufacturer shall furnish the inspector, daily, with carbon determinations of each blow, and a complete chemical analysis every twenty-four hours, representing the average of the other elements contained in the steel. These analyses shall be made on drillings taken from a small test ingot.

Finish.

Section.

6. Unless otherwise specified, the section of rail shall be the American Standard, recommended by the American Society of Civil Engineers, and shall conform, as accurately as possible, to the templet furnished by the railroad company, consistent with paragraph No. 7, relative to specified

weight. A variation in height of one sixty-fourth of an inch (1/64″) less and one thirty-second of an inch (1/32″) greater than the specified height will be permitted. A perfect fit of the splice bars, however, shall be maintained at all times.

Weight.

7. The weight of the rails shall be maintained as nearly as possible after complying with paragraph No. 6, to that specified in contract. A variation of one-half of one per cent. (½%) for an entire order will be allowed. Rails shall be accepted and paid for according to actual weights.

Length.

8. The standard length of rails shall be thirty feet (30′). Ten per cent. (10%) of the entire order will be accepted in shorter lengths, varying by even feet down to twenty-four feet (24′). A variation of one-fourth of an inch (¼″) in length from that specified will be allowed.

Drilling.

9. Circular holes for splice bars shall be drilled in accordance with the specifications of the purchaser. The holes shall accurately conform to the drawing and dimensions furnished in every respect, and must be free from burrs.

Finish.

10. Rails shall be straightened while cold, smooth on head, sawed square at ends, and, prior to shipment, shall have the burr occasioned by the saw cutting, removed, and the ends made clean. Number 1 rails shall be free from injurious defects and flaws of all kinds.

BRANDING.

11. The name of the maker, the month and year of manufacture, shall be rolled in raised letters on the side of the web, and the number of the blow shall be stamped on each rail.

INSPECTION.

12. The inspector representing the purchaser shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture, prior to shipment.

NO. 2 RAILS.

13. Rails that possess any injurious physical defects, or which for any other cause are not suitable for first quality, or No. 1 rails,

shall be considered as No. 2 rails, provided, however, that rails which contain any physical defects which seriously impair their strength shall be rejected. The ends of all No. 2 rails shall be painted in order to distinguish them.

AMERICAN STANDARD SPECIFICATIONS

FOR

STEEL SPLICE BARS.

PROCESS OF MANUFACTURE.

1. Steel for splice bars may be made by the Bessemer or open-hearth process.

CHEMICAL PROPERTIES.

2. Steel for splice bars shall conform to the following limits in chemical composition:

	Per cent.
Carbon shall not exceed	0.15
Phosphorus shall not exceed	0.10
Manganese	0.30 to 0.60

PHYSICAL PROPERTIES.

Tensile Tests.

3. Splice bar steel shall conform to the following physical qualities:

Tensile strength, pounds per square inch	54,000 to 64,000
Yield point, pounds per square inch	32,000
Elongation, per cent. in eight inches shall not be less than	25

Bending Tests.

4. (*a*) A test specimen cut from the head of the splice bar shall bend 180° flat on itself without fracture on the outside of the bent portion.

(*b*) If preferred the bending tests may be made on an unpunched splice bar, which, if necessary, shall be first flattened, and shall then be bent 180° flat on itself without fracture on the outside of the bent portion.

TEST PIECES AND METHODS OF TESTING.

Test Specimen for Tensile Tests.

5. A test specimen of eight-inch (8″) gauged length, cut from the head of the splice bar, shall be used to determine the physical properties specified in paragraph No. 3.

Number of Tensile Tests.

6. One tensile test specimen shall be taken from the rolled splice bars of each blow or melt, but in case this develops flaws, or breaks outside of the middle third of its gauged length, it may be discarded and another test specimen substituted therefor.

Test Specimen for Bending.

7. One test specimen cut from the head of the splice bar shall be taken from a rolled bar of each blow or melt, or if preferred the bending test may be made on an unpunched splice bar, which, if necessary, shall be flattened before testing. The bending test may be made by pressure or by blows.

Yield Point.

8. For the purposes of this specification, the yield point shall be determined by the careful observation of the drop of the beam or halt in the gauge of the testing machine.

Sample for Chemical Analysis.

9. In order to determine if the material conforms to the chemical limitations prescribed in paragraph No. 2 herein, analysis shall be made of drillings taken from a small test ingot.

FINISH.

10. All splice bars shall be smoothly rolled and true to templet. The bars shall be sheared accurately to length and free from fins and cracks, and shall perfectly fit the rails for which they are intended. The punching and notching shall accurately conform in every respect to the drawing and dimensions furnished. A variation in weight of more than 2½ per cent. from that specified will be sufficient cause for rejection.

BRANDING.

11. The name of the maker and the year of manufacture shall be rolled in raised letters on the side of the splice bar.

INSPECTION.

12. The inspector representing the purchaser, shall have all reasonable facilities afforded to him by the manufacturer, to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture, prior to shipment.

AMERICAN STANDARD SPECIFICATIONS

FOR

STEEL AXLES.

PROCESS OF MANUFACTURE.

1. Steel for axles shall be made by the open-hearth process.

CHEMICAL PROPERTIES.

2. There will be three classes of steel axles which shall conform to the following limits in chemical composition:

	Car, engine truck and tender truck axles. Per cent.	Driving wheel axles. (Carbon steel.) Per cent.	Driving wheel axles. (Nickel steel.) Per cent.
Phosphorus shall not exceed...	0.06	0.06	0.04
Sulphur " " "	0.06	0.06	0.04
Nickel	....	....	3.00-4.00

PHYSICAL PROPERTIES.

Tensile Tests.

3. For car, engine truck, and tender truck axles no tensile test shall be required.

4. The minimum physical qualities required in the two classes of driving wheel axles shall be as follows:

	Driving wheel axles. (Carbon steel.)	Driving wheel axles. (Nickel steel.)
Tensile strength, pounds per square inch..	80,000	80,000
Yield point, pounds per square inch......	40,000	50,000
Elongation, per cent. in two inches.....	18	25
Contraction of area per cent...........	..	45

Drop Test.

5. One axle selected from each melt, when tested by the drop test described in paragraph No. 9, shall stand the number of blows at the height specified in the following table without rupture and without exceeding, as the result of the first blow, the deflection given. Any melt failing to meet these requirements will be rejected.

Diameter of axle at center. Inches.	Number of blows.	Height of drop. Feet.	Deflection. Inches.
4 1/4	5	24	8 1/4
4 3/8	5	26	8 1/4
4 7/16	5	28 1/2	8 1/4
4 5/8	5	31	8
4 3/4	5	34	8
5 3/8	5	43	7
5 7/8	7	43	5 1/2

6. Carbon steel and nickel steel driving wheel axles shall not be subject to the above drop test.

TEST PIECES AND METHODS OF TESTING.

Test Specimen for Tensile Tests.

7. The standard turned test specimen one-half inch (½″) diameter and two-inch (2″) gauged length, shall be used to determine the physical properties specified in paragraph No. 4. It is shown in Fig. XVIII-B.

Number and Location of Tensile Specimens

8. For driving axles one longitudinal test specimen shall be cut from one axle of each melt. The center of this test specimen shall be half way between the center and outside of the axle.

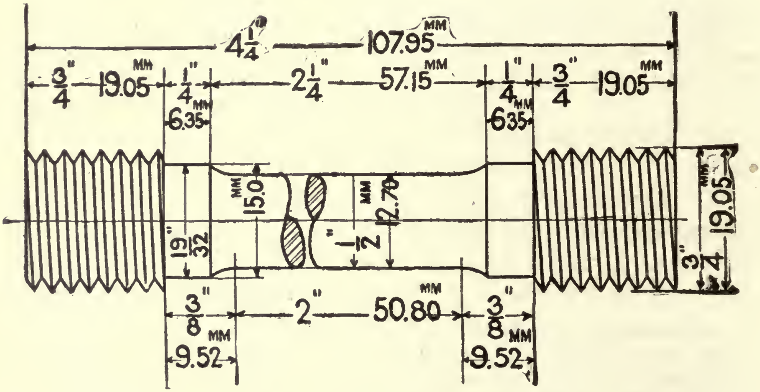


FIG. XVIII-B.—TWO-INCH TEST PIECE.

Drop Test Described.

9. The points of supports on which the axle rests during tests must be three feet apart from center to center; the tup must weigh 1640 pounds; the anvil, which is supported on springs, must weigh 17,500 pounds; it must be free to move in a vertical direction; the springs upon which it rests must be twelve in number, of the kind described on drawing; and the radius of supports and of the striking face on the tup in the direction of the axis of the axle must be five (5) inches. When an axle is tested it must be so placed in the machine that the tup will strike it midway between the ends, and it must be turned over after the first and third blows, and when required, after the fifth blow. To measure the deflection after the first blow prepare a straight

edge as long as the axle, by reinforcing it on one side, equally at each end, so that when it is laid on the axle, the reinforced parts will rest on the collars or ends of the axle, and the balance of the straight edge not touch the axle at any place. Next place the axle in position for test, lay the straight edge on it, and measure the distance from the straight edge to the axle at the middle point of the latter. Then after the first blow, place the straight edge on the now bent axle in the same manner as before, and measure the distance from it to that side of the axle next to the straight edge at the point farthest away from the latter. The difference beween the two measurements is the deflection. The report of the drop test shall state the atmospheric temperature at the time the tests were made.

Yield Point.

10. The yield point specified in paragraph No. 4 shall be determined by the careful observation of the drop of the beam, or halt in the gauge of the testing machine.

Sample for Chemical Analysis.

11. Turnings from the tensile test specimen of driving axles, or drillings taken midway between the center and outside of car, engine, and tender truck axles, or drillings from the small test ingot if preferred by the inspector, shall be used to determine whether the melt is within the limits of chemical composition specified in paragraph No. 2.

FINISH.

12. Axles shall conform in sizes, shapes and limiting weights to the requirements given on the order or print sent with it. They shall be made and finished in a workmanlike manner, and shall be free from all injurious cracks, seams or flaws. In centering, sixty (60) degree centers must be used, with clearance given at the point to avoid dulling the shop lathe centers.

BRANDING.

13. Each axle shall be legibly stamped with the melt number and initials of the maker at the places marked on the print or indicated by the inspector.

INSPECTION.

14. The inspector representing the purchaser, shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these

specifications. All tests and inspections shall be made at the place of manufacture, prior to shipment.

AMERICAN STANDARD SPECIFICATIONS

FOR

STEEL TIRES.

Process of Manufacture.

1. Steel for tires may be made by either the open-hearth or crucible process.

Chemical Properties.

2. There will be three classes of steel tires which shall conform to the following limits in chemical composition:

	Passenger engines. Per cent.	Freight engine and car wheels. Per cent.	Switching engines. Per cent.
Manganese shall not exceed....	0.80	0.80	0.80
Silicon shall not be less than...	0.20	0.20	0.20
Phosphorus shall not exceed....	0.05	0.05	0.05
Sulphur shall not exceed.......	0.05	0.05	0.05

Physical Properties.

Tensile Tests,

3. The minimum physical qualities required in each of the three classes of steel tires shall be as follows:

	Passenger engines.	Freight engine and car wheels.	Switching engines.
Tensile strength, pounds per square inch.	100,000	110,000	120,000
Elongation, per cent. in two inches.......	12	10	8

Drop Test.

4. In the event of the contract calling for a drop test, a test tire from each melt will be furnished at the purchaser's expense, provided it meets the requirements. This test tire shall stand the drop test described in paragraph No. 7, without breaking or cracking, and shall show a minimum deflection equal to $D^2 \div (40T^2 + 2D)$, the letter "D" being internal diameter and the letter "T" thickness of tire at center of tread.

TEST PIECES AND METHODS OF TESTING.

Test Specimen for Tensile Tests.

5. The standard turned test specimen, one-half inch (½″) diameter and two-inch (2″) gauged length, shall be used to determine the physical properties specified in paragraph No. 3. It has been already shown in Fig. XVIII-B.

Location of Tensile Specimens.

6. When the drop test is specified, this test specimen shall be cut cold from the tested tire at the point least affected by the drop test. If the diameter of the tire is such that the whole circumference of the tire is seriously affected by the drop test, or if no drop test is required, the test specimen shall be forged from a test ingot cast when pouring the melt, the test ingot receiving, as nearly as possible, the same proportion of reduction as the ingots from which the tires are made.

Drop Test Described.

7. The test tire shall be placed vertically under the drop in a running position on a solid foundation of at least ten tons in weight and subjected to successive blows from a tup weighing 2240 pounds, falling from increasing heights until the required deflection is obtained.

Sample for Chemical Analysis.

8. Turnings from the tensile specimen, or drillings from the small test ingot, or turnings from the tire if preferred by the inspector, shall be used to determine whether the melt is within the limits of chemical composition specified in paragraph No. 2.

FINISH.

9. All tires shall be free from cracks, flaws, or other injurious imperfections, and shall conform to dimensions shown on drawings furnished by the purchaser.

BRANDING.

10. Tires shall be stamped with the maker's brand and number in such a manner that each individual tire may be identified.

INSPECTION.

11. The inspector representing the purchaser, shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture, prior to shipment.

AMERICAN STANDARD SPECIFICATIONS

FOR

STEEL FORGINGS.

Process of Manufacture.

1. Steel for forgings may be made by the open-hearth, crucible or Bessemer process.

Chemical Properties.

2. There will be four classes of steel forgings which shall conform to the following limits in chemical composition:

	Forgings of soft or low carbon steel.	Forgings of carbon steel not annealed.	Forgings of carbon steel, oil tempered or annealed.	Forgings of nickel steel, oil tempered or annealed.
	Per cent.	Per cent.	Per cent.	Per cent.
Phosphorus shall not exceed.......	0.10	0.06	0.04	0.04
Sulphur "	0.10	0.06	0.04	0.04
Nickel "	....	....	....	3.00-4.00

Physical Properties.

Tensile Tests.

3. The minimum physical qualities required of the different sized forgings of each class shall be as follows:

Tensile strength.	Yield point.	Elongation in 2".	Contraction of area.	
Pounds per square inch.		Per cent.		
				Soft Steel or Low Carbon Steel.
58,000	29,000	28	35	For solid or hollow forgings, no diameter or thickness of section to exceed 10".
				Carbon Steel not Annealed.
75,000	37,500	18	30	For solid or hollow forgings, no diameter or thickness of section to exceed 10".
	Elastic limit			Carbon Steel Annealed.
80,000	40,000	22	35	For solid or hollow forgings, no diameter or thickness of section to exceed 10".
75,000	37,500	23	35	For solid forgings, no diameter to exceed 20" or thickness of section 15".
70,000	35,000	24	30	For solid forgings, over 20" diameter.
				Carbon Steel, Oil Tempered.
90,000	55,000	20	45	For solid or hollow forgings, no diameter or thickness of section to exceed 3".

Tensile strength.	Elastic limit.	Elongation in 2".	Contraction of area.	
Pounds per square inch.		Per cent.		
				CARBON STEEL, OIL TEMPERED.
85,000	50,000	22	45	For solid forgings of rectangular sections not exceeding 6" in thickness or hollow forgings, the walls of which do not exceed 6" in thickness.
80,000	45,000	23	40	For solid forgings of rectangular sections not exceeding 10" in thickness or hollow forgings, the walls of which do not exceed 10" in thickness.
				NICKEL STEEL ANNEALED.
80,000	50,000	25	45	For solid or hollow forgings, no diameter or thickness of section to exceed 10".
80,000	45,000	25	45	For solid forgings, no diameter to exceed 20" or thickness of section 15".
80,000	45,000	24	40	For solid forgings, over 20" diameter.
				NICKEL STEEL, OIL TEMPERED.
95,000	65,000	21	50	For solid or hollow forgings, no diameter or thickness of section to exceed 3".
90,000	60,000	22	50	For solid forgings of rectangular sections not exceeding 6" in thickness or hollow forgings, the walls of which do not exceed 6" in thickness.
85,000	55,000	24	45	For solid forgings of rectangular sections not exceeding 10" in thickness or hollow forgings, the walls of which do not exceed 10" in thickness.

Bending Test.

4. A specimen one inch by one-half inch (1"x½") shall bend cold 180° without fracture on outside of bent portion, as follows:

Around a diameter of ½", for forgings of soft steel.

Around a diameter of 1½", for forgings of carbon steel not annealed.

Around a diameter of 1½", for forgings of carbon steel if 20" in diameter or over.

Around a diameter of 1", for forgings of carbon steel annealed, if under 20" diameter.

Around a diameter of 1" for forgings of carbon steel oil-tempered.

Around a diameter of ½", for forgings of nickel steel annealed.

Around a diameter of 1", for forgings of nickel steel oil-tempered.

TEST PIECES AND METHODS OF TESTING.

Test Specimen for Tensile Test.

5. The standard turned test specimen, one-half inch (½″) diameter and two-inch (2″) gauged length, shall be used to determine the physical properties specified in paragraph No. 3. It has already been shown in Fig. XVIII-B.

Number and Location of Tensile Specimens.

6. The number and location of test specimens to be taken from a melt, blow, or a forging shall depend upon its character and importance and must therefore be regulated by individual cases. The test specimens shall be cut cold from the forging or full-sized prolongation of same, parallel to the axis of the forging and half way between the center and outside, the specimens to be longitudinal, i.e., the length of the specimen to correspond with the direction in which the metal is most drawn out or worked. When forgings have large ends or collars, the test specimens shall be taken from a prolongation of the same diameter or section as that of the forging back of the large end or collar. In the case of hollow shafting, either forged or bored, the specimen shall be taken within the finished section prolonged, half way between the inner and outer surface of the wall of the forging.

Test Specimen for Bending.

7. The specimen for bending test one inch by one-half inch (1″x½″) shall be cut as specified in paragraph No. 6. The bending test may be made by pressure or by blows.

Yield Point.

8. The yield point specified in paragraph No. 3 shall be determined by the careful observation of the drop of the beam, or halt in the gauge of the testing machine.

Elastic Limit.

9. The elastic limit specified in paragraph No. 3 shall be determined by means of an extensometer, which is to be attached to the test specimen in such manner as to show the change in rate of extension under uniform rate of loading, and will be taken at that point where the proportionality changes.

Sample for Chemical Analysis.

10. Turnings from the tensile specimen or drillings from the bending specimen or drillings from the small test ingot, if preferred by the inspector, shall be used to determine whether or not the steel is within the limits in chemical composition specified in paragraph No. 2.

FINISH.

11. Forgings shall be free from cracks, flaws, seams or other

injurious imperfections, and shall conform to dimensions shown on drawings furnished by the purchaser, and be made and finished in a workmanlike manner.

INSPECTION.

12. The inspector representing the purchaser shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture, prior to shipment.

AMERICAN STANDARD SPECIFICATIONS
FOR
STEEL CASTINGS.

PROCESS OF MANUFACTURE.

1. Steel for castings may be made by the open-hearth, crucible or Bessemer process. Castings to be annealed or unannealed as specified.

CHEMICAL PROPERTIES.

rdinary Castings.

2. Ordinary castings, those in which no physical requirements are specified, shall not contain over 0.40 per cent. of carbon, nor over 0.08 per cent. of phosphorus.

Tested Castings.

3. Castings which are subjected to physical test shall not contain over 0.05 per cent. of phosphorus, nor over 0.05 per cent. of sulphur.

PHYSICAL PROPERTIES.

Tensile Tests.

4. Tested castings shall be of three classes: "HARD," "MEDIUM" and "SOFT." The minimum physical qualities required in each class shall be as follows:

	Hard castings.	Medium castings.	Soft castings.
Tensile strength, pounds per square inch.....	85,000	70,000	60,000
Yield point, pounds per square inch..........	38,250	31,500	27,000
Elongation, per cent. in two inches..........	15	18	22
Contraction of area, per cent................	20	25	30

5. A test to destruction may be substituted for the tensile test,

in the case of small or unimportant castings, by selecting three castings from a lot. This test shall show the material to be ductile and free from injurious defects, and suitable for the purposes intended. A lot shall consist of all castings from the same melt or blow, annealed in the same furnace charge.

Drop Test.

6. Large castings are to be suspended and hammered all over. No cracks, flaws, defects, nor weakness shall appear after such treatment.

Percussive Test.

7. A specimen one inch by one-half inch (1″x½″) shall bend cold around a diameter of one inch (1″) without fracture on outside of bent portion, through an angle of 120° for "SOFT" castings, and of 90° for "MEDIUM" castings.

Bending Test.

TEST PIECES AND METHODS OF TESTING.

8. The standard turned test specimen, one-half inch (½″) diameter and two-inch (2″) gauged length, shall be used to determine the physical properties specified in paragraph No. 4. It has already been shown in Fig. XVIII-B.

Test Specimen for Tensile Tests.

9. The number of standard test specimens shall depend upon the character and importance of the castings. A test piece shall be cut cold from a coupon to be molded and cast on some portion of one or more castings from each melt or blow or from the sink-heads (in case heads of sufficient size are used). The coupon or sink-head must receive the same treatment as the casting or castings, before the specimen is cut out, and before the coupon or sink-head is removed from the casting.

Number and Location of Tensile Specimens.

10. One specimen for bending test one inch by one-half inch (1″x½″) shall be cut cold from the coupon or sink-head of the casting or castings as specified in paragraph No. 9. The bending test may be made by pressure, or by blows.

Test Specimen for Bending.

11. The yield point specified in paragraph No. 4 shall be determined by the careful observation of the drop of the beam or halt in the gauge of the testing machine.

Yield Point.

12. Turnings from the tensile specimen, drillings from the

bending specimen, or drillings from the small test ingot, if preferred by the inspector, shall be used to determine whether or not the steel is within the limits in phosphorus and sulphur specified in paragraphs Nos. 2 and 3.

Sample for Chemical Analysis.

FINISH.

13. Castings shall be true to pattern, free from blemishes, flaws or shrinkage cracks. Bearing surfaces shall be solid, and no porosity shall be allowed in positions where the resistance and value of the casting for the purpose intended, will be seriously affected thereby.

INSPECTION.

14. The inspector representing the purchaser, shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture, prior to shipment.

AMERICAN STANDARD SPECIFICATIONS

FOR

WROUGHT IRON.

PROCESS OF MANUFACTURE.

1. Wrought-iron shall be made by the puddling or by the charcoal hearth process or rolled from fagots or piles made from wrought-iron scrap, alone or with muck bar added.

PHYSICAL PROPERTIES.

2. The minimum physical qualities required in the four classes of wrought-iron shall be as follows:

Tensile Test.

	Stay-bolt iron.	Merchant iron. Grade "A."	Merchant iron. Grade "B."	Merchant iron. Grade "C."
Tensile strength, pounds per square inch	46,000	50,000	48,000	48,000
Yield point, pounds per square inch	25,000	25,000	25,000	25,000
Elongation, per cent. in eight inches	28	25	20	20

3. In sections weighing less than 0.654 pound per linear foot, the percentage of elongation required in the four classes specified in paragraph No. 2, shall be 21 per cent., 18 per cent., 15 per cent. and 12 per cent., respectively.

Nicking Test.

4. The four classes of iron when nicked and tested as described in paragraph No. 9 shall show the following fracture:

(*a*) Stay-bolt iron, a long, clean, silky fiber, free from slag or dirt, and wholly fibrous, being practically free from crystalline spots.

(*b*) Merchant iron, Grade "A," a long, clean, silky fiber, free from slag or dirt or any coarse crystalline spots. A few fine crystalline spots may be tolerated, provided they do not in the aggregate exceed 10 per cent. of the sectional area of the bar.

(*c*) Merchant iron, Grade "B," a generally fibrous fracture, free from coarse crystalline spots. Not over 10 per cent. of the fractured surface shall be granular.

(*d*) Merchant iron, Grade "C," a generally fibrous fracture, free from coarse crystalline spots. Not over 15 per cent. of the fractured surface shall be granular.

Cold Bending Test.

5. The four classes of iron, when tested as described in paragraph No. 10, shall conform to the following bending tests:

(*e*) Stay-bolt iron; a piece of stay-bolt iron about 24 inches long shall bend in the middle through 180° flat on itself, and then bend in the middle through 180° flat on itself in a plane at a right angle to the former direction, without a fracture on outside of the bent portions. Another specimen with a thread cut over the entire length shall stand this double bending without showing deep cracks in the threads.

(*f*) Merchant iron, Grade "A," shall bend cold 180° flat on itself without fracture on outside of the bent portion.

(*g*) Merchant iron, Grade "B," shall bend cold 180° around a diameter equal to the thickness of the tested specimen, without fracture on outside of the bent portion.

(*h*) Merchant iron, Grade "C," shall bend cold 180° around a diameter equal to twice the thickness of the specimen tested, without fracture on outside of the bent portion.

Hot Bending Test.

6. The four classes of iron, when tested as described in paragraph No. 11, shall conform to the following hot bending tests:

(*i*) Stay-bolt iron shall bend through 180° flat on itself, without showing cracks or flaws. A similar specimen heated to a yellow heat and suddenly quenched in water between 80° and 90° F. shall bend, without hammering on the bend, 180° flat on itself without showing cracks or flaws.

(*j*) Merchant iron, Grade "A," shall bend through 180° flat on itself, without showing cracks or flaws. A similar specimen heated to a yellow heat and suddenly quenched in water between 80° and 90° F. shall bend, without hammering on the bend, 180° flat on itself without showing cracks or flaws. A similar specimen heated to a bright red heat shall be split at the end and each part bent back through an angle of 180°. It will also be punched and expanded by drifts until a round hole is formed whose diameter is not less than nine-tenths of the diameter of the rod or width of the bar. Any extension of the original split or indications of fracture, cracks, or flaws developed by the above tests will be sufficient cause for the rejection of the lot represented by that rod or bar.

(*k*) Merchant iron, Grade "B," shall bend through 180° flat on itself, without showing cracks or flaws.

(*l*) Merchant iron, Grade "C," shall bend sharply to a right angle, without showing cracks or flaws.

Threading Test.

7. Stay-bolt iron shall permit of the cutting of a clean sharp thread and be rolled true to gauge desired, so as not to jam in the threading dies.

TEST PIECES AND METHODS OF TESTING.

Test Specimen for Tensile Test.

8. Whenever possible, iron shall be tested in full size as rolled, to determine the physical qualities specified in paragraphs Nos. 2 and 3, the elongation being measured on an eight-inch (8″) gauged length. In flats and shapes too large to test as rolled, the standard test specimen shall be one and one-half inches ($1\frac{1}{2}''$) wide and eight inches (8″) gauged length.

In large rounds, the standard test specimen of two inches (2″) gauged length shall be used; the center of this specimen shall be half way between the center and outside of the round. Sketches of these two standard test specimens have been already shown in Fig. XVIII-A and Fig. XVIII-B.

Nicking Tests.

9. Nicking tests shall be made on specimens cut from the iron as rolled. The specimen shall be slightly and evenly nicked on one side and bent back at this point through an angle of 180° by a succession of light blows.

Cold Bending Tests.

10. Cold bending tests shall be made on specimens cut from the bar as rolled. The specimen shall be bent through an angle of 180° by pressure or by a succession of light blows.

Hot Bending Tests.

11. Hot bending tests shall be made on specimens cut from the bar as rolled. The specimens, heated to a bright red heat, shall be bent through an angle of 180° by pressure or by a succession of light blows and without hammering directly on the bend.

If desired, a similar bar of any of the four classes of iron shall be worked and welded in the ordinary manner without showing signs of red shortness.

Yield Point.

12. The yield point specified in paragraph No. 2 shall be determined by the careful observation of the drop of the beam or halt in the gauge of the testing machine.

FINISH.

13. All wrought iron must be practically straight, smooth, free from cinder spots or injurious flaws, buckles, blisters or cracks.

In round iron, sizes must conform to the Standard Limit gauge as adopted by the Master Car Builders' Association in November, 1883.

INSPECTION.

14. Inspectors representing the purchasers, shall have all reasonable facilities afforded them by the manufacturer to satisfy them that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture, prior to shipment.

CHAPTER XIX.

WELDING.

SECTION XIXa.—*Influence of structure on the welding properties.*—Wrought-iron may be welded so that the point of union is as strong as the rest of the bar, for by upsetting the piece there can be an extra amount of work put upon the metal, and since the strength of the original bar was dependent upon the perfection of a great number of welds, it follows that the additional local heating and hammering may give a superior strength. Unfortunately, this is rarely the case, and it is seldom that failure does not take place in the neighborhood of the weld under destructive tests. It often does happen that a rod will break a short distance away from the actual point of union, but in spite of current supposition this by no means shows perfect workmanship, for it usually arises from the overheating of the iron at the point of fracture, without sufficient subsequent work to develop a proper structure.

In working steel the conditions are fundamentally different, for the bar is not a collection of fibres and welds, but a thing complete in itself, so that it is impossible to make any improvement in a properly worked piece by cutting it in halves and putting it together again. It is quite conceivable that a bar may originally be underworked or overheated, and that additional local work can enhance the strength at the point of welding, but this assumption of a bad material to start with may be neglected. It is also possible to finish the hammering on a welded piece at a very low temperature and thereby exalt the ultimate strength beyond the true value, but inasmuch as this will give a less ductile and unreliable material, it will not be considered.

It is also possible, much more than with wrought-iron, to have the weld stronger than a certain adjacent part of the bar, for the best of steel will be crystallized by high heat somewhat more readily than wrought-iron, and hence it can and often does happen that the metal in the neighborhood of the weld has a bad structure due to lack of hammering after high heating. The higher the critical temperature necessary to produce crystallization, the less is the danger from this source, so that, aside from the mere facility of welding at point of contact, the freedom from phosphorus and sulphur is a matter of prime importance, since both of these elements render the metal less able to withstand high temperatures.

The fundamental difference in crystallizing power between wrought-iron and steel makes a close comparison of the two impossible, but nevertheless it may be profitable to quote from Holley the following conclusions concerning iron:*

"(1) None of the ingredients except carbon in the proportions present seems to very notably affect the welding by ordinary methods. [The maximum percentages were P, .317; Si, .321; Mn, .097; S, .015; Cu, .43; Ni, .34; Co, .11; Slag, 2.262.]

"(2) The welding power by ordinary methods is varied as much by the amount of reduction in rolling as by the ordinary differences in composition.

"(3) The ordinary practice of welding is capable of radical improvement, the most promising field being in the direction of welding in a non-oxidizing atmosphere."

SEC. XIXb.—*Tensile tests on welded bars of steel and iron.*—A glance at the allowable contents of metalloids, as given in the foregoing synopsis, will show the wide gulf that separates iron from steel, and this will be still further indicated by Table XIX-A, which gives the tensile tests on a series of welded steel bars of different compositions, the investigation having been conducted under my own direction. The total lack of certainty and regularity in the results is evident, and it should therefore be said that the smiths were men of long experience in handling steel, and they fully understood that the individual results were to be compared. The bars were of a size most easily heated and quickly handled, but notwithstanding these most favorable personal and physical conditions, the record is extremely unsatisfactory.

In the case of the rounds, each workman has at least one bad weld against him, while there is only one heat which gave uniformly good results. Picking out the worst individual weld of each workman, blacksmith *"A"* obtained only 70 per cent. of the value of the original bar, *"B"* 54 per cent., *"C"* 58 per cent., and *"D"* only

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* *The Strength of Wrought-Iron as Affected by its Composition and by its Reduction in Rolling. Trans. A. I. M. E.,* Vol. VI, p. 101.

44 per cent. The forging steel showed one weld with only 48 per cent., the common soft steel 44 per cent., while even the pure basic steel gave one test as low as 59 per cent. In some cases where the break took place away from the weld, the elongation was nearly up to the standard, this being true of the four tests of the seventh group, and it should be noted that this metal contained .35 per cent. of copper, but in the other pieces the stretch was low and the fracture so silvery that it was plain the structure of the bar had

TABLE XIX-A.

Tensile Tests on Welded Bars of Steel and Wrought-Iron.

Figures in parentheses indicate that the bar broke in the weld. N=natural bar; W=welded bar. * denotes that elongation is measured in 2 inches.

Kind of steel.	Conditions of test.	Composition; per cent.					N=natural. W=welded.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Name of smith.
		C.	Mn.	P.	S.	Cu.						
Acid O H. forging	¾-inch round; lap weld.	.20	.89	.089	.03	.35	N	46670	70450	26.25	53.50	...
		...	...	...	...	...	W	45890	(60940)	*10.00	19.73	A
		...	...	...	...	...	W	45580	(55090)	*9.00	7.55	B
		...	...	...	...	...	W	...	(40840)	*7.00	8.12	C
		...	...	...	...	...	W	...	(42190)	*3.00	4.04	D
Acid Bess. forging	¾-inch round; lap weld.	.25	1.36	.083	.05	.35	N	56140	86600	22.25	35.40	...
		...	...	...	...	...	W	56750	(68810)	*4.00	29.29	A
		...	...	...	...	...	W	...	(55020)	*6.00	0.78	B
		...	...	...	...	...	W	...	(62060)	*5.00	6.50	C
		...	...	...	...	...	W	...	(41930)	*3.00	2.10	D
Acid O H. soft.	¾-inch round; lap weld.	.09	.46	.08	...	.35	N	40980	60680	30.00	53.20	...
		...	...	...	...	...	W	38230	61060	*66.33	56.51	A
		...	...	...	...	...	W	44660	60380	*36.00	58.50	B
		...	...	...	...	...	W	45030	65610	...	56.28	C
		...	...	...	...	...	W	...	(26640)	*12.00	4.53	D
Acid O. H. soft.	¾-inch round; lap weld.	.09	.39	.076	...	.35	N.	38940	56900	28.75	59.89	...
		...	...	...	...	...	W	37550	57650	*39.00	62.18	A
		...	...	...	...	...	W	37400	(42740)	*9.00	13.48	B
		...	...	...	...	...	W	40910	(43910)	*10.50	14.55	C
		...	...	...	...	...	W	39220	58790	*34.00	62.29	D
Acid O H. soft.	¾-inch round; lap weld.	.09	.40	.08	...	.35	N	41670	56300	30.00	62.56	...
		...	...	...	...	...	W	33740	(39490)	*6.00	8.63	A
		...	...	...	...	...	W	...	(30550)	*7.00	10.79	B
		...	...	...	...	...	W	38300	53880	*37.00	65.46	C
		...	...	...	...	...	W	34460	50020	*16.00	23.22	D
Basic O. H. soft.	¾-inch round; lap weld.	.06	.55	.019	...	.35	N	33880	51760	32.75	65.35	...
		...	...	...	...	...	W	37660	58650	*32.00	59.55	A
		...	...	...	...	...	W	...	(30640)	*8.00	13.88	B
		...	...	...	...	...	W	35370	(51850)	*27.00	46.77	C
		...	...	...	...	...	W	31820	49690	*41.00	67.85	D
Basic O. H. soft.	¾-inch round: lap weld.	.06	.30	.014	...	.35	N	32580	48990	31.75	71.56	...
		...	...	...	...	...	W	41930	54530	*36.00	66.68	A
		...	...	...	...	...	W	35470	52100	*39.00	70.81	B
		...	...	...	...	...	W	38280	54200	...	72.81	C
		...	...	...	...	...	W	39720	55110	*41.00	70.61	D

TABLE XIX-A.—Continued.

Kind of steel.	Conditions of test.	Composition; per cent.					N=natural. W=welded.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Name of smith.
		C.	Mn.	P.	S.	Cu.						
Basic O. H. soft.	¾-inch round; lap weld.	.08	.50	.027	. .	.35	N	39820	62000	30.00	55.96	. . .
		. . .	. . .	. . .	. . .	. . .	W	37330	(49210)	*9.00	8.22	A
		. . .	. . .	. . .	. . .	. . .	W	40880	69460	*30.00	48.15	B
		. . .	. . .	. . .	. . .	. . .	W	44510	68380	. . . .	48.54	C
		. . .	. . .	. . .	. . .	. . .	W	. . .	(55560)	*17.00	. . .	D
Acid Bess. soft.	2x⅜-inch flats; lap weld.	.06	.36	.032	.054	.69	N	40780	59140	29.50	47.65	. . .
		. . .	. . .	. . .	. . .	. . .	W	42780	50560	7.50	21.60	. . .
		.06	.40	.032	.054	.69	N	42020	61370	25.00	46.89	. . .
		. . .	. . .	. . .	. . .	. . .	W	45150	55780	8.50	24.78	. . .
		.06	.45	.032	.054	.69	N	40740	60730	26.25	46.72	. . .
		. . .	. . .	. . .	. . .	. . .	W	46720	58540	5.00	19.48	. . .
		.06	.35	.032	.054	.69	N	42680	60780	28.75	47.23	. . .
		. . .	. . .	. . .	. . .	. . .	W	43350	48740	1.25	20.20	. . .
Basic O. H. soft.	2x⅜-inch flats; scarf weld.	.08	.17	.008	.016	.10	N	30300	45070	39.00	69.70	. . .
		. . .	. . .	. . .	. . .	. . .	W	31690	43290	11.25	42.16	. . .
		.11	.32	.011	.029	.08	N	33600	50190	33.75	58.48	. . .
		. . .	. . .	. . .	. . .	. . .	W	. . .	45900	8.50	34.11	. . .
		.11	.32	.006	.018	.11	N	35730	49580	33.00	56.92	. . .
		. . .	. . .	. . .	. . .	. . .	W	32120	45280	10.00	22.18	. . .
		.09	.29	.005	.021	.10	N	36390	50050	33.00	59.82	. . .
		. . .	. . .	. . .	. .	. . .	W	37400	45280	7.50	41.08	. . .
Basic O. H. soft.	2x⅜-inch flats; lap weld.	.12	.36	.005	.022	.08	N	34580	51080	28.50	48.63	. . .
		. . .	. . .	. . .	. . .	. . .	W	30840	41600	7.50	26.34	. . .
		.13	.39	.005	.025	.10	N	35470	50770	33.75	51.50	. . .
		. . .	. . .	. . .	. . .	. . .	W	. . .	37000	7.50	29.88	. . .
		.12	.29	.005	.016	.10	N	36830	51300	31.25	52.62	. . .
		. . .	. . .	. . .	. . .	. . .	W	33300	43530	7.00	29.31	. . .
		.12	.51	.005	.021	.09	N	37650	54770	26.25	41.94	. . .
		. . .	. . .	. . .	. . .	. . .	W	35200	48280	7.00	21.74	. . .
Wrought-iron	2x⅜-inch flats; lap weld.	. . .	. . .	. . .	. . .	. . .	N	33390	50080	23.50	27.26	. . .
		. . .	. . .	. . .	. . .	. . .	W	32950	39320	6.00	15.52	. . .
		. . .	. . .	. . .	. . .	. . .	W	34060	40620	6.25	22.26	. . .
		. . .	. . .	. . .	. . .	. . .	W	32700	45140	11.75	20.98	. . .
		. . .	. . .	. . .	. . .	. . .	W	32040	44730	11.00	19.25	. . .
		. . .	. . .	. . .	. . .	. . .	W	32760	38430	4.00	9.36	. . .

been ruined. In most cases where the test-bar broke in the weld, the pieces parted at the surfaces of contact, showing that no true union had taken place; one or two fractures were homogeneous, but they showed the coarse crystallization that follows overheating.

The lap welds represent the method ordinarily used in making pipe, and are really a better criterion of the welding quality of the steel than the round pieces, for in making the union the pieces were simply laid together with no upsetting, and hence there was less chance for the manipulations of the smith. All of this steel, both Bessemer and open-hearth, had been pronounced suitable for the making of pipe, although it will be a revelation to most metallurgists that such a high content of copper could possibly be allowed. In all cases the bars broke across the weld with a more or less crystalline fracture, there being no instance where the separation was at the plane of union, so that, while thorough welding was proven, it was also evident from the lessened ductility that the metal was overheated during the operation.

TABLE XIX-B.

Welding Tests by the Royal Prussian Testing Institute.

Kind of metal.	Ult. strength; pounds per square inch.		Per cent. elongation in 200 m. m. =7.87 inches.		Per cent. reduction of area.	
	Av. 6 tests, natural.	Av. 9 tests, welded.	Av. 6 tests, natural.	Av. 9 tests, welded.	Av. 6 tests, natural.	Av. 9 tests, welded.
Medium O. H. steel	72110	41820	20.8	3.2	34.9	4.5
Soft O. H. steel	64570	45800	25.1	5.1	44.7	10.5
Puddled iron	57890	47080	22.2	7.7	39.5	14.0

The figures on the iron bars show that the situation is no better than with steel, for the welded bars are far inferior to the natural piece both in strength and ductility. The general truth of these experiments is corroborated by Table XIX-B, which gives a condensation of the results on a series of tests made by the Royal Prussian Testing Institute, the data being translated into American form.*

The average tensile strength of the welded bars of medium steel was 58 per cent. of the natural, the poorest bar showing only 23 per cent. In the softer steel the average was 71 per cent. and the poorest 33 per cent., while in the puddled iron the average was 81 per cent. and the poorest 62 per cent. The complete destruction of ductility is conclusively shown in the case of all three metals, even the wrought-iron being hopelessly wrecked.

As above stated, the flat bars given in Table XIX-A were such as had been used successfully in making pipe which would stand

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* *Journal I. and S. I.*, Vol. I. 1883, p. 425, *et seq.*

all the ordinary tests of distortion, while the soft basic metal, made to fill the stringent requirements of the United States Government, would meet the most severe tests. Such metal is used regularly in certain branches of manufacture where the best welding qualities are required, and the users are firmly convinced that "the weld is perfect."

It may be possible to produce better results by special arrangements, but it must certainly be acknowledged that a weld as performed by ordinary blacksmiths and by the usual methods on the best metal whether iron or steel, is not nearly as good as the rest of the bar; and it is still more certain that welds of large rods of common forging steel are entirely unreliable and should not be employed in any structural work. Electric methods do not offer a solution of the problem, for during the process the metal is heated far beyond the critical temperature of crystallization, and only by heavy reductions under the hammer or press can much be done toward restoring the ductility of the piece. In many cases this subsequent hammering is impracticable owing to the consequent deformation of the piece.

SEC. XIXc.—*Influence of the metalloids upon the welding properties.*—The way in which the impurities of the metal affect the welding power has been a matter of discussion, it having even been supposed that they act simply by interposition, and, again, that they increase the susceptibility of the iron to oxidation. I believe both of these theories are wrong. If the first were true, then one per cent. of carbon would have the same effect as one per cent. of sulphur, which is manifestly not the case. The second theory does not hold, since sulphur, which is notoriously one of the worst enemies of welding, is not oxidized either in the acid Bessemer or open-hearth furnace, and there is no ground for assuming that it oxidizes in welding. It will also be seen that as phosphorus, carbon and manganese protect iron from burning in the Bessemer and open-hearth, so they must also tend to be preferentially oxidized in a blacksmith's fire, and thus by preventing the formation of iron oxide, as well as by the formation of a liquid flux containing phosphoric acid and oxide of manganese, they should, as far as oxidation is concerned, assist rather than retard the welding.

A third theory is advanced that the impurities affect the mobility. When half of one per cent. of carbon is added to the metal, it produces a compactness or hardness, even when the steel is hot, that must prevent the easy flowing together that follows a pressure upon two pieces of white-hot wrought-iron or soft steel. A higher temperature cannot be used, because every increase in carbon reduces the safe working temperature at the same time that it increases the stiffness.

This decrease in mobility doubtless plays an important part in the explanation, but I believe that a greater influence is to be found in what may seem at first sight to be the same thing, but which in reality is a different quality, *viz.*: The power, or property, of passing through a viscous state on the road to liquidity. There are other metals, lead and copper for instance, which are malleable and ductile, but which do not go through a history of slow softening under the application of heat, the change to a liquid state being sudden and without any marked intermediate stage. Pig-iron is of the same character, for no matter how low the other metalloids may be, the presence of three per cent. of carbon produces a metal which changes suddenly from a solid to a liquid state, and it is reasonable to suppose that each increment of carbon, phosphorus and manganese tends in the same direction.

In addition to this effect, I believe that an equally important factor exists in the action of carbon, phosphorus, sulphur and copper in destroying the quality of cohesion by increasing the tendency to crystallization, for it is well known that these metalloids lower the point at which the steel becomes what is incorrectly, but quite naturally, called "burned." When the steel is overheated it crumbles under the hammer, and it is plain that it cannot be easily united to another piece when it is incapable of remaining united to itself. This theory also explains what seems to be a fact, that a small proportion of manganese aids in welding, for although it does decrease the mobility at any particular temperature, it allows a higher heat to be put upon the metal without the creation of a destructive crystallization, and thus indirectly renders possible a greater mobility and maintains a more favorable internal molecular structure.

The following conclusions summarize what has just been given and seem to fit the theory and the facts:

(1) With the exception of manganese in small proportion, the usual impurities in steel reduce its welding power by lowering the critical temperature at which it becomes coarsely crystalline.

(2) A small content of manganese aids welding by preventing crystallization.

(3) Only the purest and softest steel can be welded with any reasonable assurance of success.

(4) The confidence of a smith in his own powers and his belief in the perfection of the weld, is no guarantee that the bar is fit to use.

CHAPTER XX.

STEEL CASTINGS.

SECTION XXa.—*Definition of a steel casting.*—Within the last few years steel castings have come into general use in the structural world, but there is still a lamentable ignorance concerning their nature. A steel casting by very definition must be made of steel which is cast in a fluid state into the desired shape. This leaves open to discussion the great question considered in Chapter IV as to what is included in the term "steel," but although the making of a general definition is complicated by the possibility of producing "puddled steel," there is no necessity of introducing this qualification into remarks on castings, since fluidity is an essential feature. As for the distinction between "steel" and the so-called "ingot iron," it is needless to say that endless confusion would be introduced in the trade if the soft products of the open-hearth were to be styled "iron castings."

Notwithstanding the plain limits which have been set by metallurgy and common sense, there is a cloud of error hanging around the term "steel castings," which is due partly to ignorance and partly to deliberate fraud. It has been the practice of some persons to make castings from a mixture of pig-iron and steel melted in a cupola, although every metallurgist and every foundryman of intelligence knows that the metal is altered very much by remelting, and that the changes in silicon, manganese and carbon depend on all the varying and uncertain factors of temperature and exposure. In melting ordinary pig-iron, the carbon usually changes very little, for, by the nature of the case, the content of this metalloid was adjusted in the blast-furnace to about the absorptive capacity corresponding to the manganese and silicon, and as the conditions in the cupola are similar to those in the blast furnace, it follows that a metal which is the normal product of one will not be fundamentally altered by passing through the other.

But a mixture of steel and iron is not a normal product of any furnace, and in its treatment in the cupola there is a tendency to make radical changes in the composition by the absorption of carbon. Thus, by the unnatural union of pig and scrap, and by the uncertain changes in silicon, manganese and carbon, there is produced a hybrid metal which is useful for special purposes, but which is fundamentally different from any kind of steel. It is true that scrap and iron are melted together to make open-hearth steel, but this is done under an oxidizing flame and, either during the melting or afterward, the metalloids are almost entirely eliminated, giving a definite starting point from which a known and regular metal can be made by the addition of proper recarburizers.

Sometimes castings of cupola metal, made either with or without scrap, are heated in contact with iron oxide in order to burn the contained metalloids. The product is a more or less tough metal, known as malleable iron, which is extensively employed in making small, thin, or complicated shapes that could scarcely be poured in steel, but which can be made of the more liquid iron. The attempt has been made to call these "steel," and the claim has been fortified by analyses showing that the composition resembles that of some steel. The argument is too shallow for consideration, since, on the same basis, the product of the puddle furnace or the charcoal bloomary might be termed "mild steel." Malleable iron must always be inferior to steel, because any oxides of silicon, manganese, phosphorus or iron which are formed remain diffused throughout the mass, thereby breaking to some extent the bond of continuity.

Such castings are useful in a certain field, for they are far tougher than cast-iron, and they may even enter into competition with steel castings, but they must always bear a different name, since steel castings must necessarily be made by pouring into finished shape the melted product of a crucible, a Bessemer converter, or an open-hearth furnace.

SEC. XXb.—*Methods of manufacture.*—The crucible process is sometimes employed for small castings, since the conditions of the "dead-melt" give a much more quiet metal, evolving less gas in contact with cold surfaces, and the casting is more apt to be free from blow-holes. In certain special cases, as in the manufacture of big guns at Krupp's, the crucible has been used in making large masses of metal, but its great cost must prohibit its adoption for general structural work.

The Bessemer has been used to some extent in the past for making steel castings, but it is utterly unfitted for the work on account of the great cost of the operation when only two or three heats are required during the day. One way of obviating this is by taking an occasional heat from a Bessemer plant which is running regularly on other products, but this supposes, what is seldom the case, that the mixture is low in phosphorus. The day has passed away when a casting could be made of ordinary steel, and as it is now necessary to make a careful selection of the stock so that the content of phosphorus shall not exceed .04 per cent., the melting furnace is the cheapest as well as the most efficient instrument of production.

Within the last few years there has been a revival of Bessemer castings due to special developments along certain lines of procedure which have been practiced in exceptional cases for many years. After the drop of the carbon flame, a certain amount of melted ferro-silicon is added to the bath and the blowing resumed. The silicon is oxidized and produces a very high temperature, and the advocates of the small converter lay great stress upon this feature. Thus in an article in the *Iron Age,* June 5, 1902, a writer who claims to be skilled in open-hearth practice, states that the small converter will make a steel containing only .10 per cent. of carbon, with a trace of manganese and silicon, while "an open-hearth furnace cannot make this grade at all and it could not be kept liquid in the ladle." This is a complete mistake, for several open-hearth plants have made large quantities of such metal. In fact, it is not up-to-date to talk about a steel containing .10 per cent. of carbon as being extra soft, for The Pennsylvania Steel Co., as well as other works, stands ready to deliver any amount of blooms or billets with carbon below .04 per cent. with a trace of manganese and silicon and low in phosphorus and sulphur.

It has been deemed necessary to refer to this communication because it is the most recent, and because it is characteristic of a thousand similar advertisements continually appearing in the news columns of the technical press. It is essential to keep in mind that there is no difficulty at all in a good open-hearth furnace in making steel just as hot as can be wanted; in fact, considerable care must be exercised to keep the metal from being too hot. On some kinds of work an excess of temperature may not cause trouble, but in other cases the open-hearth furnace offers far better opportunities for that complete control of temperature and casting conditions which is so desirable and so essential.

The open-hearth furnace also allows more perfect control over the casting conditions. A basic hearth is sometimes used and has an advantage in the ability to make low phosphorus without much extra cost, but basic metal seems to be more "lively" in casting, and hence there is greater danger of honeycombs. It is, however, a fact which is worth a hundred arguments that basic furnaces, both in this country and abroad are making good castings, and it is economy to do so when there is a radical difference in the cost of the raw material.

Sec. XXc.—*Blow-holes.*—The use of good stock determines to a great extent the nature of the product, but it does not in the least influence the solidity of the castings. This depends partly on the temperature and composition of slag and metal before tapping, and partly on the quantity and nature of the recarburizing additions. An increase in these latter agents covers up the errors in furnace manipulations, but shows itself in a higher content of metalloids. Honeycombed metal may arise from bad casting conditions or it may come from a laudable desire to reduce to the lowest possible point the proportions of silicon and manganese, for the manufacturer well knows that the blow-holes decrease only slightly the strength and toughness of a casting, while the complete removal of them by overdoses of metalloids gives a brittle metal.

It is the current impression that during the last few years all the difficulties in making sound castings have been completely overcome by the introduction of metallic aluminum and certain alloys of silicon. It is true that great progress has been made, but there is no magic wand for sale which can be waved over a ladleful of steel to "kill" it "dead." Hadfield,* in an able article on the use of aluminum, says: "There is no rapid or royal road to the production of sound steel castings; this is only attained by long experience combined with specialized knowledge."

Some engineers specify that the cavities shall not exceed a certain percentage of the total area, but the common-sense method is to clothe the inspector with discretionary power, for a flaw may be perfectly harmless on the under surface of a base-plate when it would be fatal in the rim of a wheel. In this connection it should be noted that there is a radical difference between a "blow-hole" and a "pipe." The cavities which may often be seen where the "sink-head" or "riser" is cut off, are not evidence of unsoundness

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* *Aluminum Steel. Journal I. and S. I.*, Vol. II, 1890, p. 174.

but exactly the opposite, for they show that feeding has continued after the riser was exhausted, and that the hidden interior has been rendered solid at the expense of the visible surface.

SEC. XXd.—*Phosphorus and sulphur in steel castings.*—In writing the specifications for steel castings, the most important point is to state that phosphorus shall not exceed .04 per cent. An excess of the other elements may be guarded against by requiring a proper ductility, but phosphorus, although influencing to some extent the ordinary testing history, is often masked by other factors, and manifests itself only at a later time in that brittleness under shock which is its inherent characteristic. This is an important matter in the case of rolled metal, but it is of much more vital moment in steel castings, for these will generally fail, not by being pulled and stretched to destruction, but by sudden strain and shock.

The content of sulphur is of little importance to the user, for it affects the cold properties very slightly, but it will do no harm to specify that it shall not be over .05 per cent., good castings generally containing less than this proportion. Copper need not be mentioned, for there is no evidence that it has any influence upon the finished casting.

SEC. XXe.—*Effect of silicon, manganese and aluminum.*—The elements used to procure solidity are silicon, manganese and aluminum. Their value to the steelmaker is due in great measure to their power of uniting with oxygen, the action being as follows:

3.44 parts manganese unite with 1.00 part of oxygen.
3.44 parts aluminum unite with 3.01 parts of oxygen.
3.44 parts silicon unite with 3.93 parts of oxygen.

Hence the aluminum is three times, and the silicon four times, as efficient as manganese, weight for weight, while they have an additional value from their greater affinity for oxygen, since this enables them to seize the last traces from the iron and wash the bath so much the cleaner.

Another function which may play a part in the operation is the increase in capacity to dissolve or occlude gases, and as far as the value of the casting is concerned this will be equivalent to destroying them. It is not known how far this determines the situation, but it is evident that it has no connection with the power to unite with oxygen. It was once thought that aluminum increased the fluidity of steel by lowering the point of fusion, but experiments with a Le Chatelier pyrometer* gave the same melting point of 1475° C. for ordinary soft steel as for an alloy with five per cent. of aluminum. The tendency of both aluminum and silicon is to make the steel creamy and sluggish; it is true that such metal will run through small passages without chilling better than ordinary steel, but this is because the latter foams and froths when in contact with cold surfaces, and the flow is thereby impeded and sufficient surface exposed to chill the advance guard of the stream.

The percentage of manganese should not exceed .70 in soft castings nor .80 in harder steels, since more than this may render the metal liable to crack under shock. Silicon can be present up to .10 per cent. in the mild steels and .35 per cent. in the hard without any appreciable diminution in toughness. Aluminum is seldom present except in traces, and should not be over .20 per cent., for it decreases the ductility. The carbon must vary according to the desired tensile strength and the use to which the casting is to be put. When it is over .70 per cent. the steel becomes so hard that machining is slow, and there is danger of lines of weakness from shrinkage in complicated shapes.

SEC. XXf.—*Physical tests on soft steel castings.*—Since the failure of cast-work is almost always due to sudden strain, it is the safer plan to have the metal for common purposes between .30 and .50 per cent. in carbon, but when great toughness is required it should not be over .15 per cent. This latter specification also presupposes a low content of manganese, silicon, and, above all, of phosphorus; with this composition the casting displays all the characteristics usually associated with the toughest of rolled shapes. A test on an unannealed gear-wheel of such metal, manufactured by The Pennsylvania Steel Co., was made by cutting the rim between the spokes and then bending one arm to a right angle, twisting another through more than 180° without sign of fracture, while a third was hot-forged from a star-shaped section of about 2 inches by 1½ inches into a bar 1¼ inches by three-eighths inch, and after being cooled was twisted into a closed corkscrew. Similar pieces were exhibited by Krupp in his magnificent exhibit at Chicago, but we stand ready in America to duplicate any such metal on regular contracts.

Such trials, made on castings taken at random, are far preferable

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* See article on *Pyrometric Data,* by H. M. Howe, *Engineering and Mining Journal,* October 11, 1890, p. 426.

to tensile tests from sample bars, since the small pieces will not be in exactly the same physical condition as the larger castings. The results have a certain value, however, and avoid the necessity of spoiling good finished work. It is well to keep in mind that a flaw or blow-hole in the small test does not necessarily imply that the casting contains similar imperfections, and also that while an open cavity, however small, which is visible on the surface of a machined test will have a disastrous effect upon the strength and ductility, it might be of slight importance if buried in the interior. This necessity of having a perfect surface makes it difficult to conduct a long series of tests with exactly the same dimension of test-pieces, for if five-eighths inch in diameter is the desired size, it may be necessary to turn some of the pieces to one-half inch, while the length must sometimes be reduced to 6 or 4 inches. It is also a strong argument against the use of an 8-inch test piece, for the chance of pinholes and a consequent bad record is thereby multiplied fourfold when the presence of such holes has practically no effect upon the casting.

This test piece should not be annealed unless the castings themselves are to be treated in the same manner, and although it is customary to anneal most structural work, the trouble is not necessary in a great many cases if the very best of stock is used. This statement will be called heretical by many engineers, but the tests that have just been recorded upon an unannealed gear-wheel will show that the metal can be exceptionally tough in its original state.

In the case of castings of complicated shape and those exposed to shock, annealing should be specified, but it must be remembered that there is no magic charm in this word. It is not sufficient to simply say that they shall be annealed and make sure only that they are covered with soot or fresh oxide. The heat treatment of steel is no longer a mere heating to remove strains, with the hope that some unknown change may occur to toughen the mass; it is or should be and always can be a scientific procedure, by which the metal is raised to an accurately determined critical temperature, whereby certain molecular rearrangements occur. If these rearrangements are properly guided, the result will be seen in a fine grained structure and a tough metal. If they are not properly guided the last condition may be as bad as the first.

Up to within a few years most steel castings were made of hard metal containing from .30 to .50 per cent. of carbon, and having a tensile strength of 80,000 to 100,000 pounds per square inch, but just as engineers have long since learned that the strongest and safest bridge is not built of rolled steel with .30 per cent. of carbon,

TABLE XX-A.

Comparative Physical Properties of Bars Cut from Annealed Soft Steel Castings and Unannealed Bars of the same Heats Rolled from 6-Inch Square Ingots, together with Results of Similar Bars made from Large Ingots.

Steel manufactured by The Pennsylvania Steel Company.

Heat number.	Composition; per cent.				Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation; per cent. part in 8 inches, part in 6 inches.	Reduction of area; per cent.
	C.	P.	Mn.	S.				
3552	.17	.027	.65	.034	58190	34290	24.00	32.1
3555	.17	.027	.66	.056	56030	32440	14.90	19.7
3557	.17	.032	.60	.029	55880	32750	27.13	42.3
3559	.17	.027	.65	.038	55350	30350	23.10	42.5
3563	.17	.024	.62	.024	59390	34790	20.10	34.5
3565	.23	.029	.65	.025	60060	33130	20.65	26.8
3568	.14	.029	.70	.032	58320	31750	17.25	20.8
3571	.18	.033	.58	.028	56700	30670	26.88	46.7
3573	.17	.028	.67	.027	57440	31430	21.66	36.7
3573	.17	.036	.70	.027	58860	34260	22.04	29.8
3577	.17	.037	.59	.029	57980	33220	23.00	39.3
3578	.17	.045	.67	.026	58810	33510	22.16	30.4
3579	.15	.037	.63	.028	54940	32190	22.75	47.0
3580	.18	.038	.71	.017	58970	34180	22.25	36.7
3582	.17	.036	.63	.024	56380	31520	13.00	25.5
3583	.18	.032	.61	.022	59400	35330	14.13	18.8
3584	.18	.027	.60	.027	55970	29690	22.38	32.1
3586	.17	.027	.60	.027	55630	30300	18.50	31.4
3588	.16	.043	.63	.031	56950	32530	26.50	42.7
3592	.18	.027	.69	.028	59050	32940	20.00	33.0
Average of annealed cast bars.	.17	.032	.64	.029	57515	32564	21.12	33.44
2x⅜-inch bars rolled from 6-inch square ingots cast from the same heats and tested in natural state					63523	42700	24.74	43.80
Average of 2x⅜-inch bars rolled from 4-inch billets made from 16-inch ingots of 7 different heats of about the same tensile strength as the above castings				Natural Annealed	62089 55021	42441 31576	30.14 30.36	60.86 60.00

so they must learn that in still greater measure it would be better to use a softer metal in castings.

Table XX-A gives the results of tests made on sample bars of cast steel, showing the composition and physical qualities.

The silicon is not given, but it was below .05 per cent. in every case. The test piece was not cut from the casting itself, but from a small coupon which is much more likely to contain blow-holes, and this will explain why it was often necessary to pull the piece in a six-inch length. The test was round in every case, and therefore gave slightly worse results than a flat, but this is far from explaining the great inferiority of the casting when compared with the preliminary test, or the much more marked difference from what should be expected in properly rolled steel of similar tensile strength.

TABLE XX-B.

Physical Properties of Annealed Bars cut from Castings of Medium Hard Steel; all Bars ¾-inch in Diameter.

Manufactured by The Pennsylvania Steel Company.

Heat number.	Composition; per cent.					Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 2 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
	C.	Mn.	P.	S.	Si.					
921	.20	.54	.026	.022	.30	60580	33710	30.50	38.57	55.6
						60680	32380	36.50	51.90	53.4
						60830	32750	36.00	44.34	53.8
						61480	30740	32.00	39.80	50.0
						62420	32460	38.00	50.90	52.0
953	.22	.56	.035	.034	.30	63320	37400	36.00	46.33	59.1
						64880	34170	24.50	28.57	52.7
						65500	44850	29.00	39.40	68.5
						65845	33595	26.00	32.40	51.0
						65930	32290	30.00	33.37	49.0
						67010	48630	26.00	32.40	72.6
974	.38	.75	.029	.023	.35	72630	44940	16.00	20.70	61.9
						75240	45880	23.00	31.63	61.0
966	.35	.68	.038	.034	.34	73090	45390	17.50	21.25	62.1
						75160	45510	29.50	27.64	60.6

The results show what has so often been mentioned in these pages—that the ultimate strength and elastic limit are altered very little by the amount of work upon the piece as long as it is not finished at a low temperature. Thus, in the annealed casting the elastic limit is 56.62 per cent. of the ultimate strength, while in the annealed bars rolled from the ingot it is 57.39 per cent. This approximation is remarkable because the factors relating to ductility show that the physical state of the two metals must be radically different.

Sec. XXg.—*Physical tests on medium hard steel castings.*—It has just been shown that the average elastic ratio in annealed castings is about the same as in annealed rolled bars, but there will be much greater variations between individual tests in the case of the unworked metal owing to local imperfections, and there will also be greater variations with a stronger steel. This will be shown by Table XX-B, which gives the results on duplicate bars from four different heats of harder metal.

It will be seen that the ultimate strength is fairly regular, and this indicates that the metal itself is homogeneous, but that minute imperfections give rise to the variations in the elongation, reduction of area, and elastic ratio. In the body of a casting these defects exert little influence, but they seriously affect the integrity of a small machined piece. This will emphasize the statement already made that the safest way, whenever practicable, would be to make a drop test on a sample casting rather than to cut a small bar from the piece or from a separate coupon.

PART III.

The Iron Industry of the Leading Nations.

CHAPTER XXI.

FACTORS IN INDUSTRIAL COMPETITION.

NOTE.—In the summer of 1899, I visited many of the large steel works in England, Belgium and Austria, and most of the large plants in Germany. I was received everywhere with unvarying courtesy and hospitality, and was given every facility to inspect methods and results. I trust that nothing here written will be construed to be more than fair scientific criticism of my hosts.

SECTION XXIa.—*The question of management:*

It is a common thing in America to smile over the non-progressiveness of our foreign friends and to congratulate ourselves that we are not as other men. There are many people here who believe that foreign engineers are not quite up to our standard and that we are especially commissioned by Providence to illuminate the whole world with our spare energy. I will take away no glory from my fellow countrymen. They need no spokesman and they will be sure to get all that is due them, as the progressiveness of American metallurgists and engineers is well known in foreign lands, but it is well to remember that there is one vital difference between metallurgy abroad and metallurgy here. The direct management of a steel works in America has practically its own way. If a mill is out of date and a new system of rolling or manipulation is needed, it does not take long to get authority to make the change. It is called extraordinary repairs, it is called improvement, or it is not mentioned at all. The directors leave much to the management; they feel that they pay men to attend to the operation of the works and constant improvements are looked upon as necessary and inevitable. As for the stockholders, they are not considered, for a stockholder in America is not supposed to rise in meeting and question the wisdom of spending any reasonable sum upon improvement and then find out whether the improvement is paying for itself.

In England, especially, the very reverse is the case. The stock of many of the older steel works is very widely distributed and a large number of shareholders do not know anything about improvements and do not care. They want their dividends, and if any money is taken from profits and spent on new machinery, it must be fully explained why this was done, and it must be shown that this expenditure has been justified by results. If American managers had to go through such an inquisition whenever they proposed an improvement, and if, on the other hand, they could satisfy the shareholders by inventing nothing, it is possible they would lead a less strenuous life.

According to the usual financial custom in England, no improvements are made out of profits, new capital being authorized and obtained for this purpose when deemed necessary. There are many exceptions to this system, but it is certain that it is quite generally carried out to an extent that will hardly be credited by Americans. An instance may be cited of an English works in South Russia managed entirely on English lines. The capital stock is $6,000,000, and in the last eleven years annual dividends have been declared ranging from 15 to 125 per cent. and averaging over 32 per cent. In 1900 the disbursements were only 20 per cent., or $1,200,000, the decrease being due to low prices and bad markets. Just at this juncture it is found necessary to build certain railway lines, etc., and an issue of bonds is made of $750,000 to pay for this, just as nearly double this sum goes out in dividends. Nothing can convince our friends on the other side of the water that this is anything but the true and only right way, just as it would be impossible to convince men here that it was anything but wrong.

The English manager has also to contend against very strong labor organizations, their ignorant and tyrannical control being a hopeless bar to the progress of English industries. There was a time when such societies regulated affairs in many American steel works, but it was soon discovered that progress and labor organizations do not sail in the same boat. This has lately been discovered in England, but it is not easy to fight against established customs. In the summer of 1899 I visited the Cleveland district of England. Everything indicated prosperity in the iron trade and new work was underway that would add to the output and general business of the place. The firm in charge of this new plant stated that their boiler-makers and riveters would work only three days in the week. Their wages had been advanced to offer extra inducements, but this did not help matters in the least. for by working hard and well during Thursday, Friday and Saturday these riveters were able to earn over seven dollars per day, or twenty-two dollars in the week. When work ceased on Saturday evening a drunken carouse began, which lasted until Wednesday night. In a short walk through the streets of Middlesborough on Monday forenoon I found at least a dozen men lying drunk upon the sidewalk—a condition which cannot be paralleled in any American city. It is impossible to reform this state of affairs since the unions control the entire situation and do not consider any offense of this kind as ground for a discharge, and a strike would follow any attempt to interfere with the God-given right to get drunk once a week. All over England Blue Monday is something more than a name; it is a costly factor in all industries, standing side by side with the tyranny of the labor unions that are fighting with bulldog obstinacy against improvements that would ultimately be for the benefit of all concerned. We have had much of this sentiment brought to America by the English and the Welsh, but although they have acquired much power in certain localities and in certain trades, they have never been able to control the whole American iron industry in the way they control the great English producing districts.

In England there is a tendency to have the management of an enterprise descend from father to son, and this transference of power is often gradual, the son being perhaps the assistant of his father for many years. It is evident that such a system tends to conservatism and the perpetuation of old conditions. This tendency is, of course, acccentuated by the general sentiment of the country to bow to the opinions of older men and accept their decision as final. In America, we bow to the decision, but we reserve the right to differ.

The conservative influence of a management controlled more directly by the stockholder and by family and local traditions must inevitably result in retarding the advancement of progressive young men in the establishment, and in pushing forward the conservative element, so that the man who finally reaches the top of the ladder will be more often a conservative than in America where progressiveness must be shown before promotion is possible. Add to all this the continental opposition to change which is especially marked in England, the magnifying of every custom and tradition into a law of nature, the opposition to self-evident improvements from a simple disinclination to be different from others, and it is easy to understand why our European friends do not move as fast as we do in America.

Thus we have proved why, in many respects, our friends across the water do not keep pace with us in the race, but it remains to explain why, in many respects, they are ahead. It is not necessary to discuss the development of the Bessemer and open-hearth processes, because when these methods came to light the iron industry in America was a small affair compared with the old established plants of Europe; but in the manufacture of coke, for instance, Germany has been using the retort oven for twenty years, while America has just discovered its existence. England was very slow in adopting it, owing to the opposition of venerable authority, but our country is the most behindhand in accepting the benefits of the invention.

In the matter of gas engines driven by blast furnace gas the Continent has completely distanced us. Engines have been operating successfully in France and Germany for four years, while long before this, Riley, at Glasgow, in Scotland, put in operation an engine built by Thwaite which has been running since 1895. Immense machine shops all over the Continent are busy turning out engines whose aggregate horse-power runs into many thousands, whereas in America nothing of any consequence has been done in this direction. Much of this forwardness in so using blast furnace gas arose from the fact that gas engines driven by illuminating and producer gas have been used much more extensively abroad. The visitor to any English city is struck with the puffing of these engines in the lumber yards and the cellars of numberless workshops, while in America this economical motor is little known.

In another respect the European works are ahead of America and that is in the use of the unfired soaking pit. This practice is almost universal on the Continent and is common in England, while in America it has been a failure. This arises from the curious fact that acid steel does not give good results when heated in unfired pits, and the Bessemer plants in America make acid steel only, while almost all the plants on the Continent are basic. Moreover, in America it is the rule that nothing must interfere with the regular sequence of operations, and that if anything happens to the tools, nothing else shall be behindhand when they are ready. It is evident that a gas fired furnace is more thoroughly under control, and capable of holding ingots ready, than one which has no supply of heat. The unfired pit is simply one example of a very important truth, which may be stated thus: a method or device or improvement which is voted a success in Europe will oftentimes be voted a failure in America if it gives the same results. In other words, we will not bestow upon it as much intelligent care as our German friends, and will not consent to the delays and interruptions which they regard as of little importance. This statement may be questioned by some persons, but there are many engineers of prominence and of experience who will agree with me in this broad statement.

America has developed along its own lines, but the lines on which England and Germany have worked have not been as capable of rapid development. In the Bessemer process England has faced a continually lessening ore supply, decreasing both in quantity and quality and increasing in price. Immense progress could hardly be expected under such circumstances. Germany has had to adopt the basic vessel almost exclusively and has been much more successful with it than any works in America. In rolling mills, our friends across the ocean have used generally the two-high reversing mill, and it is quite evident that the possibilities of expansion in amount of product with this system are less than with the three-high train.

This one item, the capacity for expansion, is the great dividing line separating European and American practice and the reasons for the difference are not thoroughly appreciated. Taking the case of railroads for an illustration, we have on this side of the water a new country. The lines that form a network all over the western half of our domain and most of the lines in the older half have been built and equipped within the memory of young men. There were no old and obsolete patterns to copy. The new roads began with apparatus which to a greater or less extent was standard as far as America was concerned. The style of rail was practically uniform with all roads and the amounts ordered by many railroads were enormous. One railroad would order fifty thousand and another sixty thousand tons for delivery in one season, and all rails were so nearly alike that it usually sufficed to change one set of rolls to go from one order to another. The differences in sections that did exist arose from a desire of the railroad engineer to experiment and get a better rail, although this sometimes resolved itself down to an egotistical desire to have his name associated with a particular design. This latter state of affairs in America seldom produces the kind of glory desired, and within the last few years a concerted action on the part of the steel manufacturers and engineers has resulted in the general acceptance of one set of standard sections.

In England the conservatism and importance of the railroad engineers render such standardizing apparently impossible. Not only that, but the use of chairs and their associated paraphernalia makes a change very expensive, while the much smaller mileage of their lines, due to geographical limitations, makes it impossible to have a very large order either for replaceals or new track. One road at least in the British Isles with a high sounding name is only two hundred miles long, and it is laid with half T rails and half bullheads, and in order to make renewals it is necessary to order two kinds of rails, splice plates and accessories, and each order will be just half what it would be if the road were laid with one kind of section. Needless to say such a road must inevitably pay a higher price per ton for its rails and fastenings. In America it is now possible to keep in stock the fish plates for the standard American Society sections. The rolls do not have to be put in for a few tons and taken out and put away for a year. The railroad engineer may think this matter of roll changes is no concern of his, but it is his concern and his railroad must pay the bill in the end, and if the English railroads would unite on certain standard sections of rails and joints and abolish and forget certain details of inspection and testing that have come down from the dark ages and are perpetuated by the red tape of Boards of Trade, they would get their material at a much lower price, they would get it in half the time, and it would be just as good. The responsibility for these conditions, however, does not fall upon the English steel works. They have had to meet certain business demands and they and the railroads are prevented from making any changes by the regulations of the Board of Trade, this latter institution being practically a government commission whose hands are tied by Parliamentary legislation. All experience proves that progress is either slow or impossible when a legislative body has to be moved.

It is also to be borne in mind that England cannot extend her domain as the United States has extended, and that the increase in the cost of raw materials seems to put a limit upon future possibilities. Under these circumstances, it would have been of doubtful expediency to build a counterpart of one of our immense American mills, for the total production of steel rails in all England is only about 800,000 tons a year, while in America a capacity of 600,000 tons is considered about right for one mill. England has, therefore, clung to the two-high reversing engine, which for smaller products has certain advantages. In the first place, it is much better adapted for rolling directly from the ingot, for with a reversing mill, the bar can be backed out if there is a tendency to split. It also renders it easier to roll many different sections on one mill in steady operation instead of having several mills each adapted only to its own specialty, and it is also easier to make certain difficult sections on a two-high mill on account of the ability to vary the speed.

TABLE XXI-A.

Miles of Railway in Operation in 1899.

FROM STAHL UND EISEN, JULY 1, 1901.

United States	67 per cent. of the total.	190,360
Germany		31,570
Russia		28,750
France		26,380
Austria-Hungary		22,670
Great Britain and Ireland		21,670
Canada		17,350
Italy		9,830
Spain		8,300
Sweden		6,700
Belgium		3,870
Europe except above		13,730
Asia		35,140
South America		28,030
Australia		14,760
Africa		12,570
Mexico, Central America and Newfoundland		9,800
Total		482,480

This matter of small orders will be better understood by comparison of the total mileage of railroads in the different countries, as shown in Table XXI-A. The United States has 40 per cent. of all the railroads in the world, Germany coming next with less than 7 per cent., and if we omit those nations that make their own rails and take all the rest of the world, including Canada, the total "markets of the world" do not include as many miles of track as are laid within our borders. Thus if we can assume that Germany, which ranks next to the United States in length of track, should monopolize the rail trade of the world with the exception of the United States, Russia, France, Austria, Great Britain and Belgium, each of which is self-supporting, she would not have as much tributary track as stretches out before the doors of American steel works. These reasons have influenced the development of rolling mills all over Europe, and the newest and most thoroughly equipped plants have not copied from America, but have simply enlarged and expanded the old two-high construction. In this connection, it is worthy of note that one of the newest American rail mills is of this type.

In making the usual sections of structural material and railway splices, it is the custom in America to cut the ingot into several blooms or billets and reheat these for finishing, this being done in order that the bloom or billet mill shall run steadily at its maximum capacity. In Europe little thought is given to this argument. The question everywhere heard is this: "What could we do with all the steel if we should run continuously?" It is therefore much more common abroad than in this country to roll many different sections in one reversing mill, the stuff being finished in one heat from the ingot, the finished bar being very long; in one mill a 2″ square billet is finished 475 feet long and a 3″x3″ angle 425 feet. Oftentimes the finishing is done on a different mill, and frequently the finishing mill is three-high, the blooms being cut up and transferred without reheating.

The Germans use many three-high trains for finishing, and these are often of large size and are run fast. In more than one place 15-inch beams are rolled directly from the ingot without cropping the ends and without reheating, the work being done by hooks and tongs without any machinery except a steam cylinder to raise the swinging support of the hooks used to catch the piece. Such a lifting motion is necessary when the rolls are 30 inches in diameter and the mill runs 110 to 120 revolutions. I have seen a mill of this size and speed handling 8-inch blooms weighing about 1200 pounds, and few American workmen would care to work as fast and as hard as these hookers, although American workmen would have smiled at the idea of a man being able to do anything when wearing wooden shoes. In rolling beams by hand in a train of that size an army of men is required, and the average visitor can hardly understand why some simple labor-saving devices are not introduced. It is related of an American at a German works that he offered to spend a certain reasonable sum in machinery and save so many dollars every month. The manager answered by showing him the cost sheets and proved that the total expenses for labor in the mill did not equal what he proposed to save. Such an answer, however, cannot possibly be true of all places where labor is thrown away. In one of the famous steel works of the world are two blooming mills, three-high, and exactly alike, turning out a combined product of ten thousand tons per month. In America one such mill would take care of from forty to sixty thousand tons per month and two men on each turn would operate it, while in this place it took fourteen men on each mill. The fundamental difference was that the table rollers were not driven, and it would be safe to say that the introduction of machinery to drive those rollers would have paid back the money every three months, to speak moderately.

It will not do, however, to suppose that the management was entirely contented with this condition. On the contrary, plans were drawn for an entirely new works, which involved immense expenditure of money, and it seemed to be the accepted law not only at this particular works but elsewhere, that an old plant should not be improved when a new one was contemplated. The reasons for this are, of course, self-evident and must have force everywhere, but in America such improvements do go on constantly even under exactly those conditions, because with our high priced labor and almost unlimited demand for steel, it is often easy to pay for new apparatus in a year, while in Germany with cheap labor and a much smaller product, it would take a much longer time. At another works, in another district, there were four mills under one roof, the building being large enough to cover all the room necessary for handling and shipping the product of all the mills, making it one of the largest buildings in the world. The total output of these four mills was about 400 tons each twenty-four hours. In America the same outlay would be expected to produce from five to ten times that amount.

This condition, however, is not universal, and the American visitor will find other plants more to his mind. It is impossible to obtain the same output from a basic converter that can be obtained from an acid lined vessel, as the addition of the basic materials, the greater amount of oxidation to accomplish, and the much greater wear of the linings, render it out of the question. Nevertheless there are several German works, among which may be mentioned Rothe Erde, Phoenix, Hoesch and Hoerde, which can make from

32,000 to 35,000* tons of steel per month from a plant of three basic converters ranging from 11 to 18 tons capacity, and there is no need to say that this cannot be done without an all-sufficient supply of "push."

The diversity of product in a German mill and the intermittent work, arise oftentimes from the universal control by syndicates of all the items of production, and there is no incentive to rush out a heavy tonnage for a week and then shut down with an empty order book, but it would seem difficult to ever get a mill up to its maximum output and efficiency with workmen who wear wooden shoes. It would be good business to pay for a leather outfit simply for the moral effect.

There are some American writers and metallurgists who ascribe the forwardness of steel manufacture in America to the ingenuity and brilliancy of a little group of men who developed our great plants a quarter of a century ago. It is an unkind act to disparage the work of our predecessors, but I am actuated not in the slightest degree by any personal feeling in expressing the opinion, which is not simply of my own creation, that no one man should be lifted upon a pedestal of fame unless the foundation stones bear the names of many others almost if not quite equal to him in worthiness. It was the custom twenty years ago to pick out as an idol one who could deliver a witty after-dinner speech, and to forget that something was due to the cook. Nothing is easier than to join a mutual admiration society and gradually have every member become in his own estimation more and more indispensable to the daily routine of the universe. In my judgment the characteristics of American metallurgy have been developed by so many minds that it is invidious to name a few, and these minds were not creators, but creatures; they were carried forward in the flood of "push," which has been and is to-day the predominant feature of our countrymen, who will forgive mistakes if they are made while going forward.

Much of the difference between the two sides of the Atlantic is due to the fact that no spirit of rivalry has ever entered into European steel works. Men do not go from one place to another; they do not brag of outputs; they do not challenge every one to enter the race. It is beyond question that many of the great advances that America has made have been due almost wholly to vainglory

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* Schrödter, private communication.

and a simple desire to "beat all creation." Another factor was the desire to increase outputs when the margin of profits justified the most lavish expenditure, and it is doubtful if in every case it was foreseen that these outlays would result in such a great decrease in the operating cost per ton. In foreign countries this argument of beating a competitor has absolutely no place. In one of the old works in Germany there are blast furnaces in operation which are only 48 feet high, but as they are running on a fuel consumption of from 1790 to 1840 pounds of coke per 2240 pounds of iron, the management sees no possible justification for destroying existing plant and starting in on new construction involving immense expenditure. The facts that the furnaces are out of date, that they are slow, that they are curiosities, have no bearing on the matter at all and are not considered for a moment. In our country we might keep such furnaces if we had no money to build others, but we would apologize for them; we would say they were not worth looking at, but in Germany this sentiment is entirely unknown. It is open to debate whether a little of the foreign spirit would not be as valuable an acquisition for the American, as a little American spirit is valuable for the European.

In America we enter contests from the time that we are born, and we always play to win. Europe does not know this feeling and she will not make two thousand tons of rails in a day from one rail mill until she acquires it. She has engineers who are as bright and smart as any in America; they are as progressive as any of our nation; they are working along many lines; they are introducing many labor saving devices; they are building mammoth mills and great machine shops; they are not narrow; they are copying America where America is good; they are filling their machine shops with American tools and they are taking a fresh start. In Austria a grand transformation scene is in progress: a syndicate controlling most of the iron and steel works of the kingdom is dismantling and abandoning most of them and concentrating the work into a few plants, which are being reconstructed and rebuilt with a thoroughness that we egotistically think is American. In Germany individual works are doing and have done the same thing; but in Europe these improvements are not always announced to the world with a flourish of trumpets.

There is a district in Germany which is said to possess financial advantages over any other, and the question is naturally suggested why the works at that place do not expand and monopolize the business. There are two answers, each of which is deemed sufficient in Germany. First, it would be difficult to get the necessary labor to move to a new place. Second, there is no inducement for the stockholders to spend money, as they are quite satisfied with dividends at the rate of seventy-five per cent., and there is no use of exhausting ore to pay dividends to new capital. These two reasons are equally incomprehensible to Americans; they represent the difference between Europe and America. Each land has much to give to the other. Perhaps we can teach them how to work, but they can teach us how to save up just a little of our surplus energy and use it in enjoying the fruits of labor.

SEC. XXIb.—*The question of employer and employed.*—This is usually called the "labor question," and is often spoken of in much the same way that the consumption of fuel would be discussed, but although it may be convenient to treat it thus in books, it cannot be so handled in actual life. There are three distinct methods of arranging relations between the employer and the employed. The first is the paternal system, where the employer does everything for the workmen, as at Pullman in our own country, and at Creusot in France. This is probably the worst thing possible and breeds a servile lot of men, whose highest thought is expecting the next spoonful of gruel. It is soup-house charity when there is no necessity for philanthropy.

The second method is the treatment of men as men. The self-respecting man does not ask charity; he wishes to pay one dollar for one dollar's worth of goods. There are exceptions to this rule, but there are also many other objectionable people in the world. This self-respecting man should be the one for whom all rules are made and the others may do as they like. This man is a free agent, able to make his own contracts, to work or to leave, and as a rule he generally has a job and is too busy to make speeches on the labor question.

The third system is the labor organization where men bind themselves together and appoint a committee of those who can talk longest and whose duty it is to get all they can for "labor." These unions declare that every man is the equal of every other man—when he is not; that a fast workman shall not be allowed to do any more work than a slow workman—which would seem to be an attempt to upset the decree of Providence; that a good workman shall not receive more than a lazy dummy—which is absurd; that labor saving devices shall not be introduced unless the money saved is distributed among the workmen; and, worst of all, that dealings with the men shall be done through certain intermediary officers, when it is notorious that in some cases the men chosen to such office have gained power by cajolery, bribery and the lowest methods of ward politicians.

It must be acknowledged that the same class of men achieve political success in both small and large cities under our system of popular sovereignty, and it would certainly be unwise to change our government in order to prevent the election of demagogues to office; but it must be remembered that no demagogue nor Board of Aldermen is given authority over the freedom of the individual nor over the operation of great industries. The Czar of Russia might hesitate to order one hundred thousand men out of employment, and practically expose to mob rule great industrial establishments and ruin the trade of a million people. There is only one power on earth in any civilized land which has such authority, and this is a committee of men chosen by a small fraction of the community and often by a minority of the interested parties. It is of record that the disastrous decisions of such committees have often been condemned by the greater bodies of which they form a part, although such condemnation generally does about as much good as an apology for hanging the wrong man.

These faults are recognized by the labor unions themselves, and many well meaning persons advocate "compulsory arbitration" as the panacea for all ills; but it is impossible to see how a manufacturer can be forced to take orders and to operate his mill if he chooses to shut down. To compel him to do so would be condemnation of property, and the slightest consideration of fairness would lead the state or the community to make good any loss he might sustain by the continuance of operations. On the other hand it is impossible to see how a workman can be compelled to work at any wage which is not satisfactory to him, when perhaps he is offered more elsewhere, and no manufacturer would ask for such an unconstitutional infringement upon the personal rights of his workmen. Moreover the labor unions themselves, while anxious for a law to compel employers to abide by an award, recognize the injustice and the impossibility of forcing a workman to labor for less than he considers his due. It would therefore seem that the best way is the simplest: it is to let each man exercise the rights given him by our laws of working for the highest wage he can get, and of leaving when he is not treated rightly. If a man is unreasonable he may be discharged, while if an employer is unjust he will be unable to find laborers to do his work.

Under the system of labor unions the men who perform some particular line of work may often be entirely unrepresented on the committee. The works with which I am connected has in operation seven different rolling mills and each one is essentially different, both in amount and character of product. In some of these mills there are over thirty different kinds of positions where the men are paid by the piece or ton, not counting the work done by the day or hour, and each of these tonnage positions has a special rate agreed upon. Under any system of committees it is plain that the great majority of positions will have no representative, and that there will always be an incentive on the part of a committeeman to look after his own job and his own friends, while, on the other hand, the management of the works will be only too glad to give such a committeeman anything he may ask if he will agree to a low rate for those who are not present at the conference. A few years of such work will generally bring on a strike, and a thousand well-meaning humanitarians will then advocate "arbitration," by which is usually meant a reference to some men who do not know a pair of tongs from a straightening press, and who probably will recommend that the difference be split, the whole question of disproportionate rates being left exactly as it was. To what extent this disproportion can obtain has been shown by sworn testimony before a Congressional committee, where it was proved that men who joined the disastrous strike at Homestead drew thirty thousand dollars a year.

It might be of advantage for the manufacturer to pay still higher bribes to the leaders of the workmen, since such wages for rollers cannot be called earnings, if it were not for the fact that there is a limit to what the members of a union will stand, for it is necessary to keep in mind the all important point that the action of the committee is not final. The signature of the company bears with it the highest responsibility, but the signature of the committee is worthless. It may or may not be agreed to by the union. but whether it is or whether it is not, the decision does not carry with it the slightest financial responsibility. It does not bind and cannot bind any individual to work for the company a single day longer than he chooses, and if the industrial situation brightens and men find other more remunerative employments it is the privilege of each and every man to leave, and if they choose to go out on a sympathetic strike, as unions have done before, there is absolutely no redress for a violated contract.

I do not believe in such inequitable arrangements, nor do I believe in arbitration on many of the questions arising, or in a system of committees so organized. I believe that each man who thinks himself ill treated should have access to the office of the manager. It is the right of appeal to a higher court and it is my experience that it is the rare exception that a body of men appear to discuss a question unless there is some ground for their action. Investigation generally shows that their statements are correct, and while, of course, the workmen are trying to get all that they can, and while the manager is naturally trying to give as little as he may, it generally happens that the level-headed men lead in the argument, and that a fair and equitable arrangement can be made, and no man feels that he is outwitted by a committeeman. He has stated his case; he has heard the reply; he remains a free citizen to accept the offer or to decline it, and no works can long operate if the offer is not just and right.

I do not know whether these rules are universal, and there may be cases where different conditions govern and where large bodies of skilled men of one trade may join for mutual protection; but in a steel works where hardly any two positions are alike either in nature of work or in rate of pay, the labor organization as at present constituted has no place. Moreover, under no condition will it ever be more than an unworthy and petty factor in the universal labor problem until it gives up once and for all the tenet it now holds to be fundamental, that a limit of production should be set for each man. If labor unions will drop this primal error, reason may find a basis for discussion, while with this dictum as a premise there can be no reconcilement with the spirit of progress. They must also drop the tyrannical theorem that non-union men may not work with union men, and the anarchistic conception that non-union men must not deliver goods to union shops. Many modern strikes are based on these ideas, and it is quite evident that arbitration is utterly out of the question since the answer is either yes or no. Any board of arbitrators, by the mere act of considering such claims, thereby acknowledge that they have a standing in equity, when a moment's consideration will show that they subvert the principles of our government. Almost all of the large steel plants of America manage their own affairs. The result is that the introduction of labor saving devices creates no trouble, the more so because such devices, while they decrease the number of men, demand a higher grade of workmen, so that it often happens that the man who operates the new machine will earn a higher rate of wages than any man made before at the same kind of work. Another reason why labor saving machines are not entirely contrary to the interests of the skilled workman lies in a fact which seems to be unknown to the average social economist. In the manufacture of steel, there is a great deal of very hard and heavy work. Formerly, when most of the work was done by hand, a skilled man was almost necessarily one who was superior physically, and as soon as he reached middle life he was obliged to accept some less arduous and less remunerative employment. With the introduction of machinery the skilled employee may often retain his position during the remainder of his life, and the ability to keep an old and trusted employee in a position where his experience is of value to himself and to his employer is not merely a question of sentiment; it is an advantage as great to the employer as to the workman.

There is a singular paradox in regard to labor saving machinery in that such improvements always tend to an increase in the number of men employed, for the inevitable result is a cheapening of the product and the usual result is an increase in capacity. The cheapening brings more business and the establishment taken as a whole employs more men than before. The progressive works grows while the others disappear.

The current argument in favor of labor unions may be stated thus:

(1) Capital is allowed to organize;
(2) Labor must have the same rights as capital;
(3) Labor must be allowed to organize.

It is impossible to dissent from the truth of the premises, and it is impossible to escape from the conclusion; but it is necessary to define the terms used. It is essential to the argument that we know just what is meant by "organize." Capital is allowed to organize into corporations, but the rights and privileges of these bodies are regulated by law. They may not overstep whatever regulations may be made, and the people can make or change these rules. In only one case in America can a corporation interfere in any way with the private rights, property or freedom of the individual. That exception is the right of eminent domain possessed by railroad companies, and it is well known that the conditions under which this right may be exercised give to every injured party more than sufficient compensation for the trespass. Nevertheless, it is an infringement of a personal right, and for this reason such corporations have always been regarded as *quasi* public and subject to legislative control. This control moreover has not been entirely theoretical, for some of our socialistic Western States have enacted laws that have brought ruin to all the capital invested.

Taking into consideration simply manufacturing corporations as being the only ones pertinent to our inquiry, it may be safely asserted that in no particular do their corporate rights allow any trespass upon the private rights of individuals. It is true that they may use their money to injure men or communities, but so may any private person. Any multi-millionaire might buy a factory and shut it down and ruin a village, and it is difficult to see what could be done about it. He might discharge all his old and trusted servants and the law could hardly touch him. He might commit all the sins charged against corporations and there would be no redress. It is wrong to condemn corporate laws for allowing acts which a private individual may legally do, and it is quite certain that manufacturing corporations have been given no rights of eminent domain, no privilege to infringe upon the private estate of the citizen. They have the power to issue bonds, to issue stock, to conduct business under a perpetual name, and in return have certain duties, certain taxes to pay, certain regulations under which they must conduct their business and protect the interests of the minority. This is the extent of their powers as granted by the State. All other powers are inherent as vested in general constitutional prerogatives.

This then is the definition of "organize" and the right of men, whether so-called "laborers" or not, to so unite has never been questioned. They may form organizations for pleasure, for improvement or for business; but it is another matter when they "organize" to restrict personal liberty. That a band of men may agree among themselves not to work more than a certain number of hours per day is as certain as that they may agree not to smoke, or not to eat meat. Their right to do so is unquestionable. It is their privilege to agree that they will only handle two shovelfuls of earth per hour, or one shovelful per day. It is their right to refuse to work for less than five dollars per day or twice that amount. It is their right to ask their employer to sign a scale and agreement to that effect for one year or ten years, but it is also the right of the employer to ask what guarantee is given that they will stay in his employ, no matter what other inducements are held out to them in other places, and it is also his inalienable right to tell them that such agreements are not according to his wish and that he will try and get men who will work without them; and if such "organization" should reach the last stage and the "organizers" should demand that no one should work in the shop except those subscribing to the union and paying the salaries of the officers, the only possible answer is that such a rule is contrary to the fundamental tenets on which this government rests.

It has already been stated that certain matters cannot be arbitrated. Thus it is of record that a certain "union" works in America was shut down several times, not on account of any disagreement between employer and employe, but on account of disputes between two rival labor unions. It is quite comprehensible why under such conditions or under many other circumstances a manufacturer might conclude to employ only non-union men. His right to do so is as unquestionable as the right of a farmer to employ only colored laborers or to employ only white men, or to employ both as he chooses. Granting that the manufacturer has concluded to run his place non-union, it is evidently impossible to submit the matter to arbitration. If his conclusion is unwise, he will suffer most, for if men will not work for him then he will lose money, and if he can get only the scum of the streets then also will he lose; but if he can obtain good men in sufficient numbers, then it is quite certain that the conditions are acceptable to them and to him and that therefore his position is just and equitable.

It is impossible to conceive how a decision to employ only non-union men can be susceptible to arbitration, and it would seem unnecessary to more than state the theorem were it not that politicians and certain lecturers at Chautauqua are advocating compulsory arbitration. It must always be remembered that no employer ever entertained a prejudice against a labor union on general grounds alone. The opposition arose from the plain fact that labor unions regularly develop into the most tyrannical and outrageous violators of individual rights. It has happened many times that a hundred union men have left a shop because one non-union man was at work. Is it possible that any employer with a grain of self-respect, or any intelligent person, will say that such a matter is open to arbitration. Our common law recognizes prosecution and imprisonment, but it recognizes the arbitration of crime as the compounding of a felony and calls this a crime in itself.

The proposition has been made by a President of the United States that employers should not discriminate against union men, but that union men on the other hand should not interfere with non-union men working beside them. This is a most excellent solution from an academic standpoint, but in nine cases out of ten where such an arrangement is attempted, it is overthrown by the union element, and in places where the troubles have developed into riot and murder we have yet to hear of any assistance given by labor leaders to the legal authorities to punish the instigators of crime.

Labor organizations are a form of socialism. In the same category stand the comprehensive paternal laws of Germany and other European countries and the less radical measures either proposed or enacted in our own land. This fact does not necessarily brand them as wrong, for socialism may contain elements of right and justice. I do not make the senseless generalization that since trades unions are socialistic and socialism wrong, that therefore the unions are wrong, for it would be necessary to prove that all phases of socialism are wrong. But I do make the point that if socialism is right at all, it is right for all; there must be no classes in America. There is no stone wall between the humblest laborer in a steel works and the manager. The pathway is wide open from the workshop or the mill to the sanctum of the administrative head. The rule that applies to one must apply to the other. If eight hours is the maximum time the laborer is allowed to work, then the same law must govern the manager. If the humblest workman must not *work* except within certain hours, then the manager must not *think* except during the same interval. The mechanic must not go home and think how a job can be done better, the superintendent must not try to improve the plant, nor make one more ton of steel to-day than was made yesterday. Moreover, if no man is to do work except at his own trade, then no man must work in his own garden, raise his own flowers, or mend a broken fence. Such is the inevitable logic of the labor union.

The labor leaders will hardly wish to say that there are classes and castes in America, and if there are no classes then the same rules should govern all; and if these rules are to be made for all, then they must be laws, made by the regular law-making bodies; made by the people through their chosen representatives. This has been done in New Zealand; it may be well to await the result.

It is necessary, however, to remember that in this great experiment success will not be measured solely by freedom from strikes, for the industrial peace compelled by arbitration is not necessarily the best thing, any more than political and social peace compelled by the superior force of an autocratic monarchy betokens the highest triumph of government. The excitement of a political campaign in America is more desirable and more truly an exponent of a healthy condition than the sullen passivity with which servile subjects might view a change of masters. The current views of many political leaders in interfering with industrial freedom resemble the medieval notion that a decree of the king could fix the price of wheat, prohibit the export of gold, or exalt the value of a debased currency. The success or failure of such measures cannot be determined by the immediate effect; some people imagine that when the arbitration laws of New Zealand have prevented a strike by the easy method of splitting the difference, a great triumph has been won. They forget that this is a backward step; that it is abandoning the business method of fixing a price, and substituting the ancient Jew practice of asking twice as much as is expected in order that an intermediate price may be secured. If the public supposes that the truth is a compromise between extreme demands, it is easy to keep business in a ferment by asking for an advance.

It will take a generation for New Zealand to discover the result of her innovations, but even at this early day the situation is not entirely happy. The employers in three provinces have come out strongly against the present system of compulsory arbitration, while on the other hand the labor union of one of these same provinces is up in arms at the unexpected and strange phenomenon of an award against the workmen, and the Labor Council is asking "why should we obey an adverse award, when no jail in large enough to hold us all?" Not until the regulations made in this distant island have had time to produce their proper fruit, not until New Zealand becomes thickly settled and possessed of the complex industrial life existing in those countries which are factors in the business of the world, not until the new schemes of labor regulation have proven their efficacy under international competition, can the laws of this much-discussed country become more than an interesting experiment to be watched rather than to be copied.

SEC. XXIc.—*The question of tariffs.*—In the minds of many of my readers this discussion will not be in the least complete if I do not place upon record my unqualified belief that the present condition of the American iron manufacture is solely due to the operation of the high protection system, which has been in force for so many years. Let me say therefore that there are some men in the iron trade who believe that the entire business of this country is not represented by a tariff measure, just as on the other hand there are men not connected with the iron business at all who fail to appreciate that the tariff is robbing them of their last cent. During the period that high tariffs have been in force our iron industry has expanded to most wonderful proportions, but that such expansion is due to the tariff is not a necessary conclusion. That such expansion has from time to time been interrupted by periods of panic and disaster is unquestioned, but it is rash to say that such disasters are the inevitable results of protective tariffs.

It is quite true that American manufacturers have sometimes sold a part of their products to foreign customers at a lower price than the ruling market quotations at home, and this fact is immediately grasped and spread broadcast by petty politicians and by so-called economists, who seem always to be climbing out on the scale beam in one direction as far as they can go to balance the equally erratic high tariff promoters who are climbing the other way. Nothing can so quite keep in countenance the fallacies of fanatics as counter fallacies gravely argued. Nothing could more please the advocates of free trade than to see protectionists trying to prove that iron ore is not raw material. My mind is not broad enough to grasp all the complex conditions that surround the industrial progress of America, and I cannot see as clearly as some men that no steel would ever have been made here had it not been for certain divinely inspired orators in Congress; neither can I see as clearly as others that the nation would have been richer and greater had no duty ever been imposed on foreign manufactures. It is possible that the reason why I cannot see so clearly is that my information is gained at first hand, and is not made up of partisan statements. An able and honest President of the United States publicly announced that a tariff was a tax, and that the price of an article here was the price abroad plus the tariff. If the statement concerning the price had been true then undoubtedly the tariff would have been a tax, but unfortunately for the reputation of the said President, the statement was not true, as he might easily have found and should have found by the most casual inspection of the regular trade papers. In the case of steel rails, for example, the price in the United States is not equal to the foreign price plus the tariff, and has not been for fifteen years, while there have been many times when they were sold here much cheaper than they could be bought at European works.

Such free trade nonsense is matched by many protectionist pamphlets declaring that high tariffs mean high prices and high wages, when on the one hand we have seen the United States selling steel cheaper than any other country in the world, and we may see Austria and France, both high tariff nations, paying starvation wages to their work-people, and using women in great numbers as laborers in the roughest kinds of work.

The following conclusions may be wrong, but I trust they are not fanatical or entirely unfounded:

(1) A high tariff on a certain article hastens very much the establishment of factories to produce that article.

(2) The establishment of a new industry like making steel, cotton or woolen goods, carpets, etc., etc., requires at least ten years before all the social and industrial conditions have become so correlated that the cost of production reaches an economical footing.

(3) During this period the general public pays a somewhat higher price for this article, the excess depending on the amount of protection and the amount of domestic competition.

(4) In some cases and in industries not requiring very large investments of capital or the creation of communities of special workmen, this period during which the public is so taxed may be very short, and the price may soon drop even below that paid to foreign manufacturers.

(5) If the profits to the protected manufacturer are large, new works will be erected, and if these combine to extort an unreasonable profit, still other works will be built, the end being the same

in any event in that the needs will be met and internal competition ultimately bring about a price representing in the long run not much over a fair profit.

(6) Whether this price, the cost plus a fair profit, is or is not more than the price abroad will depend upon the natural advantages of the situation. If an article cannot be made here as cheaply as abroad, then the question must be answered whether the public should pay the premium. If it can be made as cheaply, then competition will force it to be so made.

(7) The "price abroad" is a term which must be used carefully, for the price at which standard articles can be bought from time to time for delivery beyond the borders of the home market does not in the least represent what would be the price under a greater demand; such a demand, for instance, as would be made on Germany and the United States if all the steel works of England should shut down. Neither do these quotations represent the real cost of manufacture.

(8) The real cost of manufacture includes many things which are usually overlooked, but which are of immense importance. The main items are as follows, it being assumed for the sake of simplicity that a steel works owns its own ore and coal mines and coke ovens:

(a) Actual operating costs at all mines and works, including labor, fuel, repairs, etc., etc.

(b) Freight charges on all raw materials and incidentals.

(c) Interest at 6 per cent. on all money actually invested in mines and plant, and on all floating capital needed to carry on the business.

(d) Expenses incident to superintendence, selling agencies, taxes, bad debts, pensions, damages, etc., etc.

(e) Depreciation, by which is meant a class of items generally overlooked. The ore and coal must bear not only the interest on the money invested, but a sum sufficient to pay for an equal quantity of material when the beds are exhausted. The depreciation of the steel plant itself is still higher, for it is almost safe to say that to keep a steel works up to its value, to keep it as a factor in the great strife of competition, requires an annual expenditure of ten per cent. of its cost. Engines, boilers, rolling mills, cranes, shears and all the manifold equipment may last that time, may last longer, or may be outlawed before that period expires. A mill not up to date cannot compete with one that is, and if it cannot compete, then it loses money; and if it loses money, then it is worth nothing, absolutely nothing, no matter how new it is or how much it cost.

(9) This item of depreciation is often represented on the cost sheets by new equipment and machinery, but sometimes these are erroneously or falsely put into the capitalization account. Whether ten per cent. is or is not the correct figure for a steel plant, it is quite certain that a very considerable amount must be included in the true cost of manufacture.

Assuming that the plant cost ten million dollars, a depreciation of ten per cent. is equal to one million annually; and if the production during the year is five hundred thousand tons, then this charge amounts to two dollars on every ton of steel made. It may be more in some works and may be less in others.

(10) When business is slack it is necessary that the manufacturer ignore this item altogether, for he will assuredly operate his plant if he can cover his actual running expenses. If therefore he does not earn his depreciation during a period of one, two or three years, then he must earn a double amount for an equal period when good times return, and this must not be considered as profit. He must also ignore the interest on the money invested in plant and in floating capital, as well as the expenses of selling agencies, taxes, insurance, etc., since all these items, like depreciation, will go on whether steel is made or not.

(11) During this era of low prices, the actual cost sheets and the annual reports may show no loss or even a margin of profit, and the average observer might conclude that these figures represent the proper selling price, a conclusion which would be entirely erroneous.

(12) It is the part of common sense for rival manufacturers to get together and agree to prevent cutthroat competition, by which not only are all profits thrown away and all depreciation and interest charges ignored, but even operating costs encroached upon. A fair price under such an arrangement would include depreciation and interest as fundamental parts of the cost.

(13) Having made such an agreement for home trade it becomes good policy to ignore these items on competitive business for foreign deliveries, since they are both fixed quantities, not depending on the amount of steel produced, and the extra output caused by such foreign deliveries cheapens the cost to the manufacturer. Moreover certain lines of foreign trade cannot be held if prices are varied

with every local advance. Having secured for instance the business of a certain railway in Australia, it is evidently quite impossible to retain it if the price quoted follows every boom in the home market; and it is certainly good policy to keep the trade of this railway for future business, in spite of the hue and cry about lower prices to foreign buyers.

(14) This argument is not new, but has been an accepted commercial and industrial maxim in every country, under both protection and free trade, and all the "prices abroad," so freely quoted, are based on this rule as existing in foreign lands. It is even true that bounties are actually paid in some instances to encourage export trade.

(15) The payment of a bounty for export trade is directly in line with the maintenance of a protective duty after the incubative period has passed. Practically it must be looked upon as out of the question owing to the impossibility of arriving at a complete knowledge of just what would be equitable, but although such a system would breed many wrongs, it is theoretically justifiable to a certain limited extent.

A steel works, in common with every manufacturing plant, is a benefit to the general public in many ways. It contributes to the payment of taxes and thus saves an equivalent amount of individual expenditure. It is the foundation of large communities which influence and increase the general prosperity of the country by giving a market for all kinds of commodities. It supplies freight to the railroads in enormous quantities. In the twelve months immediately preceding the time of writing, the works with which I am connected received 54,903 cars and sent out 17,471 cars loaded with finished material. Allowing for some empty cars received and estimating the average of the whole to be 30 tons per car, we have a total of 2,170,000 tons of traffic and a total train length of 500 miles. The average length of haul is unknown, but was over two hundred miles. This business brings in an enormous income to the railroads, the gross receipts from a steel works being four or possibly six times as much as though a similar amount of material were imported from abroad, and there were no raw materials or incidental supplies to assemble. It will be evident on the slightest consideration that the cost of moving other freight is reduced by this increased business, and the establishment of other industries thereby made possible, which, in turn, react by further lowering the cost of transportation by their contribution to tonnage moved.

A nation would lose no money if a bounty were paid to support manufactures, provided such support were necessary, and provided that the bounty did not exceed the sum directly and indirectly paid or saved by the manufacturer to the state and to the public. If German steel is laid down in England at one shilling per ton cheaper than English steel works can make it, and if that shilling represents the dividing line of business, then it would be money in the pocket of the taxpayers of England if a protective duty of one shilling were levied upon foreign steel, since the amounts contributed by works in operation must be much more than this. It is impossible to give the upper limit of such a tariff, for the conditions are too various and include all the correlated conditions, down to the higher value of farm products in industrial communities. Within this range, whatever the limits may be, a protective tariff is not illogical; beyond the limit, it is uneconomical.

Such are my opinions. They may not embrace absolute truth. Few things have ever been written that were beyond need of change, but it has been deemed advisable to revise the first chapter of Genesis and it is barely possible that some alteration may be necessary in the Wealth of Nations by one Adam Smith.

CHAPTER XXII.

THE UNITED STATES.

Section XXIIa.—*General view.*—It is impossible to treat the iron and steel industry of the United States with the same completeness that the different nations of Europe will be discussed. This arises from the fact that the scale upon which our country is constructed is so entirely out of proportion to the scale by which other countries are always considered. It also arises from the absence of any tariff restrictions between parts of our country; thus it is quite conceivable that if New York State were a separate empire she might have a high tariff on steel and a low tariff on raw materials, and have long since created within her own limits a permanent steel industry on a considerable scale. In the absence of such a great center of production the output of the State is not only left undivided but is combined with that of New Jersey. From one point of view, however, it is wrong to consider as a unit a district as large as New York alone. The iron industry of the State is made up of two parts, entirely independent of each other. In the northeastern section are the ore mines of the Lake Champlain district and in the extreme west are the furnaces of Buffalo and Tonawanda, smelting Lake Superior ores. These two districts have no relation whatever to one another; they are 250 miles apart in a straight line, farther than from the ore mines of the Cleveland district to the coal of Cardiff; as far as from Prague in Bohemia to Gleiwitz in eastern German Silesia. It would be more logical after the erection of the new steel plant at Buffalo to make a group embracing the works upon the southern shore of Lake Erie, although this would be combining two entirely independent producers like Buffalo and Cleveland, which are as far apart as Dortmund and Saarbrucken.

The State of Virginia is always considered as a whole, but it covers an area nearly as great as England. It is not looked upon as one of the great centers of pig-iron production, but it makes half as much as the whole of Belgium, half as much again as South Yorkshire, with Leeds and Sheffield, and nearly double the output of Aachen and Ilsede combined. In any book treating exhaustively of pig-iron it would hold a prominent place, but it is discussed here simply as proof of the vastness of the subject, when this State may be neglected as having little bearing on the general business of making steel.

One of the fundamental differences between American and European conditions arises in this geographical separation and the distances through which the raw material must be assembled. In Europe a haul by railroad of 200 miles is considered very long and the cost is excessive, while in America it is not unusual at all. Coal and coke are carried this distance in several instances, while Chicago draws its blast furnace fuel from West Virginia and the Connellsville field, the distances ranging from 500 to over 600 miles.

The most magnificent disregard of distance, however, is seen in the official publication of the American Iron and Steel Association, wherein the steel production of Colorado is combined with that of East St. Louis in Missouri. These are entirely independent producing centers and they are 800 miles apart in a straight line; as far as St. Petersburg is from the coal fields of South Russia; as Middlesborough is from Upper Silesia; Westphalia from Styria and Paris from Warsaw. The fault however does not rest with Mr. Swank, but in the secrecy enforced upon him by certain interests.

The statistical reports of this country are by no means what they should be and this is due to disinclination on the part of some manufacturers to give information. The data on pig-iron are quite full as a general thing, but the records concerning steel production are very meagre. It is impossible to make out from the usual sources of information any accurate statement of the amount of steel made in the various well known and most important districts.

The *Directory to the Iron and Steel Works of the United States*, published by the American Iron and Steel Association, 261 South Fourth street, Philadelphia, gives details of almost every plant in the United States. This information is so complete that it is more than useless to give a list of works for each district, but I have compiled, with some labor, the number of converters, open-hearth furnaces and rolling mills in each district, and have calculated from this basis, and from several private sources of information and from official statistics, the output of iron and steel in each locality as nearly as possible. The private information was in some cases confidential and is used only in groups, as for instance, the data concerning a portion of the Pittsburgh district. The results are given in Table XXII-A.

In Table XXII-B are given the records of production of steel for the whole country from 1867. This has been condensed to make Table XXII-C in order to show, for both the United States and for Great Britain, the amount of the different kinds of steel made, while Table XXII-D gives the percentage of each product.

TABLE XXII-A.

Output of Pig-Iron and Steel in 1901 in the United States, together with Data on Producing Capacity; estimates in parantheses.

Note: See text for boundaries of districts; thus "Pittsburgh" includes parts of three States and output of pig-iron for "Steelton" includes the product of two counties.

	District.	Blast Furnaces.		Pig Iron.		No. of works having rolling mills.	No. of works making crucible steel.	Bessemer Converters.			
								Small, mostly for steel castings		Standard size. 7 to 20 ton.	
		Coke.	Charcoal.	Output; tons.	Per cent. of total			No.	Average capacity.	No	Average capacity.
1	Pittsburg	82	......	6,880,000	43.3	137	17	......	....	30	10
2	Illinois	20	......	1,597,000	10.1	21	2	3	2	5	11
3	Alabama	39	6	1,225,000	7.7	10	....	......	....	......	....
4	Cleveland, Ohio	8	......	783,000	4.9	15	....	......	....	4	11
5	Steelton. Pa	18	......	695 000	4.4	12	....	......	....	3	10
6	Johnstown, Pa	6	......	512,000	3.2	3	....	......	....	4	12
7	Lehigh Valley, Pa	29	......	481,000	3.0	11	1	......	....	4	7
8	Southeastern Pennsylvania	17	1	478,000	3.0	36	3	5	2	......	....
9	Virginia	22	4	449,000	2.8	6	....	......	....	......	....
10	New York and New Jersey	27	3	439,000	2.8	38	8	......	....	....	....
11	Tennessee	15	1	337,000	2.1	2	1	......	....	....	....
12	Hanging Rock, Ohio	11	8	309,000	2.0	4	....	......	....	......	....
13	Sparrow's Point, Md	4	......	303,000	1.9	6	...	......	....	2	20
14	Wisconsin and Minn.	6	1	208,000	1.3	7	4	3	2	....	....
15	Colorado	3	......	185,000	1.2	2	....	.....	....	2	5
16	Michigan	......	9	171,000	1.1	6	....	2	2	......	....
17	Other parts Penn.	17	3	398,000	2.5	45	2	.....	....	......	....
18	Other parts Ohio	9	......	301,000	1.9	27	3	1	1	2	4
19	Kentucky	8	......	68,000	0.4	9	...	......	....	2	5
20	Missouri	1	1	18,000	0.1	5	....	2	2	......	....
21	North Carolina	2	......	{ 27,000	0.2	...	....	......	....	......	....
22	Georgia	1	4								
23	New England	.....	7	12,000	0.1	15	3	2	2	....	....
24	Indiana	......	......	....	......	28	1	.....	....	......	....
25	Delaware	......	......	....	......	7	....	.....	....	......	....
26	Other States	......	6	2,000	......	8	...	1	2	......	....
	Total	345	54	15,878,000	100.0	460	45	19	... .	58	....

TABLE XXII-A.—Continued.

	District.	Open Hearth Furnaces.						Steel; all kinds.	
		Acid.		Basic.		Steel castings not included in foregoing.			
		No.	Average capacity.	No.	Average capacity.	No.	Average capacity.	Output; tons.	Per cent. of total.
1	Pittsburgh	35	30	84	40	20	18	(7.317,000)	54.3
2	Illinois	3	25	9	40	13	15	1,750,000	13.0
3	Cleveland, Ohio	3	25	10	30	2	10	870,000	6 4
4	Johnstown, Pa	2	35	8	40	2	4	656 000	4.9
5	Southeastern Penn	12	30	33	40	14	20	629,000	4.7
6	Steelton, Pa	3	45	9	40	2	15	427,000	3.2
7	Sparrow's Point, Md	......	......	......	......	......	......	352,000	2.6
8	Scranton, Pa	......	......	......	......	......	......	352.000	2.6
9	New England	5	15	6	40	6	15	173,000	1.3
10	Alabama	......	......	13	45	1	20	(150 000)	1.1
11	Colorado	......	......	......	......	......	......	(150,000)	1.1
12	New York and New Jersey	2	25	8	20	10	10	107,000	0.8
13	Lehigh Valley, Pa	6	30	2	40	......	......	69,000	0.5
14	Missouri	......	......	......	......	3	20	(50,000)	0.4
15	Hanging Rock, Ohio	......	......	4	30	......	......	15,000	0.1
16	Other parts of Ohio	4	11	......	......	15	15	165.000	1.2
17	Other parts of Penn	4	20	3	15	4	15	53 000	0.4
18	Tennessee	......	......	......	......	1	3	(189,000)	1.4
19	Wisconsin and Minn	1	20	3	15	3	20		
20	Michigan	1	15	......	......	......	......		
21	Kentucky	1	7	7	25	......	......		
22	Indiana	1	30	1	30	7	20		
23	Delaware	1	50	4	50	......	......		
	Total	84	......	204	......	103	......	13,474,000	100.0

The grouping in irregular periods may seem arbitrary, but the lines of division were found by calculating each year separately and taking the years that seemed to mark a change in practice. These tables, when taken in conjunction with a knowledge of the conditions that have ruled the steel industry of the country, tell a very clear story which may be related as follows:

In 1867 the production of Bessemer steel in the United States was 2679 tons. Some small quantities were made before this, but the industry was put on a permanent footing by the establishment of an entirely new Bessemer plant at Steelton, Pa., a plant which has continued to make steel from then until now. This was followed soon afterward in the same year by Troy, while Cambria, at Johnstown, was the next to enter the field, this latter plant having also continued to be an important producer to the present time.

From 1867 to 1871 about 20,000 tons per year, or about half the steel of all kinds made in the country, was made by the Bessemer

TABLE XXII-B.

Production of Steel in the United States in Gross Tons from 1867 to 1900.

Year.	Bessemer Ingots.	Open Hearth Ingots.	All Kinds of Steel.	Bessemer Rails.	Bessemer Steel; per cent. of total Steel.
1867	2,679	....	19,643	2,277	14
1868	7,589	....	26,786	6,451	28
1869	10.714	893	31,250	8,616	34
1870	37,500	1,339	68,750	30,357	53
1871	40,179	1,785	73,214	34,152	55
1872	107,239	2,679	142,954	83,991	75
1873	152,368	3,125	198,796	115,192	77
1874	171,369	6,250	215,727	129,414	79
1875	335,283	8,080	389,799	259,699	86
1876	469,639	19,187	533,191	368,269	88
1877	500,524	22,349	569,618	385,865	88
1878	653,773	32,255	731,977	491,427	89
1879	829,439	50,259	935,273	610,682	89
1880	1,074,262	100,851	1,247,335	852,196	86
1881	1.374,247	131,202	1,588,314	1,187,770	87
1882	1,514,687	143,341	1,736,692	1,284,067	87
1883	1,477 345	119,356	1,673,535	1,148.709	88
1884	1,375,531	117,515	1,550,879	996,983	89
1885	1,519,430	133,376	1,711,920	959,471	89
1886	2,269,190	218,973	2,562,503	1,574,703	89
1887	2,936,033	322,069	3,339,071	2,101,904	88
1888	2,511,161	314,318	2,899,440	1.386,277	87
1889	2,930,204	374,543	3,385,732	1,510,057	87
1890	3,688,871	513,232	4,277,071	1,867,837	87
1891	3,247,417	579,753	3,904.240	1.293,053	83
1892	4,168,435	669,889	4,927,581	1,537,588	85
1893	3,215,686	737,890	4,019,995	1,129,400	80
1894	3,571,313	784,936	4,412,032	1,016,013	81
1895	4,909,128	1,137,182	6.114,834	1.299,628	80
1896	3,919,906	1,298,700	5,281,689	1,116,958	74
1897	5,475,315	1,608,671	7,156,957	1,644,520	77
1898	6,609,017	2,230,292	8,932,857	1,976,702	74
1899	7,586,354	2,947,316	10,639,857	2,270,585	71
1900	6,684,770	3,398,135	10,188,329	2,383,654	66
1901	8,713,302	4,656,309	13,473,595	2.870,816	65

process, and all of this went into rails. From 1872 to 1874 the annual production was about 140,000 tons, all of which was rail steel, and, in spite of the development of the open-hearth process, this represented about three-quarters of the total steel output. From 1875 to 1879 the output of Bessemer increased nearly fivefold over the period just previous, and averaged about 560,000 tons per year. A great part was made in the eastern portion of Pennsylvania, at Steelton, Johnstown, Bethlehem and Scranton; but the then new works of Edgar Thomson, at Pittsburg, and the plants at Chicago and Cleveland had by this time become factors of great importance. The Bessemer output during this time was 88 per cent. of the total steel output of the country and all of it was rolled into rails.

From 1880 to 1882 the output more than doubled, averaging 1,320,000 tons, which constituted 87 per cent. of all the steel made,

TABLE XXII-C.

Production per Year during Certain Periods of Bessemer and Open-Hearth Ingots and Rail Steel.

Note: It is assumed that 100 tons of ingots=83.3 tons of rails.

Period.	United States.				Great Britain.			
	Total Steel.	Bessemer Ingots.	Open Hearth Ingots.	Bessemer Rails plus 20 per cent. = Rail Ingots.	Total Steel.	Bessemer Ingots.	Open Hearth Ingots.	Bessemer Rails plus 20 per cent. = Rail Ingots.
1867–1871 incl.	44,000	20,000	800	19,000	....	180,000	....	....
1872–1874 "	186,000	143,000	4,000	131,000	....	482,000	....	....
1875–1879 "	632,000	558,000	26,000	508,000	963,000	742,000	141,000	*564,000
1880–1882 "	1,524,000	1,320,000	125,000	1,330,000	1,808,000	1,387,000	342,000	1,196,000
1883–1887 "	2,167,000	1,910,000	182,000	1,627,000	2,280,000	1,563,000	638,000	1,042,000
1888–1890 "	3,521,000	3,040,000	401,000	1,906,000	3,585,000	2,063.000	1,429,000	1,172,000
1891–1893 "	4,284,000	3,540,000	663,000	1,584,000	3,109,000	1,545,000	1,463,000	712,000
1894–1896 "	5,269,000	4,130,000	1,074,000	1,373,000	3,611,000	1,629,000	1,883,000	808,000
1897–1899 "	8,910,000	6,560,000	2,262,000	2,357,000	4,751,000	1,823,000	2,813,000	1,004,000
1900	10,188,000	6,685,000	3,398,000	2,861,000	5,050,000	1,745,000	3,156,000	912,000
1901	13,474,000	8,713,000	4,656.000	3,445,000	4,904,000	1,606,253	3,297,791	878,000

*1875 is estimated.

TABLE XXII-D.

Proportion of Various Kinds of Steel made in the United States and Great Britain.

Period.	Bessemer Steel.				Open Hearth.	
	Per cent. of Total.		Rail Steel per cent. of Bessemer.		Per cent. of Total.	
	United States.	Great Britain.	United States.	Great Britain.	United States.	Great Britain.
1867–1871 inclusive	45	....	95	....	2	....
1872–1874 "	77	....	92	....	2	....
1875–1879 "	88	77	91	76	4	15
1880–1882 "	87	77	100	86	8	19
1883–1887 "	89	70	85	67	9	28
1888–1890 "	87	58	63	57	11	40
1891–1893 "	83	50	45	46	15	47
1894–1896 "	78	45	33	50	20	52
1897–1899 "	74	38	36	55	25	59
1900	66	35	44	52	33	62
1901	65	33	40	55	35	67

and almost all was put into rails. A small amount was made at Steelton of high carbon special steels, and Cambria also made some for use in her Gautier Department for agricultural tools. During this period there was a marked increase in the make of open-hearth steel, a start having been made by the building of a furnace at the works of the New Jersey Steel and Iron Co. in 1868, but the introduction of the process was slow and it was not until 1880 that the output reached 100,000 tons per year. Up to this time the steel industry was largely dependent upon Spanish ores, and the works near the eastern seaboard were in the most advantageous position; but during the period from 1880 to 1890 the development of the Lake Superior deposits and the establishment of cheap methods of transportation made the United States practically independent of foreign ore, while the exploitation of the Mesabi range in 1893 transferred the command of the steel market to a point west of the Allegheny Mountains.

From 1883 to 1887 the production of Bessemer steel was 1,900,000 tons per year, being 89 per cent. of the total, the open-hearth furnaces making about one-tenth as much. Only 85 per cent. of the Bessemer steel was rolled into rails, for about this time at Steelton, Cambria, Bethlehem and elsewhere, considerable high carbon steel was being made, as well as some soft steel. Some Bessemer plants not connected with rail mills were operated to make steels for special purposes and supply the general trade, and this development became more pronounced in the next period from 1888 to 1890, when only 63 per cent. was put into rails, while in the period from 1891 to 1893 more than half the Bessemer output went into miscellaneous work, and from 1894 to 1896 only one-third was used for rails.

This great change was brought about by many causes, prominent among which was the general use of the reversing mill for rolling four-inch square billets directly from the ingot, and the immediate acceptance by the trade of that size as the one standard. By the economies following this innovation wrought-iron was driven from the market and was superseded by steel. One of the most important fields affected by this change was the making of railway joints or splices, which amount to from five to seven per cent. of the weight of the rails themselves. A still greater change was the rapid and almost complete substitution of steel for plates and sheets of all kinds.

During all these years, however, the open-hearth process has been making very heavy strides and narrowing the field of the Bessemer converter. One of the first acts of trespass was in the making of high carbon steels; it was found that the steel made in the regenerative furnace gave better results, and to-day very little high steel is made by the pneumatic method. The next great encroachment was in structural shapes, where the Bessemer product found a great outlet in the years from 1885 to 1893 or thereabout. The proportion of converter product going into bridges is very small at present, while it is becoming less for ships and buildings. This growth of the open-hearth furnace is shown by the fact that in 1901 the steel made in the converter formed only 65 per cent. of the total output, while in the period from 1875 to 1890 it was about 88 per cent. It is also shown by the fact that in the two years of 1900 and 1901 the proportion of Bessemer steel used for rails increased to an average of 42 per cent., it being only 33 per cent. in 1894 to 1896.

To-day two-thirds of the steel made in the United States is Bessemer and one-third open-hearth. Practically all the rails are Bessemer, but open-hearth steel is used for almost all other work where the material is subject to physical and chemical specifications. One-quarter of this open-hearth steel is made on an acid hearth, the remainder on dolomite or magnesite linings. The use of the basic furnace is rapidly spreading both in small and large plants, but very few new Bessemer plants are being erected. No fuel is imported for the making of iron and steel, but a considerable quantity of ore is brought from Cuba and elsewhere to points on the Atlantic seaboard, as shown by Table XXII-E.

TABLE XXII-E.

Iron Ore Imported into the United States.

U. S. Geol. Survey, John Birkinbine.

Imported from	1896	1897	1898	1899	1900
Cuba	380,551	383.820	165,623	360.813	431,265
Spain	121,132	66.193	13.335	145,206	253,694
French Africa	79.661	3,504		22,233	20.000
Italy	29,882			43.363	18.951
Greece	33,750		7,200	16.765	23.350
Newfoundfand and Labrador	20.800	29.250		77.970	140.535
United Kingdom	8,528	358	683	172	397
Colombia	3.150				3 000
Quebec, Ontario, etc.					5.588
Other countries	5.352	6 845	367	7.560	1,051
Total	682,806	489.970	187.208	674,082	897.831

A map is given in Fig. XXII-A, which is taken from the U. S. Geol. Survey. This shows in the shaded portions the principal coal fields of the United States, the anthracite deposits of eastern Pennsylvania being represented by solid black. The crosses denote localities which are important producers of ore, the only ones deemed worthy of note as determining factors being the Lake Superior deposits, and those of Alabama, Colorado and Cornwall, Pa.

FIG. XXII-A.—UNITED STATES; EASTERN HALF.

The circles indicate the position of the important steel producing centers and in the following pages will be given a detailed description of each of these districts.

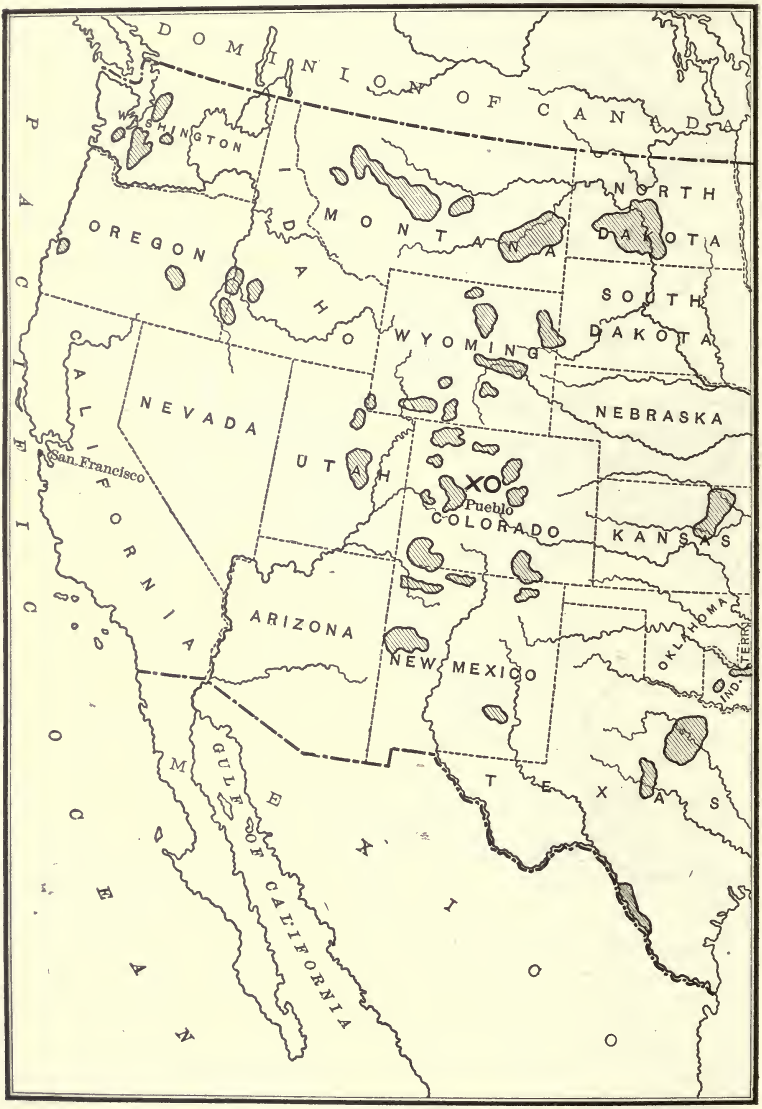

Fig. XXII-A.—United States; Western Half.

SEC. XXII-b.—*Coal:*

The United States may be said to import no coal. This is perfectly true as far as the general iron industry is concerned, but as an explanation of certain facts given in the official statistics, it is necessary to note that a considerable quantity is shipped from British Columbia to points on the Pacific Coast, while a lesser quantity is brought from Cape Breton, Nova Scotia, to Boston, Mass., for the manufacture of illuminating gas in by-product coke ovens. Within the last few years a very considerable trade has grown up in the export of coal, mostly to Canada and Mexico, but a great deal to places oversea. In 1900 about 635,000 tons were shipped to Europe, a considerable amount going to Mediterranean ports, attracted by the phenomenally high prices ruling in France. Accompanying is a statement showing the foreign trade, including Canada and Mexico:

IMPORTS AND EXPORTS OF COAL IN 1900 IN LONG TONS.

Production	239,567,000
Imports	1,909,000
Exports	7,917,000

Anthracite.

In the consideration of the fuel supply of the United States a word should be said concerning anthracite, because there is much misunderstanding among foreign metallurgists as to the amount of this coal used in iron smelting. Many years ago lump anthracite was very commonly used in Eastern Pennsylvania, New Jersey and other neighboring districts as the only fuel put into the blast furnace, but this practice has become the exception, and coke from Connellsville has for a long period been carried to the furnaces that are situated in the very heart of the hard coal region. Some furnaces do use anthracite alone, and at many plants it is not unusual, in cases where coke cannot be obtained or when it is very high in price, to use a certain proportion of hard coal, but this hardly warrants the misleading classification of many of the Eastern plants under the head of "anthracite furnaces."

There is a great amount of hard coal used in firing boilers in industrial establishments of all kinds, but only the small sizes are available for this purpose, the larger kinds commanding a higher price for household use. Except in the immediate neighborhood of the mines it is more economical to use bituminous coal brought from a long distance than to use the sizes that can be sold for domestic purposes, while the smaller grades will not burn readily and require a blast when used under boilers. Every few years the price of the smaller sizes advances and the manufacturer must either change to soft coal or alter the grates to handle still smaller pieces. This arises from the fact that the small pieces are a by-product produced in crushing, and the mines produce as little as possible of the less valuable product, while on the other hand there has been much progress in devising grates and stokers to handle the fine sizes. In many Eastern cities the community demands a smokeless stack, so that factories are practically compelled to use hard coal. The demand is founded on æsthetic considerations, the claim that smoke is unhealthful being rather amusing. Aside from this consumption of anthracite for steam making, hard coal may be considered simply as the fuel which is universally used for household purposes in the northeastern part of the country, all of this district being supplied from the mines in Eastern Pennsylvania. A certain amount is also raised in Colorado and New Mexico, but the quantity is trifling compared with the output of the Appalachian field. The value of a short ton of anthracite at the mines in Pennsylvania in 1900 is given as $1.79, while in Colorado it was $3.00, and in New Mexico $2.75.

The hard coal district of Pennsylvania is divided usually into three parts, which are shown in Fig. XXII-B as Nos. 14, 15 and 16. Following is a description of each division:

No. in Fig. XXII B.	Name.	Local Districts.	Situation in Counties of Pennsylvania.
14	Wyoming.	Carbondale, Scranton. Pittston. Wilkesbarre, Plymouth, Kingston.	Luzerne and Lackawanna.
15	Lehigh.	Green Mountain, Black Creek, Hazleton, Beaver Meadow	Luzerne and small parts of Carbon. Schuylkill and Columbia.
16	Schuylkill.	Panther Creek. Lorberry. East Schuylkill. West Schuylkill. Lykens Valley. Shamokin. East Mahanoy West Mahanoy.	Carbon. Dauphin, Schuylkill, Columbia and Northumberland.

All of this region is in the eastern center of the State. The total production of anthracite in 1900 was as follows in short tons:

Pennsylvania	57,363,396
Colorado	59,244
New Mexico	41,595
Total	57,464,235

FIG. XXII-B.—PENNSYLVANIA, WEST VIRGINIA, OHIO, ETC.; EASTERN HALF.

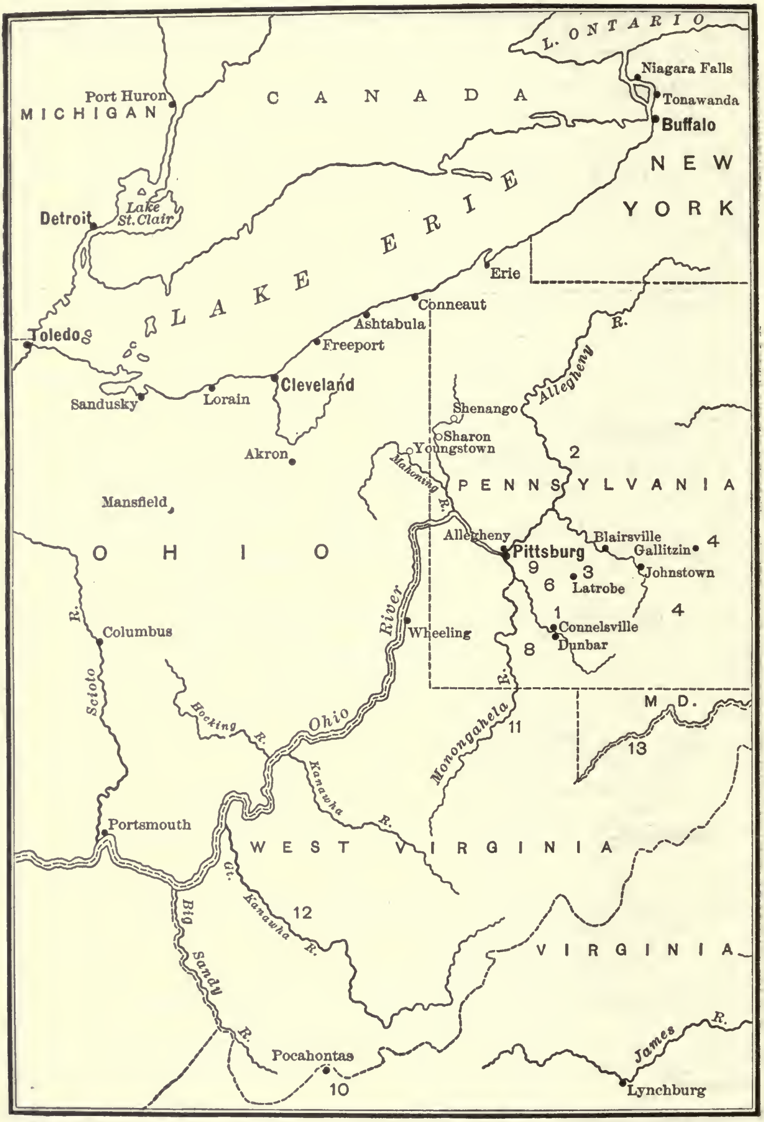

FIG. XXII-B.—PENNSYLVANIA, WEST VIRGINIA, OHIO, ETC.; WESTERN HALF.

Bituminous.

In the production of anthracite coal Eastern Pennsylvania not only is first, but stands almost alone, while in bituminous coal Western Pennsylvania stands not quite alone, but pre-eminently first. In 1900 she made over three times as much as any other State and more than one-third of the total of the country. The leading counties are Westmoreland, Fayette and Allegheny, with Cambria, Clearfield, Jefferson and Washington following with heavy outputs. The Clearfield coal is one of the best coals in the world for steam purposes, and, together with the Pocohontas and New River coals of West Virginia, is carried in great quantities to Eastern points. Some of the Westmoreland coal is exceptionally rich, and as it is sold at about the same price as leaner coals, and as the freight rates are not always proportional to the distance, it follows that it is economical to use it in the manufacture of fuel gas in producers not only in neighboring districts, but in places quite remote from where it is raised.

The foregoing remarks concerning the use of the best gas coal apply to many other things in America. On account of the comparatively low freight rates the tendency is to obtain the best, while in Europe the high rates compel the use of local inferior raw materials; by the American system the railroads do a much greater business and thereby reduce costs. In some parts of Europe the steel works have a score of different mines from which coal is drawn, and a score of places from which ore comes, and the sources of supply are constantly changing with local conditions, with perhaps periodical reversions to the utilization of poor supplies near at hand. The limited capacity of certain ore and coal fields will account for a portion of this difference.

The coal deposits of the United States are divided into seven fields, which are shown in Fig. XXII-A, but only four are of any importance:

(1) The Appalachian, extending from New York to Alabama, a length of 900 miles, and a width varying from 30 to 180 miles.

(2) The Central, embracing parts of Indiana, Illinois and Western Kentucky.

(3) The Western, including the coal west of the Mississippi River, east of the Rocky Mountains and south of the forty-third parallel.

(4) The Rocky Mountain, including the basins in that range.

The smaller fields include a deposit in Northern Michigan, one in Virginia and North Carolina, and one in Washington, Oregon and Northern California, the latter claiming attention owing to the absence of a good supply on the Pacific Coast.

The coal from the Central and Western divisions, including a very considerable part of the Mississippi Valley, is of importance from a general economic standpoint for industrial and domestic purposes, but need not be considered here, as it has little bearing on the iron industry; but it is necessary to discuss the beds of the Appalachian and Rocky Mountain districts, which supply practically all the coal and coke used in the iron industry.

TABLE XXII-F.

Production of Coal and Coke in the United States in 1900 (1 ton =2000 pounds; taken from U. S. Geol. Survey for 1900.)

The number of ovens given is the total number standing, less those that are marked abandoned in the report.

	Coal.		Coke.	
	Anthracite.	Bituminous.	No. of Ovens.	Production.
Pennsylvania	57,363,000	79,318,000	32,464	13,798,893
Illinois	....	25,154,000	154	2,631
Indiana	....	6,358,000	14	
West Virginia	....	21,153,000	10,142	2,358.499
Ohio	....	20,671,000	369	72.116
Alabama	....	8,504,000	6,529	2,110,837
Colorado	59,000	5,436,000	1,488	618,755
Utah	....	....	204	
Iowa	....	5,090,000	....	....
Kentucky	....	4,991,000	458	95,532
Kansas	....	4,507,000	91	5,948
Wyoming	....	4,129,000	74	14,501
Maryland	....	3,924.000	....	....
Tennessee	....	3,904,000	2,106	475,432
Virginia	....	2,505,000	2,331	685,156
Massachusetts	....	....	400	*
Georgia	....	333.000	480	73,928
Montana	....	1.662,000	342	54,731
Indian Territory	....	1,922 000	230	38,141
Others	42,000	11,261,000	376	128,248
Total	57,464,000	210,822,000	58,252	20,533,348

* Massachusetts and New York are included in Pennsylvania.

Table XXII-F shows the production of coal and coke in the United States in 1900 by States, and Table XXII-G the output of the different coal fields. There are also given in Table XXII-H the records for each county in Pennsylvania for coal and coke, and

TABLES XXII-G.

Output of Coal from the Principal Coal Fields of the United States in 1900 (Mineral Resources U. S. Geol. Survey for 1900.)

Field.	Product, tons.	Per cent. of Total.
Appalachian (including Alabama)	142,497,208	67.1
Central	35,358,164	16.6
Western	17,549,528	8.3
Rocky Mountain	13,398,556	6.3
Pacific Coast	2,704,665	1.3
Northern	849,475	0.4

TABLE XXII-H.

Production of Bituminous Coal in Pennsylvania and Amount used for making Coke. (Mineral Resources, U. S. Geol. Survey for 1900). One ton=2000 pounds.

County.	Total Coal Mined.	Amount Coked.
Fayette	15,055,000	9,421,500
Westmoreland	14,980,000	7,001,000
Allegheny	10,052,000	....
Cambria	8,190,000	413,000
Clearfield	6,621,000	301.000
Jefferson	6,199,000	1,034.000
Washington	4,856.000	....
Somerset	4,779,000	32,500
Armstrong	1,313,000	....
Center	932,000	....
Tioga	931,000	....
Elk	926,000	2,500
Indiana	925.000	91.000
Bedford	570,000	164,000
Mercer	528,000	....
Blair	497.000	108,000
Clarion	405,000	....
Huntingdon	369,000	....
Bradford Clinton	321,000	....
Beaver	262.000	....
Butler	222.000	....
Lawrence	187,000.	....
Lycoming McKean	119,000	....
Others	600,000	....
Total	79,842,000	18,571,500

in Table XXII-I the coke production in the different fields of Pennsylvania and West Virginia, the leading States. The division into fields is in accordance with the recognized usage of the Geological Survey, and I append a condensation of their descriptions, taken from the reports on both coal and coke. The numbers refer to Fig. XXII-B, on which the location of these fields is shown.

TABLE XXII-I.

Coke Statistics for Pennsylvania and West Virginia for 1900. (Mineral Resources, U. S. Geol. Survey); one ton=2000 pounds.

State and District.	Coke Ovens.		Production.
	Built.	Building.	
Pennsylvania—			
Connellsville	21,061	686	10 039.000
Pittsburgh	2,096	....	827,000
Reynoldsville and Walton*	2,010	....	1,067,000
Upper Connellsville	2,203	....	754,000
Allegheny Mountain	1,341	....	557,000
Clearfield Center	568	....	135,000
Greensburg	476	....	133,000
Broad Top	532	....	113,000
Lower Connellsville	1,498	1,112	111,000
Irwin	697	....	62,000
West Virginia—			
Flat Top (Pocahontas)	5,290	666	1,209,000
Upper Monongahela	1,563	....	356,000
New River and Kanawha	2,569	640	507,000
Upper Potomac	827	....	287,000

* The figures for the Reynoldsville and Walton district are worthless. They include the production of the coke ovens in New York and Massachusetts "for want of a better classification." It is elsewhere stated that this is done in order that "individual information (for Massachusetts) may not be divulged," which is hardly sufficient ground for vitiating the statistics of Pennsylvania.

Pennsylvania Coke Districts.

No. 1.—Connellsville: The County of Fayette and the southern half of Westmoreland.

Pittsburgh: Vicinity of Pittsburgh, the coke being made from coal brought down the Monongahela River.

No. 2.—Reynolds and Walton: All the ovens on the Rochester and Pittsburgh Railroad, those on the Low Grade Division of the Allegheny Valley Railway, and the mines on the New York, Lake Erie and Western Railway.

No. 3.—Upper Connellsville: The region around and north of Latrobe, the coal here being somewhat different from the deposit farther south.

No. 4.—Allegheny Mountain: Ovens along the line of the Pennsylvania Railroad from Gallitzin to beyond Altoona, and those in Somerset County. This includes also the coke ovens near Johnstown.

No. 5.—Clearfield Center: The two counties of Clearfield and Center.

No. 6.—Greensburg: Near the town of Greensburg, in the central part of Westmoreland County.

No. 7.—Broad Top: The Broad Top coal field in Bedford and Huntingdon counties.

No. 8.—Lower Connellsville: A new district, first appearing in the U. S. reports in 1900. Known also as the Klondike district, a southwest extension of the Connellsville Basin.

No. 9.—Irwin: The neighborhood of the town of Irwin on the Youghiogheny River, in the western part of Westmoreland County.

The Beaver, Allegheny Valley and Blossburg districts, formerly recognized, are no longer of importance.

West Virginia Coke Districts.

No. 10.—Pocahontas: The ovens in West Virginia in the Pocahontas coal field; this embraces the counties of McDowell and Mercer in West Virginia and Tazewell County in Virginia. Most of the output comes from the West Virginia side. This district is traversed by the Norfolk and Western Railroad.

No. 11.—Upper Monongahela: This is also called the Fairmount district; it is the northern part of the State, drained by the Monongahela, and sending its coal to market by the Baltimore and Ohio Railroad. It embraces Preston, Taylor, Harrison and Marion counties. The statistics include the ovens located at Wheeling, at the Riverside Iron Works.

No. 12.—New River and Kanawha: These two are named from the rivers draining them, and embrace Fayette and Kanawha counties. The coal is shipped partly by the Chesapeake and Ohio Railroad and partly by the Kanawha River.

No. 13.—Upper Potomac: Also called the Elk Garden district, includes Mineral, Tucker and Randolph counties and is the southern extension of the Cumberland district of Maryland. The West Virginia Central and Pittsburgh Railway runs through this field.

Sec. XXIIc.—*Lake Superior*:

Note: I am indebted to Mr. G. F. Knapp, of Ogleby, Norton & Co., for a careful reading of this manuscript.

Up to 1880 the State of Pennsylvania was the greatest producer of iron ore in the Union, but the amount raised was entirely insufficient to supply its blast furnaces, and large quantities were imported from Spain, some from the west coast of England, and some from other countries like Algeria, Greece and even Ireland. For many years Michigan had been mining ore, the Marquette deposits having been opened in 1845, but it was not until 1856 that as much as 5000 tons was shipped to the furnaces of Pennsylvania. The cost of transportation was high and Spanish ores were taken to Pittsburgh as cheaply as the Western ores could be laid down at that point. The Menominee beds were opened in 1877, the first shipments from Escanaba being made in 1880, and in about the year 1881 the output of Michigan exceeded that of any other State. In 1884 the Gogebic range was opened, all three districts being in Northwest Michigan, and this still further added to its prominence; but in the same year the Vermilion mines in Northeastern Minnesota began to produce, and when finally, in 1892 and 1893, the Mesabi range was exploited, Minnesota became a dangerous rival. In 1901 the Mesabi mines produced 9,303,541 tons and the Vermilion 1,805,996 tons, a total of 11,109,537 tons, while Michigan raised only 9,654,067 tons, this giving first rank to Minnesota.

The cause of this enormous increase is not simply the opening of new mines, for this is but one factor in the work, the other factor being the great decrease in cost of transportation. These two conditions are interdependent, since the lessening in the cost of freight could not have come about without the transport of enormous tonnages. In no other part of the world has there been such a complete system of handling material worked out on such a gigantic scale; the steam shovels in the mines, the railroads to the ports, the mammoth docks and arrangements for loading vessels in a few hours, the special fleet of ore carriers, the improvement of the locks, the unloading machinery at the lower lake ports, and the storage yards and handling apparatus at the Eastern furnaces, each one of these is a link in a chain of specialized machinery, by which it has become possible to transport ore a thousand miles and make pig-iron for less than half a cent a pound.

Table XXII-J shows the production of the different ranges in 1901, and gives figures for comparison with the other large producers. The three States of Michigan, Wisconsin and Minnesota, constituting what is known as the Lake Superior region, raised 21,445,903 tons of ore. The only competitor is the Minette district of Germany, France, Belgium and Luxemburg, which mined

17,000,000 tons, while Northern Spain raised less than half as much, its output being only 7,740,000 tons.

Table XXII-J.

Sources of American Ore Supply in 1901.

U. S. GEOL. SURVEY.

Lake Superior Ranges.	Location.	Date when opened.	Output; tons.	Fe.	P.	S.	SiO_2.	$CaCO_3$.	H_2O.
Mesabi.........	N. E. Minn.	1892	9,303,541	61–64	.03–.08	.01	3-5	0.5	8-12
Menominee....	N.W. Mich.	1877	3,697,408	56–62	.01–.75	.01	3-6	1.0	5-10
Marquette......	N.W. Mich.	1855	3,597,089	60–67	.02–.15	.02	2-6	0.5	1-12
Gogebic........	N.W. Mich.	1884	3,041,869	58–62	.04–.08	.01	3–7	0.3	10-12
Vermilion......	N. E. Minn.	1884	1,805,996	61-67	.04–.15	tr.	3-5	0.4	1-6
Total L. Superior......	....	....	21,445,905	......	....	.....	....	......	....

Other States.		Other States.	
Alabama	2,801,732	New Jersey..........................	401,989
Pennsylvania	1,040,684	Rocky Mountains..................	234,514
Virginia and West Virginia........	925,394	Georgia, North and South Carolina.	215,599
Tennessee....................	789,494	Other States........................	207,915
New York..................	420,218		
Colorado......	404,037	Total..............................	28,887,479

The Marquette ores are magnetites and hard and soft hematites, and are rich in iron. The ores from the Menominee and Gogebic ranges in Michigan and Wisconsin are hematites and are very desirable as being in porous lumps and easily smelted. The Vermilion ores are very rich hematites and in very hard lumps; the softer kinds are lower in phosphorus, while the hardest run beyond the Bessemer limit. The Mesabi deposit is the most easily mined, large areas being close to the surface and of such a nature that a steam shovel can be used without the use of explosives. The great objection is the fine, and in some cases almost pulverulent condition of the ore.

Different mines vary in the character of the product, some ore being of such an average size that it can be used in a blast furnace to the extent of 70 per cent. of the burden, while other beds are so fine and dusty that the average furnace manager will not use over 20 per cent. The composition of the ore not only in the Mesabi districts, but in other mines, varies considerably, and constant vigilance is necessary to insure the separation of the "Bessemer" from the "non-Bessemer," by which terms are meant those portions which will give a pig-iron running below 0.10 per cent. in phosphorus, and those which will give an iron above that limit. The non-Bessemer was formerly more or less of a drug in the market, but the development of the basic open-hearth furnace has furnished an outlet for this off-grade iron. In fact, it may almost be said that the existence of so much non-Bessemer ore, mixed with the Bessemer and therefore necessarily taken out with it, was the primal cause of the rapid extension of the basic open-hearth process during the last few years.

It has been stated that the fine condition of Mesabi ores prevents their being employed alone in the blast furnace, and it is necessary to mix with them a certain proportion of the ore from the other deposits, commonly known as the "old range" ores. The necessity of doing this renders it possible for the old mines to sell their product at a higher price and thereby cover their greater cost, while it also renders useless the calculations in which many foreign engineers and many American newspaper writers indulge, whereby they estimate the cost of pig-iron on the assumption that Mesabi ores are used exclusively.

The price of these ores has varied very much. In 1898 the "old range" Bessemer ores from the Gogebic, Marquette and Menominee were sold at $2.80 per gross ton; delivered at lower ports on Lake Erie. In the same year the Mesabi Bessemer ores were $2.20 and the non-Bessemer $1.80. In 1900 the price was $5.60 for old range Bessemer, $4.60 for Bessemer Mesabi and $4.10 for non-Bessemer Mesabi. This price does not include the freight from Lake Erie to Pittsburgh, but gives the cost at Cleveland or similar points.

In regard to the relative amounts of the two kinds of ores I will quote from an article by D. E. Woodbridge, in *The Iron Age*, January 3, 1901.

"The fancy Bessemer ores of the older ranges, excepting the Gogebic and new Vermilion fields, are practically gone. On the Mesaba, whatever may have been said, the far greatest share of desirable Bessemers is included in the limits of one township, or close to its edge. The Menominee range has little Bessemer ore, nearly all coming from the Aragon, Loretto and Pewabic mines. On the Marquette the once famous Lake Angeline mines are fast nearing the end of its fine Bessemer ores, and there remains but a few years more of their production. All the mines of the Oliver Company on that range are now classed as non-Bessemer, and the Cleveland Cliffs are disappointingly light in their Bessemer production. The ore bodies under Lake Angeline are not furnishing the percentage of high grade ores that was expected. Explorations on the range are showing few Bessemer deposits. On the Gogebic one company controls four-fifths of the deposits, if one may judge by the production, and a large share of the rest is off the market. Explorations around the old Comet and Puritan, Federal and Jackpot group are said to be producing good results, and there are hopes of some considerable tonnage in that section. On the Vermilion the original mine, the hard ore property at Tower, is now practically a producer of non-Bessemer ores exclusively. The Chandler is reducing its output, and in a very few years will be exhausted. The new mines of the Oliver Company are large properties and are growing larger, but they have no effect on the general situation, as their ores are of a class that the owners will retain for their own use. On the Mesaba there have been some satisfactory explorations during the year, but the chief fact resulting from the immense activity on the range is that its stores of low grade non-Bessemers are very much in excess of its fancy ores. There have been found very large deposits of lean ores and of ores high in phosphorus or of ores so fine and dusty that they are discriminated against; but of high grade desirable Bessemers the discoveries can be counted quickly. It would appear that the larger deposits of the range have been found and that subsequent work will discover smaller, perhaps more inaccessible and less valuable deposits."

The freight rates on the lakes vary so much that it is impossible to make a clear statement for a year or for a month. A vessel may be chartered for a season or for a definite amount at a "contract rate," or the ore may be shipped on the best bargain that can be made at the moment—what is known as a "wild rate." In the long run the two come out about the same; thus in the ten years from 1890 to 1900 the average contract rate from the head of the lakes was 90½ cents per ton and the wild rate 90 cents. In 1887 the wild rates were $2.23 and the contract rates $2.00, but in 1900 the average charter was $1.25.

These figures are for the full journey from the head of the lakes, Duluth or Two Harbors, the rate being lower for lesser distances; for instance, the average contract rate from Marquette for the last ten years has been 85 cents and for Escanaba 67½ cents.* A cer-

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* These figures are from an article by W. Fawcett in *The Iron Age,* March 21, 1901.

tain amount is shipped all the way by rail, but this constitutes only 2 per cent. of the whole.

The ores of the Vermilion range are shipped from Two Harbors, the rail transportation being from 70 to 95 miles. The Mesabi deposits send their product by railroad to Duluth and Two Harbors, the distance being from 75 to 100 miles. The Menominee ores are all shipped from Escanaba and Gladstone, the distance hauled being from 40 to 92 miles. The Gogebic ores are mostly shipped from Ashland, the distance being from 40 to 52 miles. The Marquette mines divide their shipments between Marquette and Escanaba, as it often pays to make a slightly longer land journey to save a great distance by water, and this is especially true of material going to Chicago.

TABLE XXII-K.

Movement of Lake Superior Ore.

COMPILED BY THE IRON TRADE REVIEW.

	1897	1898	1899	1900	1901
Mesabi	4.280,873	4,613,766	6,626,384	7,809,535	9.004.890
Marquette	2,715,035	3.125.039	3,757,010	3 457,522	3,254,680
Menominee	1 937.013	2,522,265	3.301,052	3,261,221	3.605,449
Gogebic	2.258.236	2,498.461	2,795.856	2,875,295	2.938.155
Vermilion	1,278,481	1,265,142	1,771,502	1,655 820	1,786,063
Total	12,469,638	14,024,673	18,251,804	19,059,393	20,589,237
Shipping Port—					
Two Harbors	2.651,465	2,693,245	3 973 733	4,007.294	5.018,197
Duluth	2,376.064	2,635,262	3.509,965	3,888,986	3.437,955
Escanaba	2,302,121	2,803.513	3,720.218	3,436.734	4,022.668
Marquette	1 945,519	2.245,965	2,733.596	2,661,861	2.354,284
Ashland	2,067,637	2,391.088	2,703,447	2.633 687	2,886,252
Superior	531.825	550.403	878,942	1,522,899	2,321.077
Gladstone	341.014	335,956	381.457	418.854	117 089
All rail	253,993	369,241	350,446	489,078	431,715
Total	12.469 638	14,024,673	18,251,804	19,059,393	20,589,237
Lake Erie Receiving Port—					
Ashtabula	3 001.914	2,684,563	3,341,526	3,700,486	3 981.170
Cleveland	2,456,704	2,645.318	3,223,582	3,376,644	3,831.060
Conneaut	495.327	1,404,169	2,320.696	2,556,631	3,181,019
Buffalo	797.446	1.075,975	1.530.016	1,616,919	1.475,386
Erie	1 311.526	1.092,364	1,309.961	1,240.715	1,379,377
Lorain	355.188	536,086	1,112,946	1.090,235	721,662
Fairport	1,008,340	912,879	1.241 013	1,085,554	1,181.776
Toledo	416,438	414,012	792 348	645,147	798,298
Huron	198.231	126,755	263.600	321,914	431,311
Sandusky	79,792	136,200	87 499	154,542	33,017
Total	10,120,906	11,028,321	15,222,187	15,797,787	17,014,076
On docks Dec. 1	5,923,755	5,136,407	5,530,283	5,904,670	5,859,663

FIG. XXII-C.—MAP OF LAKE REGION.

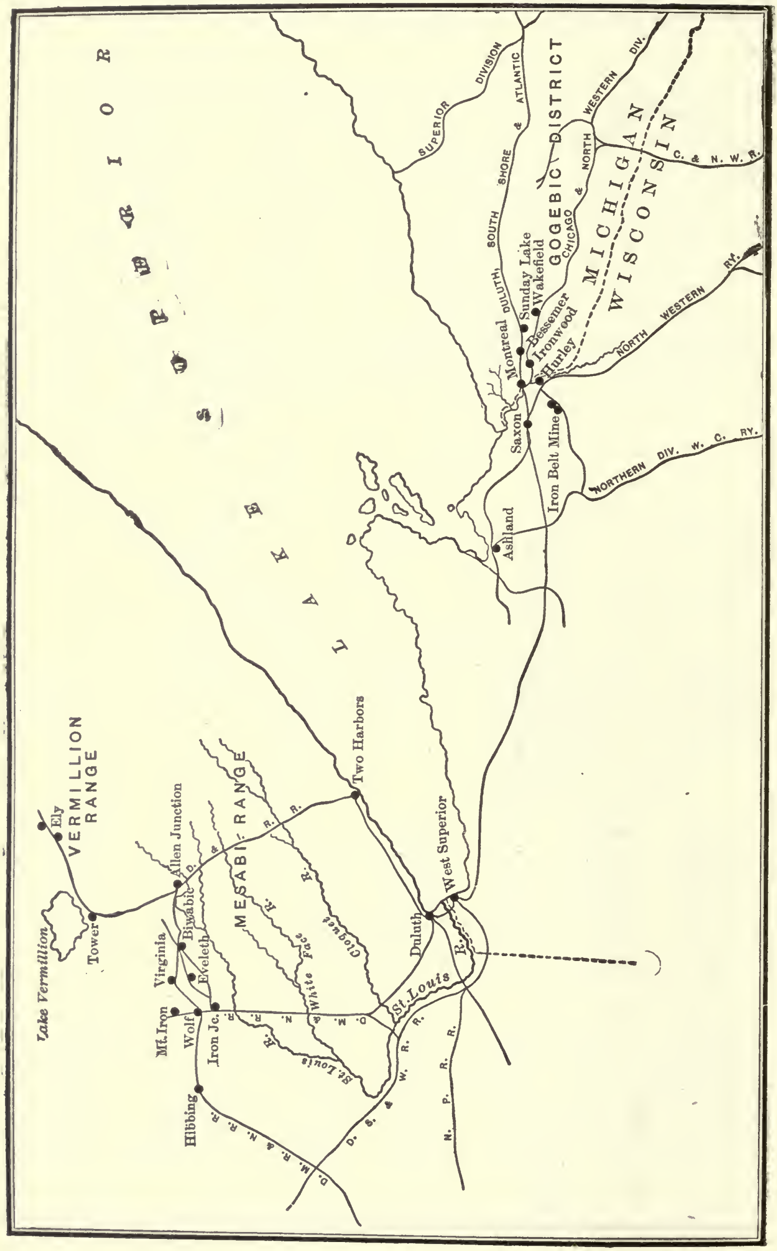

FIG. XXII-D.—MESABI, VERMILLION AND GOGEBIC RANGES.

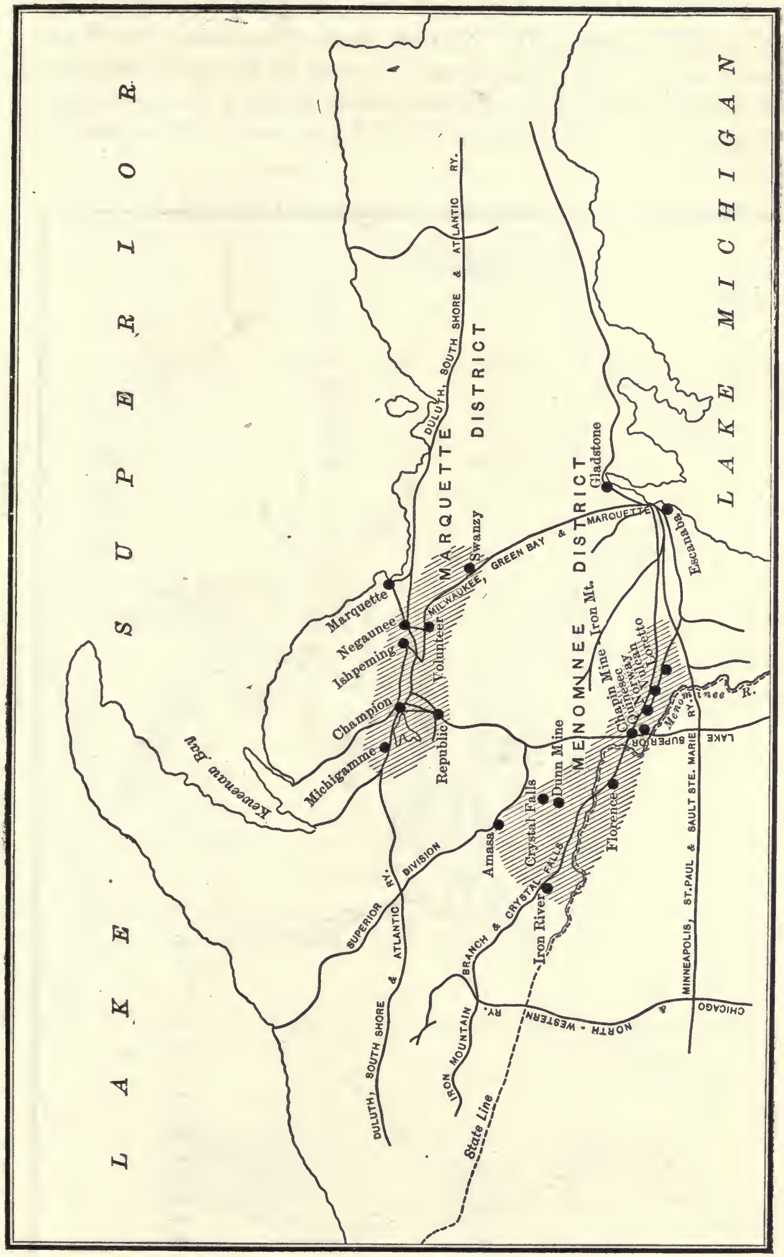

FIG. XXII-E.—MARQUETTE AND MENOMINEE RANGES.

The movement of ore during the last few years may be seen in Table XXII-K, while Fig. XXII-C shows the route followed to Chicago and the Lake Erie ports. The map in Fig. XXII-B gives more detail concerning the Eastern points to which the ore is carried, while Figs. XXII-D and XXII-E give views of the mining districts.

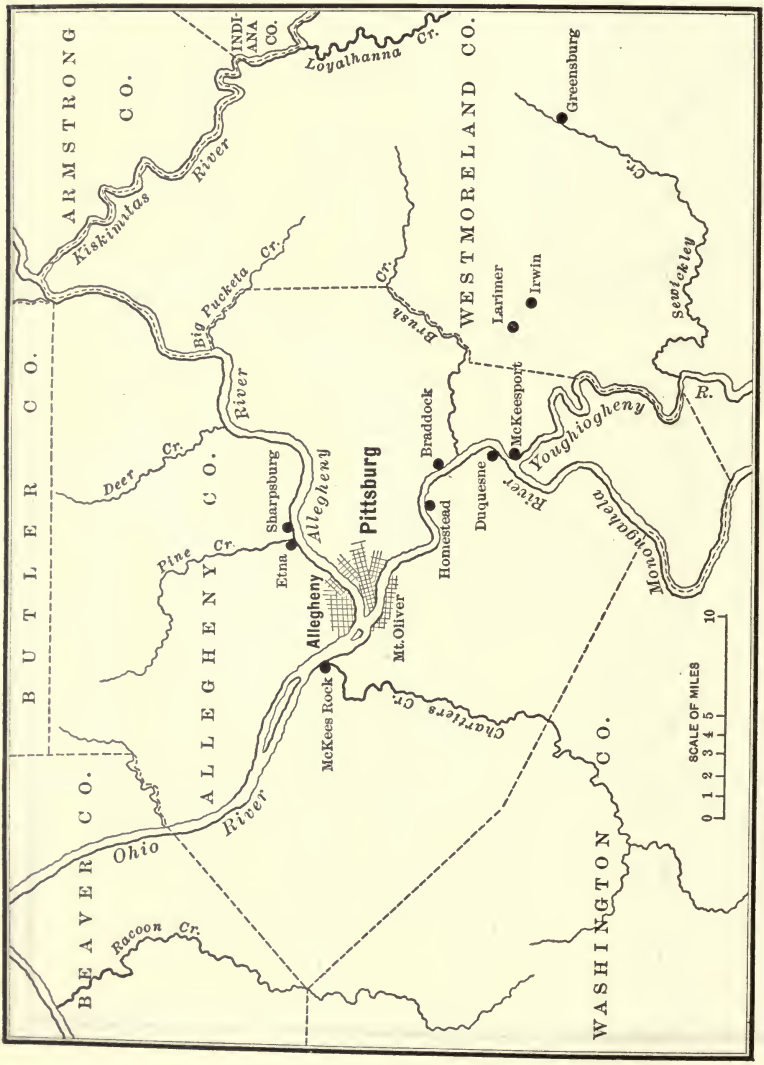

FIG. XXII-F.—ALLEGHENY COUNTY AND VICINITY.

SEC. XXIId.—*Pittsburgh*:

The great center of the iron industry of the United States is around Pittsburgh in Allegheny County, Pennsylvania, a map of which is shown in Fig. XXII-F. This one county produces about one-quarter of all the iron made in the country and hence might be and often is discussed separately. But from an economical standpoint we must ignore political boundaries and embrace parts of three States as follows:

Pennsylvania: Allegheny, Westmoreland and Fayette counties and the Shenango and Beaver Valleys, including Mercer and Lawrence counties.

Ohio: A section of Eastern Ohio, including the Mahoning Valley and the Ohio River counties.

West Virginia: The northern point between Pennsylvania and Ohio, comprising Marshall and Ohio counties and Preston County in the northeast.

A glance at Fig. XXII-B will show that this is a logical and natural grouping. It gives a rectangle about 70 miles north and south and about 80 miles east and west, and hence may be compared with some districts in other countries. The statistics for each county of Pennsylvania are of record, and are given in Table XXII-L, but this cannot be done in the case of Ohio or of West Virginia, as these States do not collect such information; but we do have at hand the total production of pig-iron and steel in Ohio and the output of pig-iron in West Virginia. We also have the location and number of converters and open-hearth furnaces and their productive capacity for each works, while I am in possession of considerable private information as to the output of certain centers. This information may not be published in detail, but may be used in forming a total. The result of this investigation is given herewith:

Output of Pig-Iron and Steel in the Pittsburgh District in 1901.

	Pig Iron.	Steel.
Allegheny County	3,685,665	5,138.839
Shenango Valley	979.415	484,692
Westmoreland, Fayette, etc.	115,261	153,525
Mahoning Valley	1,404,857	Est. (1,540,000)
Southeastern Ohio	527,958	
West Virginia	166,597	
Totals	6,879,753	7.317,056

TABLE XXII-L.

Production of Pig-Iron and Steel in Pennsylvania in 1901; Gross Tons.

Advance information, Pennsylvania Industrial Statistics.
The figures are preliminary and differ slightly in one or two cases from the final report.

County.	Rolled Iron and Steel.		Steel Ingots.		Pig Iron.	
	Tons.	Per cent. of total.	Tons.	Per cent. of total.	Tons.	Per cent. of total.
Allegheny	5,087,088	58.84	5,138,839	64.60	3,685,665	50.32
Dauphin	497,985	5.76	426,787	5.37	312,400	4 27
Cambria	443,655	5.13	655,775	8.24	511,533	6.98
Montgomery	339,617	3.93	198,150	2.49	170,816	2.33
Lawrence	332,123	3.84	267 174	3.36	359,260	4.91
Lackawanna	326,609	3.78	351,845	4.42	80,241	1.10
Westmoreland	273,348	3.16	152,715	1.92	37,347	0.51
Chester	271,742	3.14	308,990	3 88	....	....
Mercer	263,861	3.05	217,518	2.74	620.155	8.47
Montour	92,760	1.07	....	....	....	....
Lebanon	86,528	1.00	....	....	382,436	5.22
Berks	86,405	1.00	3,570	0.04	265.065	3.62
Lehigh	84,157	0.97	....	....	239,579	3.27
Philadelphia	79,968	0.92	61,111	0.77	....	....
Blair	57,930	0.67	....	....	....	....
Lancaster	54,867	0.64	....	....	....	....
Mifflin	41,137	0.48	....	....	....	....
Northumberland	37,937	0.44	....	....	....	....
Northampton	36,781	0.43	68,796	0.87	179,647	2.45
Columbia	31,285	0.36	....	....	....	....
Washington	24,899	0.29	....	....	....	....
Delaware	24,817	0.29	57,197	0.72	....	....
Bedford	....	....	....	....	99,534	1.36
Fayette	....	....	....	....	77,914	1.06
Jefferson	....	....	....	....	68,342	0.93
Armstrong	....	....	....	....	55,000	0.75
Others	69,667	0.81	46,112	0.58	178,916	2.45
Total	8,645,166	100.00	7,954,579	100.00	7,323,850	100.00

The Shenango Valley, in Northwestern Pennsylvania, made nearly one million tons of pig-iron in 1901, but two-thirds of its product was shipped to Pittsburgh for conversion. The Mahoning Valley makes nearly half of all the pig-iron made in Ohio and probably over half of all the steel. Some of the pig-iron goes to Pittsburgh, while the furnaces of Southeastern Ohio ship considerable quantities to the steel plants of West Virginia. In any other part of the world districts like these would stand alone, but they are overshadowed by Allegheny County in Pennsylvania, which in 1901 produced nearly 3,700,000 tons of pig-iron and over 5,000,000 tons of steel. It will be noticed that 1,300,000 tons of steel are made in excess of the pig-iron made, and it has been stated before that Pittsburgh draws large amounts of pig-iron from the Shenango Valley and from all the district round about.

This county in 1901 produced "over 23 per cent. of all the pig-iron made in the United States; over 33 per cent. of the Bessemer ingots; over 47 per cent. of the open-hearth steel; over 38 per cent. of all the steel of all kinds; over 24 per cent. of the rails; over 60 per cent. of the structural shapes, and 32 per cent. of all the rolled products."* Fifty-six per cent. of all the output was made in the converter, but it seems quite probable that not many years will pass before Pittsburgh will make more steel in the open-hearth furnace than in the Bessemer vessel.

The foundation of this industry lies in the coal fields of what is known as the Connellsville district, embracing the counties of Westmoreland and Fayette in Pennsylvania, and the whole district including this section is approximately a square of about 80 miles on a side. Throughout this area the conditions are practically uniform, the ore supply coming from Lake Superior by way of the Great Lakes to some Lake Erie port, and thence by rail. A ship canal has been under discussion for many years from Lake Erie to Pittsburgh, but there is little prospect of its construction. As a rule, the plants near the coal must haul the ore farther, while the plants nearer Lake Erie have a longer distance to bring the coke. In the case of finished products the difference in freight is trifling on shipments to distant points. It would be difficult to explain the special reasons for locating each works at the particular place where it is built, but it must be remembered that there are economic and industrial conditions to consider, aside from the cost of coal and ore. In the immediate vicinity of Pittsburgh, about every piece of level ground is taken that lies along the river front where water is abundant and that can be reached by a railroad. The country is very rugged and suitable sites for large steel works are not numerous. In the city itself land needed for extensions by existing works can only be bought at rates that would be high in the business district of New York. In many parts of Europe works are built where water is scarce, but in America it is considered essential that a river be available, and this river is looked upon as small unless it is as large as the Rhine. Pittsburgh stands at the junction of two rivers, and both of these streams are bordered by very high and steep hills, so that the iron and steel works extend in long narrow lines along both banks of both rivers. In some instances it has been necessary for a plant to extend by going across the river, and melted metal and other

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* Report Am. I. & S. Assn., 1902.

materials are transported on private bridges. On account of this congested condition it has been necessary to find new locations. It is also an advantage to get away from a city which has more than once been a hot bed of labor agitation, and it is a benefit to the workmen to live where the high rents and costs of Pittsburgh do not prevail.

In about the year 1884, natural gas was discovered in the region around Pittsburgh, and during the next ten years this district enjoyed one of the best and most convenient fuels at very low rates. Many plants are using it to-day, but the cost is much higher than formerly and the supply is uncertain in the densely populated districts owing to the great and varying amount used in the houses, almost every dwelling being furnished with pipes. As a consequence many plants in the city proper have been forced to install gas producers, but natural gas is still used at Homestead in the open-hearth furnaces and for all other purposes, and it is also used at Duquesne and elsewhere.

The advantages of this fuel are not confined to its first cost, as an open-hearth furnace using it becomes a proposition radically different from the usual type. The gas needs no regeneration and is introduced at the point where the port opens into the furnace, so that there is no gas chamber, and both chambers are used for air. There is no tendency to leak from one to the other and no combustion if such leakage occurs; there are no ports to wear out and to repair, and when the furnace is rebuilt or repaired the brick work may be laid in the most rapid manner, without any attention to making joints tight. The gas also contains no sulphur, so that it is easy to make steel very low in this element.

It is not known how long the supply of gas will last. At the present time new wells are constantly being sunk and the supply replenished from a greater distance and a greater area, but the time seems to be near when the amount obtained will be so scanty and the cost so high that it will be used for household purposes only.

It is in this district around Pittsburgh that the methods have been developed in blast furnaces and rolling mills which have become known throughout the world as "American practice," and I believe it is but the truth to state that these standards have in the main been established by the Carnegie Steel Company.*

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* It will be explained later, however, that the system of casting upon trucks, without which the great products in a Bessemer plant are difficult to obtain, as well as some other features of Bessemer construction, were inaugurated at the works of the Maryland Steel Company, at Baltimore.

The policy of the Carnegie management for twenty years has been diametrically opposed to the policy prevailing in European works, and quite different from what is possible in most cases. Most manufacturing corporations must distribute a very considerable share of their earnings in the way of dividends, and the most successful management is the one that distributes the most, without much regard to what happens to the plant; but where there are but a few stockholders and when the control rests in a man with a definite plan, that plan can be carried out, when in other works the plan might be conceived, but could not be accomplished.

The fundamental principle which has been carried out at Pittsburgh was to destroy anything from a steam engine to a steel works whenever a better piece of apparatus was to be had, no matter whether the engine or the works was new or old, and the definition of this word "better" was almost entirely confined to the ability to get out a greater product and get it out uninterruptedly. Such a course involved the expenditure of enormous sums of money, it involved the constant return of profits into the business, it involved many mistakes, but it produced results, and the economies arising from the increased output soon paid for the expenditure. This example has exerted a great effect upon other American steel works, and is also felt to a considerable extent abroad.

The European visitor to Pittsburgh, however, will find a lack of attention to many of the minor economies. He will find that the saving of fuel does not receive its rightful share of attention and that most of the engines in use are wasteful and that thousands of dollars are spent to dispense with the labor of one or two men, while thousands of dollars in fuel are being constantly wasted. In Europe it is the labor that is wasted and the fuel saved. There is a partial excuse in both cases. In Europe fuel is costly and labor cheap; in Pittsburgh fuel is cheap and labor costly. When a mill is working to its ultimate capacity, it takes more than one man to fill one job, because continuous attention and work is physically impossible throughout twelve hours, or even eight hours. Consequently in American practice, extra hands or "spell" hands must be provided, something that would be superfluous in most foreign works. Thus a machine that saves the work of "one man" really saves more than one man, and in the case of skilled labor in Pittsburgh, this will often represent from five to ten or even twenty times as much as in Silesia or Lothringen. On the contrary, fuel is cheap in Western Pennsylvania, and it is better to waste money every day than to have complicated engines or superheaters or furnaces that might get out of order and stop the works for a day or a week. It may be accepted as final that no American engineer will install a piece of machinery, no matter how much economy is promised, if there is the least probability of irregular working with a break in the continuous and uninterrupted production.

This dominant idea has led to a certain sameness in the general methods of manufacture in America and this has been rendered quite natural by the fact that the metallurgical conditions are uniform over a very large area. Throughout the greater part of America, the use of Lake Superior ores is universal, these ores being of two kinds: (1) those that give a pig-iron with not over 0.10 per cent. of phosphorus; (2) those that give a pig-iron ranging from 0.10 to 0.25 in phosphorus. The last, the so-called "non-Bessemer," is sold at a somewhat lower price, and thus while all of the Bessemer steel is made in acid converters, a great part of the open-hearth product is made on the basic hearth, the non-Bessemer pig-iron being used for this purpose. The very low content of phosphorus in the charge takes away all difficulties as far as this element is concerned, and the metallurgical problems therefore in Pittsburgh are comparatively few; the coke is good, the ores rich and pure, the basic Bessemer process entirely out of the question, and the basic open-hearth furnace is charged with a mixture almost fit for an acid hearth. It is therefore much easier in America than in most parts of Europe to make steel according to rigid specifications, this being proven by the fact that foreign metallurgists refuse to bid on contracts which are accepted as standard in America.

The Pittsburgh district mines practically no ore, all this coming from the western end of the Great Lakes. During a considerable portion of the year navigation is closed on account of ice, so that furnaces working this ore must arrange to store enough for all winter. The time varies with the weather, but it may be roughly stated that no ore arrives between the first of December and the next May. Consequently, it is necessary to arrange for an enormous storage yard, which is one of the most characteristic features of an American plant. In the case of some furnaces not having sufficient room, the ore may be held on the docks at the lake, but it is very difficult to handle during the cold weather.

The coke arrives by rail, and at most furnaces very little is kept on hand as stock. It comes as before stated from what is known as the Connellsville district. This coke is somewhat higher in ash than that of Durham, but is nearly or quite as good in physical structure, and, of course, superior to any coke on the Continent. The coal contains from 30 to 35 per cent. of volatile matter. The beehive oven is used almost universally throughout the region, and it is the rule that the coke is made at the mine, but this rule has some important exceptions, and within the last few years a number of by-product ovens have been erected at furnace plants and the coal brought to the works. In Sec. IXe a list is given of all the by-product ovens in the country. Only a few of those named are in the Pittsburgh district, viz., those at Glassport, Dunbar and Sharon, Pa.; Hamilton, Ohio, and Wheeling, W. Va.

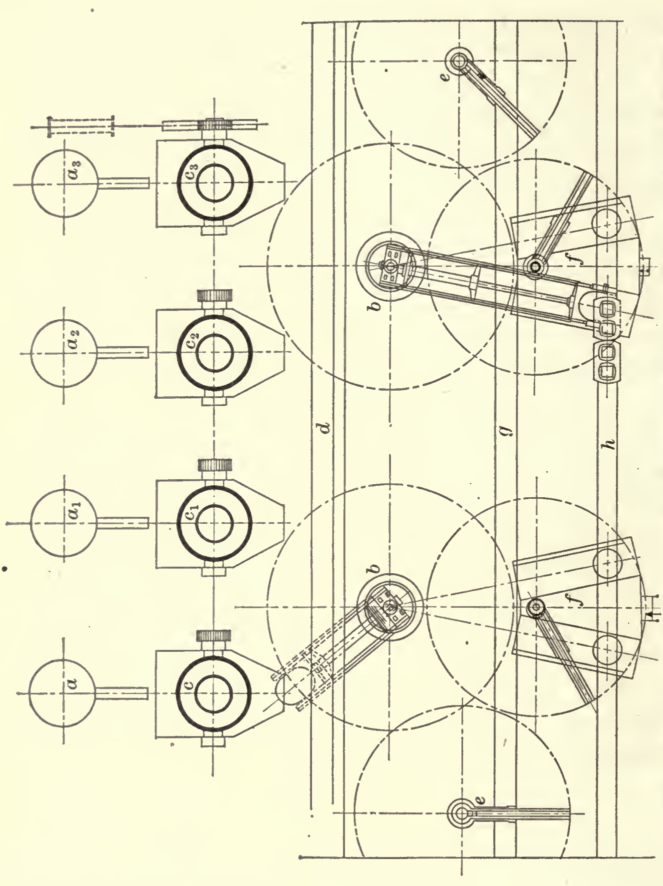
The coke from Connellsville is used not only near home, but is sent in greater or less measure all over the land. It has been used in years gone by in smelting copper in the Rocky Mountains, where it cost $45.00 per ton delivered. It is sent in great quantities to Eastern Pennsylvania, New Jersey and Maryland, northward to Buffalo and Canada and westward to Chicago and Duluth.

Table XXII-M shows the distribution of works in the Pittsburgh district, while Fig. XXII-G illustrates the Edgar Thomson Bessemer plant at Braddock. No list of names is given either for this district or any other, as the directory before referred to, issued by Mr. Swank, gives complete information.

TABLE XXII-M.

Distribution of Iron and Steel Works in the Pittsburgh District.

	Blast Furnaces.		Bessemer Plants.		Open Hearth Plants.		Works making crucible steel	Works having rolling mills.
	Cok.	Charcoal.	No. of works.	No. of converters.	No. of works	No. of furnaces.		
Allegheny, Westmoreland. Fayette and Washington Counties	37	......	7	16	28	118	13	73
Shenango Valley	19	......	1	2	5	21	4	22
Eastern Ohio, including Mahoning Valley and Ohio River Counties	23	......	4	8	....	....	....	29
West Virginia	3	......	2	4	....	....	....	13
Total	82	......	14	30	33	139	17	137



a, Cupolas; b, Casting crane; c, Converters; d, Elevated track from receiver; e, Crane for ladle stands.

FIG. XXII-G.—BESSEMER PLANT, EDGAR THOMSON WORKS, PITTSBURGH, PA.

SEC. XXIIe.—*Chicago:*

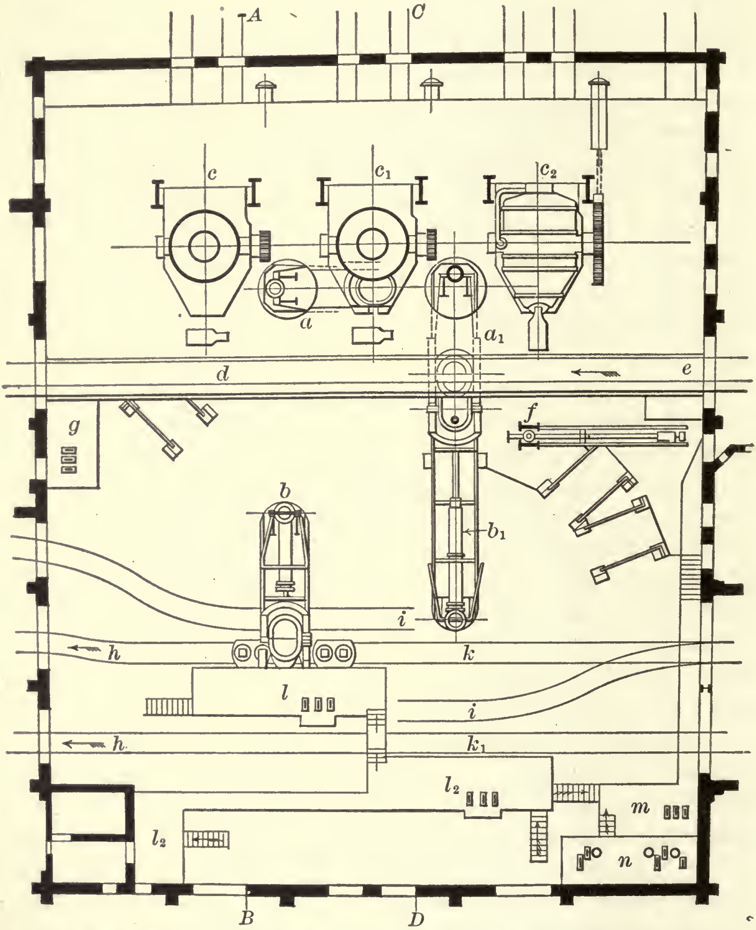
I am indebted to Mr. C. E. Stafford, president of the Tidewater Steel Company, at Chester, Pa., for much of the information in this article.

In the district of Chicago I have included the producing plant at Joliet, Ill., about 40 miles to the southwest and the rolling mills at Milwaukee, Wis., about 80 miles to the north. The metallurgical conditions here are exactly the same as in Pittsburgh, and hence need not be discussed again. The coke is brought by rail from Connellsville or from West Virginia, the distance ranging from 525 to 625 miles. The strong point of the situation is the comparatively short distance through which the ore must be brought, and the haul is entirely by lake vessels, this being cheaper than ordinary ocean transportation owing to the special vessels used in the traffic. The blast furnaces at South Chicago are on the water front, the vessels being unloaded directly into the stock yard.

The subsidiary fuel has come from different sources at different times. The gas coals of Central Illinois contain as high as 45 per cent. of volatile matter and are used for heating furnaces, but cannot be used in open-hearth work on account of the high content of sulphur. For this reason the melting furnaces use the gas coal of Pittsburgh, West Virginia and the Big Muddy field of Southern Illinois. Oil has been used in the past, the neighboring refineries, working on Ohio and Indiana oils, supplying residuum at a price which has sometimes been attractive. Natural gas is pumped from the Kokomo field of Indiana for domestic purposes in Chicago, but only a small surplus can be had at a price warranting its use in the steel works.

Chicago is one of the greatest railroad centers of the world, and the manufacture of rails has been the natural direction of development, one of the greatest of American rail mills being in operation here. By virtue of the tributary railroad systems the Chicago market has always had a surplus of scrap for disposal, and this fact perhaps influenced the development of a very extensive open-hearth plant, which has been erected within a few years. The plant includes a slab mill for roughing down the ingot, the plates being all rolled from slabs. Melted iron is used to a great extent in the open-hearth furnaces, the iron being taken from the same receivers that take care of the Bessemer plant.

The industry of this section is concentrated in the plants of the Illinois Steel Company. The plant at South Chicago embraces ten blast furnaces and a Bessemer plant which feeds a rail mill. The converting department is shown in Fig. XXII-H and the rail mill in Fig. XXII-I. The open-hearth and plate mill plant have already been mentioned. The rolling mill also turns out a certain proportion of axle billets and general merchant billets, the latter being sent to the Bay View works at Milwaukee for finishing into splice plates, small structural shapes and miscellaneous merchant bar. The defective rails are also sent from Chicago to Milwaukee to be rerolled into light rails. At Joliet, about 40 miles away, there is a Bessemer plant, fed partly by pig-iron used directly and partly by iron brought from furnaces at the North and Union Works at Chicago, which is remelted in cupolas. The mills at Joliet roll splice bars, skelp, wire rod and a large amount of sheet bar, and also send some billets to the Bay View Works at Milwaukee.



a, **Intermediate crane;** ***b***, **Casting crane;** ***c***, **Converter;** ***d***, ***e***, **Elevated track from receiver;** ***f***, **Ladle crane;** ***g***, Operating stand for casting crane; ***h***, To stripper; ***i***, Slag track; ***k***, Casting track; ***l***, Casting platform; ***m***, Operating casting crane; ***n***, Operating converter.

FIG. XXII-H.—BESSEMER PLANT AT SOUTH CHICAGO, ILL.

The distribution of the plants in this region is not founded on any special system, but arises from the absorption of several old plants under one head. Certain rolling mills, as for instance, at the North and at the Union Works, have been abandoned, but it has

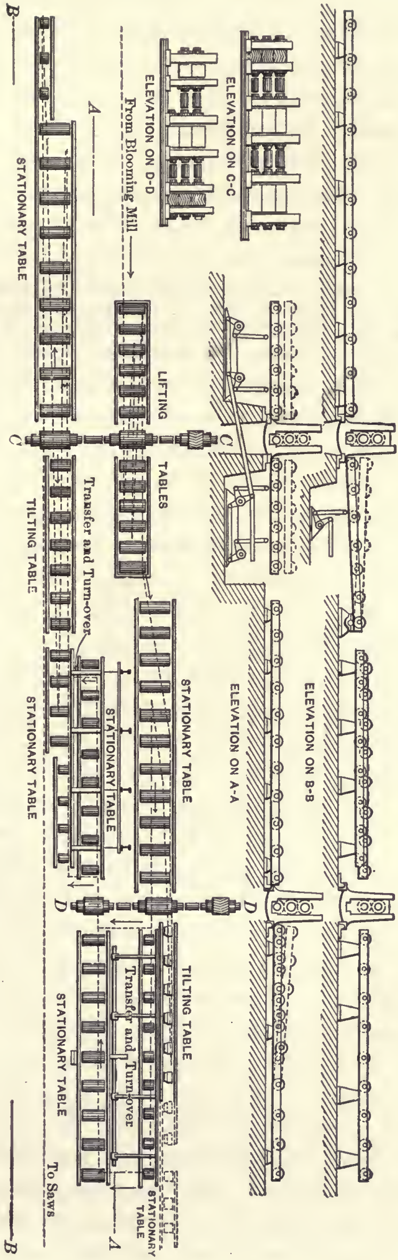


FIG. XXII-I.—RAIL MILL AT SOUTH CHICAGO, ILL.

been profitable in the face of extra freight and handling to keep the finishing mills of Joliet and Milwaukee in operation. The region round about offers an enormous market for miscellaneous products, there being many large agricultural works, shipyards, rod and wire mills and other establishments making everything from pipes and tubes to smaller cold stamped wares. The steel plants of Ohio, Pittsburgh and the East are active competitors for much of this business, but Chicago naturally claims a large proportion.

SEC. XXIIf.—*Alabama:*

Note: Most of the facts and data herein set forth are derived from a most comprehensive pamphlet issued in 1898 by the Alabama Geological Survey, entitled "Iron Making in Alabama," by Dr. W. B. Phillips. I am also personally indebted to Dr. Phillips for reading the manuscript concerning this State.

The third district in regard to output of pig-iron is the northern central part of Alabama, with Birmingham as its best known representative, the mines of the Red Mountain group contributing half the total ore production of the State. Nowhere else in America is there a great producing district where ore and coal are side by side. The problem in most other districts is the smelting of good ore with good fuel and the making of acid Bessemer steel. In Alabama the conditions are much more difficult, and resemble those confronting some metallurgical centers of the Continent. The ore is of low grade, the limonites being better than the hematites and the richer hematites have been practically exhausted. A great deal of the coke used is made from coal that has been washed in order to lower the percentage of ash and sulphur. The phosphorus in the ores is not high enough to render possible the use of the basic Bessemer process, and it is rather high for the basic open-hearth furnace. This fact does not mean that steel cannot be made in Alabama; it merely means that the cost of conversion will be greater in the long run than in more favored districts, a fact which has not been considered by some investors and metallurgists.

The iron industry of Alabama has suffered from the extravagant statements of promoters, and it may be well to quote from the writings of W. B. Phillips, who has done so much to forward the interests of the State, but who has no word of praise for those who have brought the district into ridicule. I quote from this most excellent and friendly authority to show that what is here written is not put down in malice: "We may keep the great outcrops of ore for a sort of show-place and continue to publish photographs showing 15, 20 and 25 feet of ore as evidence of the prodigality of nature. But there is not a single place on Red Mountain, from Irondale to Raymond, where even 12 feet of ore is mined, and the huge seams taken as a whole are worthless. It is all very well to take visitors to some great cut in the seam, and ask them what they think of *that* for ore. What they will think depends entirely upon how much they know about the ore." *

The ores used in Alabama are of three kinds:

Brown ore=Limonite.

Soft ore=Hematite, carrying about 1 per cent. of lime.

Hard ore=Hematite, self-fluxing.

The composition of each varies very much, and sometimes there have been found small seams of ore running fairly low in phosphorus, but in no place and at no time has any considerable amount been located which would justify the hope of making Bessemer iron on a large scale. Phillips states that the general run of ore as it is smelted will give an iron containing 0.20 to 0.80 per cent. of phosphorus, but in another place (p. 167) he states that no furnace in the State is warranted in guaranteeing under 0.75 per cent. in the pig-iron.

BROWN ORE.

The brown ore or limonite is the best ore in the State and more is being mined every year, as new deposits are developed, but a brown ore bank is a very uncertain proposition; it may yield good material for a number of years, or it may be exhausted within a comparatively short time. Brown ore is almost always a mixture of lumps of ore with a more or less tenacious clay, and a thorough washing is usually necessary. The average composition as delivered at the stockhouse is as follows, it being assumed that all hygroscopic water is expelled:

Fe	51.00
SiO_2	9.00
Al_2O_3	3.75
CaO	0.75
P	0.40
S	0.10

SOFT ORE—(HEMATITE).

The so-called soft ore of Birmingham is the result of ages of atmospheric influence upon a deposit of hard calcareous hematite. The disintegrating action has not only softened the mass, but the

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* Geological Survey of Alabama, 1898, p. 277.

percolating water has removed the lime, and as a consequence, the percentage of iron is higher in this soft ore than in the underlying hard and limey deposit on the dip. The extent of this decomposed layer varies very much on the dip, in some places being 300 feet, while in other places the hard ore appears on the surface. When the overburden is stripped off, there is found a seam of ore, quite soft, of a deep red or purple color, the so-called "gouge." It may be only a few inches thick and may run up to two or even three feet. Under this comes the solid ore, diminishing in iron as the depth increases. The best quality of "gouge" will carry 52 per cent. of iron, while ten feet down the limit of good ore is reached. Including this "gouge" it is found that the first ten feet of the seam will average about 47 per cent. in iron, while the second ten feet will run about 42 per cent. In former times the rule was to send to the furnace "anything that was red," but operations are now limited to the upper ten feet. An average analysis of stock-house samples shows as follows:

SOFT RED ORE.

	Wet.	Dry.
Fe	47.24	50.80
SiO_2	17.20	18.50
Al_2O_3	3.35	3.60
CaO	1.12	1.20
Water	7.00	

HARD RED ORE.

The relation of the deposits of soft and hard ores is shown by Fig. XXII-J, which is copied from the work of Dr. Phillips. Sometimes, as before stated, the hard ore reaches to the surface, and sometimes both soft and hard ores of the good variety are lacking, but usually the hard good ore is found, reaching to a great depth.

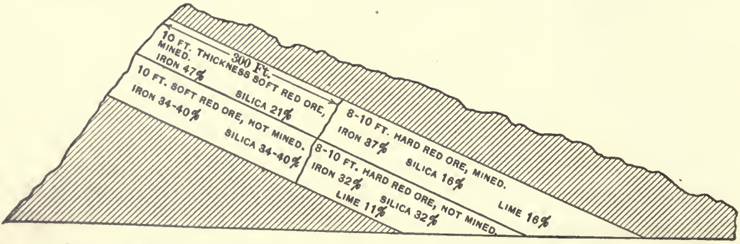

FIG. XXII-J.—ORE DEPOSIT OF BIRMINGHAM, ALA.; VERTICAL SECTION.

Not many years ago the soft ore was the only kind used, but it has been found that the supply will be exhausted in a comparatively short time and the furnaces are carrying more and more of the hard ore, some plants using it almost alone, and as before stated, there is a greater proportion of limonite (brown ore).

This hard ore naturally follows the same rules that hold for the soft ore, that the content of iron decreases toward the dip, but it will be made clear by the diagram that this has nothing to do with the uniformity of the ore at right angles to the dip. The hard ore, as before explained, contains a considerable proportion of lime, the relative amounts of other substances being correspondingly decreased. A general average is as follows:

HARD ORE.

Fe	37.00
SiO_2	13.44
CaO	16.20
Al_2O_3	3.18
P	0.37
S	0.07
CO_2	12.24
Water	0.50

An examination of these figures will show that the ore is self-fluxing. This, of course, is not true of the output of every part of the bed, for some parts give too much silica and some too much lime, but it is important to consider the general fact because it places in a different light the low content of iron.

Under the subject of flux it may be well to note that dolomite is used quite generally in Birmingham furnaces, the average composition being as follows:

BIRMINGHAM DOLOMITE.

Silica	1.50 to 2.00
Oxide of iron and alumina	1.00
Carbonate of lime	54.00
Carbonate of magnesia	43.00

It is quite rare to find dolomite thus used, but the results seem to show that magnesia will remove the sulphur as successfully as lime.

COAL AND COKE.

The principal coal deposit in Alabama is known as the Warrior field, which raises 85 per cent. of the total output of the State, the chief centers being in the counties of Jefferson, Walker and Tuscaloosa. In 1897 the average price at the mines was 88 cents per ton. Most of the coal of the State will give a fair coke, but it has been found necessary to wash it in order to remove both sulphur and ash, and this also improves the quality. There was a time when furnacemen talked of making a fuel ratio of ton per ton, but that day has gone by, and it is now considered good work if a ton of pig is made with 1.3 tons of coke, while the average is higher than this.

PIG IRON.

The pig-iron made in Alabama has been sent to all parts of the country and much of it abroad. There is a comparatively limited demand in the State, but there is quite a market in Northern cities within a reasonable distance, as for instance Cincinnati, and a great deal is sent by rail and water to Philadelphia, New York and other seaboard points. Most of this is for foundry purposes, and although no one consumer takes an enormous quantity, the items foot up a good total. Some of this iron is carried into the heart of the iron districts of Pennsylvania, and is used to some extent for puddling. The freight rates are made as low as possible by the railroads to encourage business, but the distances are very great. The cost of foundry iron in Alabama is usually placed at from seven to eight dollars per ton, and the freight to Northern points is oftentimes four dollars and even more. The natural answer to this condition is to manufacture the iron on the spot into finished products, and the making of steel is the most attractive field, but it must be considered that pig-iron for the basic open-hearth furnaces should be low in sulphur and silicon, and only a portion of the product of Southern furnaces as now operated will satisfy this condition, and it is quite clear that if only the best of the iron is available for making steel, and that if the poorer grades must be sold at prices below the standard, the steel furnace must be charged a correspondingly higher price for its stock. That good basic iron can be made is unquestioned, but it will not be made at the same price as the average run of foundry and forge irons.

For several years Alabama has occupied the fourth position among the iron producing States, with an annual output equal to that of Belgium, or Scotland; but according to the system of districts which we have assumed she occupies third place, the great producing part of Ohio being included in the Pittsburgh district. The growth of the industry is shown in Table XXII-N.

TABLE XXII-N.

Production of Pig-Iron in Alabama.

Year.	Long tons.
1875	22,418
1880	68,925
1885	203,069
1890	816,911
1895	854,667
1896	922,170
1897	947,831
1898	1,033,676
1899	1,083,905
1900	1,184,337
1901	1,225,212

STEEL.

During the last few years great progress has been made in the manufacture of steel in Alabama. At first there was much doubt as to whether it could be successfully made and long and enthusiastic articles were written describing the results of the first tap of steel, with figures showing the percentage of carbon, and phosphorus, and sulphur, and everything else, with many more figures about the ultimate strength and elastic limit. It is not alone in Alabama that this sort of nonsense is perpetrated, for leading technical journals gravely copy figures showing the physical results on a piece of steel made in some new district as if the information were of importance. Nothing can be of less moment.

If iron ore can be found, and fuel brought to it, steel can be made; and by proper attention it can be made equal to the best; and by proper treatment it can be worked into a bar, and that bar will give a known and definite tensile strength, elastic limit, elongation and reduction of area, depending on the composition of the final metal and the rolling conditions, without any regard to the quality of the ore or whether it was mined in Alabama or Japan. The important point is the cost of the finished material, and this can usually be estimated just as well before a pound of steel is made as it can during the first few weeks or months of working. It is necessary to know the general character and location of the ore, and the quality and location of the coal, and some other general conditions in order to determine the probable cost of pig-iron. It is necessary to know whether the conditions are uniform, and whether the sulphur and phosphorus vary very much in order to know whether the practice can be reduced to the most economical basis. Knowing these things it is possible to state whether steel can be made commercially and along what lines the best financial results will be obtained. Following this the operation must be conducted by intelligent metallurgists and by honest managers. Unfortunately Alabama has lacked these essentials in some notable instances, but there has been continual progress, and it is believed that the steel industry of the State has now acquired a secure footing. The only important works, however, is at Ensley, where there are ten 50-ton basic tilting furnaces, operated by the Tennessee Coal, Iron and Railroad Company.

One of the great drawbacks in the South is the labor question. Owing partly to the climate and partly to the absence of a white population trained to industrial pursuits, it is necessary to depend upon the negro, and the colored man has had no education in this line of work. The whole history of the race in this country has been in agriculture, and in the days of slavery they were treated either like beasts of burden, or in some cases like children. In saying that they were treated as beasts of burden it is not necessary to infer that such treatment was necessarily unkind or cruel. Setting aside all considerations of humanity it was the part of economy to properly feed and clothe the workmen, as it is profitable to take good care of horses. But the important point is that during this era the negro individually and collectively was not called upon to provide for the future and in most cases could not provide if he would.

It would be too much to expect that such ignorant men, suddenly loosed from thraldom, would instantly become a saving, provident, hard-working people, and the wonder is that so large a proportion do fall into this class. The greater part of those in the Southern States, so I am informed, are entirely improvident and many of them will work only long enough to get a little cash, whereupon they quit work and live in idleness upon their earnings. A summary discharge has no terrors, as living is cheap and their wants few. I was told by one of the furnace managers in the South that he has an average of three names on his payroll every year for each job. The two idle men were spending most of their money for liquor and in gambling games, while a certain proportion never worked, but devoted their time to politics, and made speeches on the equality of colored men and their right to occupy the highest positions of the land.

I believe that this condition will pass away in time. The negro in the North has overcome in great measure this hereditary tendency, although it must be remembered that this part of the country has received the pick of the race, for as a rule it is the progressive, energetic and industrious man that leaves his home to make his way in a new field. There are many agitators whose only vocation is to wear good clothes, and there are too many lazy and shiftless men; but this is quite true of other races in every land. Taking the Northern colored people as a whole the great proportion are industrious workmen, who are amenable to discipline and who possess their full measure of intelligence. My experience is, however, that they do not readily submit to dictation from one of their own color, and so by their own choice they perpetuate the supremacy of the white race.

Sec. XXIIg.—*Johnstown:*

The western central part of Pennsylvania is usually considered a district by itself, the statistics including the output of the counties of Cambria, Jefferson, Armstrong, Westmoreland and Fayette. The last two have already been considered as part of the Pittsburgh district, while Jefferson and Armstrong are of little importance. It may, therefore, be well to consider Cambria County by itself, since the plant of the Cambria Steel Company, at Johnstown, is the one predominant works in this part of the State. The district produces no ore and the supply is brought from Lake Superior. The coke comes partly from Connellsville and partly from a new installation of by-product ovens which runs on the leaner coals of the mountain field. The great advantage possessed by this plant is the cheapness of its coal supply, the hills in the very outskirts of the works furnishing a supply for steam purposes. Its position is isolated, but this confers a benefit in the way of labor, as it tends to produce and, in this case has produced, a larger proportion of employees who have been in the service of the company for many years.

The works not only makes a large tonnage of standard rails, but is now an important factor in beam and structural work, and has for many years operated very large special shops, called the Gautier Department, wherein special steels are worked into springs, forks and a thousand similar products.

Sec. XXIIh.—*Steelton:*

Ranking fifth among the pig-iron producing districts of the

United States and fourth in output of steel is the district of Dauphin and Lebanon counties, in Pennsylvania. More than one-half of all the pig-iron is made in the furnaces of The Pennsylvania Steel Company and all the steel is made at its plant at Steelton near Harrisburg. The northern part of Dauphin County includes a part of the Lykens anthracite coal field, but this has little bearing on the iron industry, save as offering a certain amount of steam fuel in the smaller sizes made at the breakers. The ordinary bituminous coal is brought from Clearfield and gas coal from Westmoreland, while most of the coke is from Connellsville, although considerable "mountain" coke has been used.

The distinguishing feature of this district is the deposit of ore at Cornwall, near Lebanon. The hills in which the ore occurs were held in private hands, by legacies from father to sons, from 1732 down to 1894; but in that year the Lackawanna Iron and Steel Company acquired a one-third interest and in 1901 The Pennsylvania Steel Company bought a still larger share, these two companies together now owning a majority of the stock. This mine has been worked since 1740, and up to the end of 1900 had produced 14,000,000 tons of ore, which is more than had been obtained up to that date from any other one deposit in the United States, and up to 1893 it was the largest single producer. The Port Henry mines in New York have raised two-thirds as much, having been operated since 1804. Some of the Lake Superior deposits will soon sum up a greater total, for the Vermilion range in Minnesota in 1899 turned out 1,750,000 tons, while the maximum ever raised at Cornwall was 769,020 tons in 1889. The Vermilion mine is selected since the other divisions of the Lake Superior district include many separate mines under one range name. The present rate of production at Cornwall is about 750,000 tons per year, and in the tables of the U. S. Geol. Survey, compiled by John Birkinbine, there is no other mine north of Alabama and east of Michigan which raised as much as 100,000 tons in 1900. The extent of the deposit is not definitely determined, but it is known that an enormous body of ore is available, which may be mined open cut. The ore is a magnetite, very low in phosphorus, but intimately mixed with clayey matter, and it is peculiar in that the deposit is permeated by streaks of copper bearing sulphides. Some of these streaks can be separated, but there is such a complete mixing of the minerals that the ore as mined contains a considerable quantity of both of these elements. The copper varies very much and it is impossible to take a true sample, but experience proves that the pig-iron made from selected ore will contain about 0.60 per cent. of copper, while the run of the mine will give a somewhat higher proportion.

The sulphur in the ore will run from 2.00 to 2.50 per cent., and roasting is always practiced, about half the sulphur being removed in this way. Formerly anthracite was used in the kilns, but the latest type uses the waste gases from the tunnel head. Leaving out of the question the country rock and streaks of silicious stone which are cast aside by superficial inspection, the run of mine contains from 40 to 42 per cent. of iron and about 20 per cent. of silica, with a small proportion of lime and magnesia. It has been stated that the roasted ore going to the furnaces contains from 1.00 to 1.25 per cent. of sulphur, and about 40 per cent. of iron, so that in order to make 100 pounds of pig-iron, the ore will carry from 2.5 to 3.0 pounds of sulphur into the furnace. There will also be needed about 1.5 tons of coke carrying 1.0 per cent. of sulphur, or 1.5 pounds per 100 pounds of iron, and there will therefore be from 4.0 to 4.5 pounds of sulphur added per 100 pounds of iron. In ordinary blast furnace practice, where the ore has no sulphur and the fuel ratio is one to one, the total sulphur added per 100 pounds of iron will be 1.0 pound, so that in using Cornwall ore the sulphur in the burden is from four to five times as much as in ordinary practice.

It has been found by experience, long before the reason was fully understood, that it was necessary to run the Cornwall furnaces extremely hot in order to make good iron and the reason for this will be quite clear when the sulphur question is considered. As a consequence, the good iron is generally very high in silicon, usually containing over two per cent. and very frequently from three to four per cent. For thirty years this iron has been used in the making of Bessemer steel at Steelton, usually forming about one-third of the total charge, but sometimes it has been converted alone. It has also been used for many years by the Lackawanna Company at their Scranton works for the manufacture of rails, the ore being smelted at the mine and the pig-iron remelted at the steel plant. Quite a large amount of iron is also sold to makers of steel castings and for use in acid open-hearth furnaces, because when smelted with the best coke, the phosphorus in the pig-iron will be from

.025 to .04 per cent., and this metal brings a premium in the market and is even sent in considerable quantities into the Pittsburg district.

There are several blast furnaces in the immediate vicinity of the Cornwall banks, some of them owned by The Pennsylvania Steel Company, some by the smaller stockholders in the ore company, some by private individuals, and some by the Lackawanna Company, as before mentioned, the latter possessing also a plant of 232 Otto Hoffman ovens at Cornwall. The Lackawanna Company has for years operated a steel works at Scranton, but has now abandoned this situation and is moving to Buffalo, N. Y., and the pig-iron from Cornwall will be carried to that point. The only works therefore in the district which is a steel producer is The Pennsylvania Steel Company. This company was not the first to produce Bessemer steel in this country, but it was the first to make it regularly and to continue its manufacture on a commercial scale. The Bessemer plant was built in 1868, and from that time onward has been a factor in the steel trade of the country. During the last ten years The Pennsylvania Steel Company has not attempted to increase the rail making capacity of its Steelton plant to keep pace with some of its competitors, but has expanded in several other directions:

(1) By building a new railmaking and shipbuilding plant at Sparrow's Point, near Baltimore, known as the Maryland Steel Company, of which more will be said later.

(2) By making a specialty of frogs, switches and general railway equipment, the plant at Steelton being the largest in the country in this line of work. It divides with two other shops all the business of street railway equipment, and has invaded to a considerable extent the foreign markets.

(3) By enlarging its open-hearth departments for the making of special steels.

(4) By the development of a bridge shop which has become widely known for some very large operations, among which may be mentioned the following:

Niagara steel arch, 550 feet span, double track railroad.
Duluth draw-bridge, 500 feet draw span.
Gotkeik viaduct in Burmah, 320 feet high, 2280 feet long.
The new East River Suspension Bridge, 1700 feet span.

Between Steelton and Harrisburg are the plate rolling mills of the Central Iron and Steel Company, while some smaller establishments exist nearby, and the output of finished iron and steel in Dauphin County stands second only to that of Allegheny County among the counties of Pennsylvania.

Fig. XXII-K shows the Bessemer plant at Steelton and Fig. XXII-L a cross-section of the open-hearth department.

SEC. XXIIi.—*Sparrow's Point:*

In the western part of Maryland the Cumberland coal field has been known as an important producer for over fifty years. This field is located in Allegheny and Garrett counties in the extreme west of the State, and extends from the north branch of the Potomac River and Piedmont to the Pennsylvania State line, but the mining operations occupy only half that distance, or about fifteen miles. There is however a very heavy production in proportion to the area, and the coal ranks among the best for steam purposes and is sent in large quantities to New England and other Eastern points.

The iron and steel industry of the State is entirely independent of the fuel production, as it is practically all represented by one plant in the extreme eastern part, which makes use of the Cumberland coal only in an incidental way. This plant is the Maryland Steel Company, which is really an extension of the works of The Pennsylvania Steel Company, at Steelton, Pa., and which is in fact owned by this latter company, although in law the companies are entirely distinct and are operated independently. This is the only rail-making plant in America on tidewater, and we might say the only large steel works. There are some plants, like the Pencoyd works at Philadelphia and one or two others, which are situated on the seaboard, but neither their supply of raw material nor the field in which they market their products has been greatly influenced by their situation. Moreover, their positions were not chosen with foreign trade in view, but solely with the idea of supplying the wants of the great industrial and commercial centers immediately around them.

The plant was started in the year 1887 on entirely new ground, on the Chesapeake Bay, about 15 miles south of Baltimore. It is far from any other seat of the iron industry and was founded with the broad plan of receiving ore from Cuba, converting it into finished steel products, and loading on vessels for shipment abroad or for New England points, or for points on the South Atlantic or Gulf Coast, without any charges for land freights. This compre-

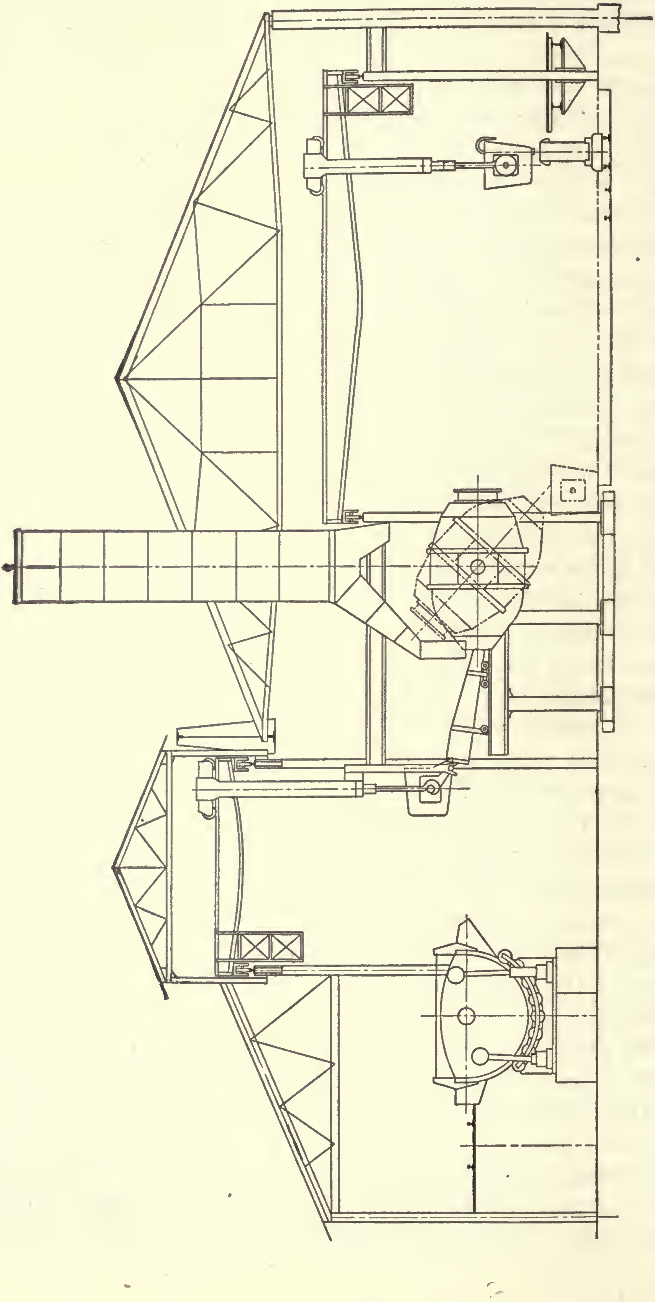

Fig. XXII-K.—Bessemer Plant, The Pennsylvania Steel Co., Steelton, Pa.

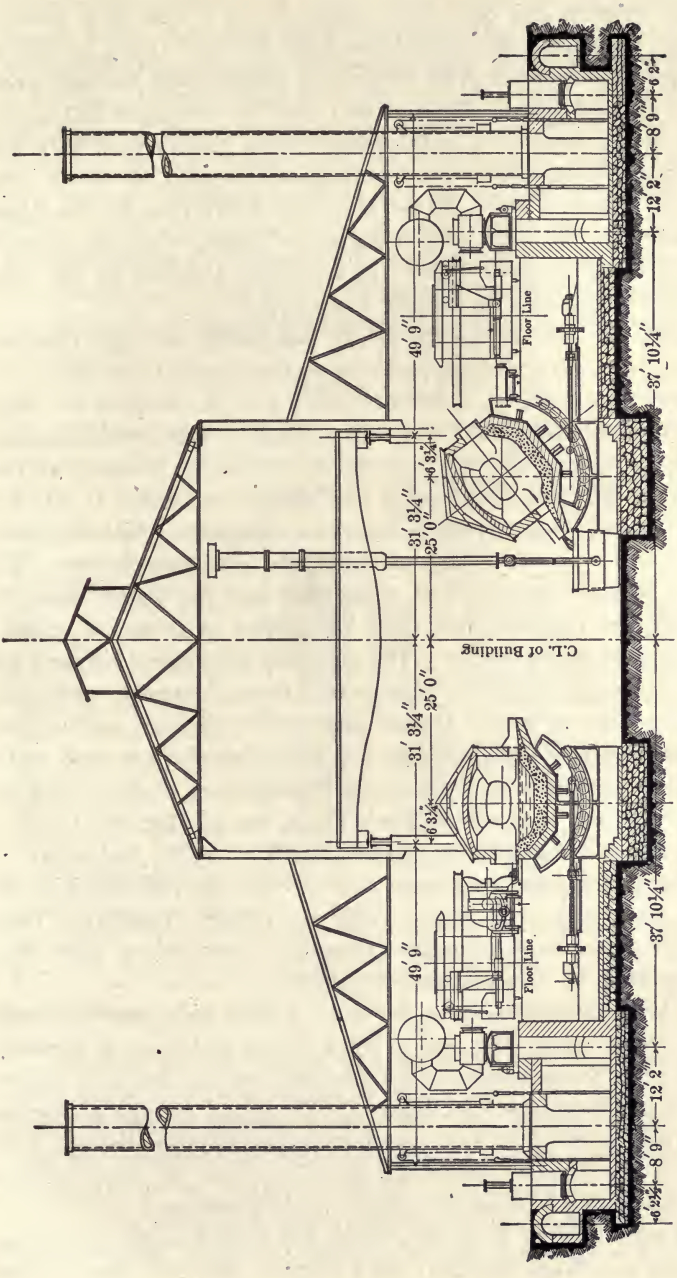

FIG. XXII-L.—CROSS-SECTION OF OPEN-HEARTH PLANT AT STEELTON.

hensive scheme has been interrupted by two untoward circumstances: First, by the general financial panic of 1893; second, by the Spanish-American War, which was waged upon the very property of the company at Santiago de Cuba, the great pier in the harbor, so often mentioned in the public press, having been built and used by the company for the handling of the ore. Moreover, even the declaration of peace did not solve the difficulties, for the Spanish workmen had been driven from the mines, while the Cubans preferred the generous charity of the United States to the more independent position of earning their living.

During the war period the works ran partly on Lake Superior ore, and since then in great measure on the supply from Spain, but it is now certain that a sufficient supply will be available for many years from the mines in Cuba. The Pennsylvania Steel Company was the pioneer in the development of the mining industry of this island, its Jurugua mines being first worked in 1884. It was followed in 1892 by the Spanish-American Company, which developed property only a short distance from the Jurugua deposit. The Sigua Company has also done some work and the Cuban Steel Ore Company has opened a new field, but neither of these has raised a very large quantity of ore. The Spanish-American Company has now been bought by The Pennsylvania Steel Company, which also holds an interest in the Cuban Steel Ore Company, so that this company controls practically all the mines which have been active and large producers of iron ore in Southeastern Cuba. This ore will be used not only at Sparrow's Point, but at Steelton, Pa.

The ore is a mixture of magnetite and hematite, and occurs in hard lumps irregularly streaked with pyrites, the proportion of the latter not being sufficiently high to require roasting. Table XXII-O shows the shipments from the Cuban mines since their opening and the composition of the ore.

The total shipments up to the close of 1901 have been 5,050,858 tons, of which some was sent to Nova Scotia and some to England. The United States however took 98.6 per cent. of the total output, most of this being used at Sparrow's Point and a large proportion of the rest at Steelton, but considerable quantities of the ore, especially of the Spanish-American, have been used at blast furnaces or open-hearth plants on the North Atlantic seaboard.

The coke used at Sparrow's Point has been brought from Connellsville and West Virginia, but a plant of 200 coke ovens is now under construction which will use exclusively the coal of the Pocahontas field. The steel plant consists of two 18-ton acid lined converters and these supply a mill which rolls either rails or billets, the piece being finished from the ingot to the hot bed without reheating the bloom. This plant also has one of the largest shipyards in America. In the construction of the Bessemer plant there were two radical innovations introduced by its now president, F. W. Wood. The old swinging hydraulic ladle cranes were discarded, and a traveling crane introduced for the first time. As this was before the general use of electricity, the motive power was a steam engine carried on the bridge, although electric power has since been applied.

TABLE XXII-O.

Shipments of Ore from Southeastern Cuba; Gross Tons.

Year.	Jurugua Iron Co.	Spanish American Iron Co	Sigua Iron Co.	Cuban Steel Ore Co.	Total.
1884	25,295	....	....	....	25,2 5
1885	80.716	....	....	....	80.716
1886	112,074	....	....	....	112,0 4
1887	94,240	....	....	....	94.240
1888	206,061	....	....	....	206,061
1889	260,291	....	....	....	260.291
1890	363,842	....	....	....	363,842
1891	264,262	....	....	....	264,262
1892	335,236	....	6,418	....	341,654
1893	337,155	....	14,020	....	351,175
1894	156,826	....	....	....	156,826
1895	307,503	74,991	....	....	382,494
1896	298.885	114,110	....	....	412,995
1897	248,256	206,029	....	....	454,285
1898	83.696	84,643	....	....	168,339
1899	161,783	215,406	....	....	377,189
1900	154,871	292,001	....	....	446.872
1901	199,764	334,833	....	17,651	552 248
Total	3,690,756	1,322,013	20,438	17,651	5,050,858
Total to foreign ports	....	....	....	....	70,160
Aver composition of cargoes.					
Fe	57.00	63.30	65.85	62.80	....
S	0.288	0.092	0.037	0.211	....
P	0.025	0.032	0.015	0.036	....

The most radical change however was in placing the molds on trucks ready for casting, these trucks with the molds being then taken to the rolling mill while the steel is solidifying. A mechanical stripper then removes the molds from the ingots in close proximity to the heating furnaces, all the exhausting labor of the "pit" being abolished and the ingots charged hotter in the rolling mill furnaces. The consumption of fuel for heating at Sparrow's

Point has been as low as 20 pounds per ton of ingots rolled. This arrangement of casting on trucks, which was first put in operation here, is now the standard construction not only in America but in the most progressive plants of Europe. A minor novelty in this plant, but an advance in line with more recent progress, was the installation of the Bessemer blowing engine near the blast furnace boilers in order to use the excess power developed at the smelting plant.

During the last few years the Maryland Steel Company, or, as it is often known from its location, "Sparrow's Point," has furnished a great proportion of the rails exported from America. This is quite a natural result of its situation, and also of the fact that the United States Government exacts no duty on the iron ore which goes into articles of export.

Following is a statement showing the amount of steel rolled in the last four years with the amount of material exported. There is also given in Fig. XXII-M a plan of the rolling mill at Sparrow's Point, while Fig. XXII-K gives a cross section of the Bessemer plant at Steelton, Pa., showing the above described method of casting on trucks as applied at a later time.

	1898	1899	1900	1901
Production.	130,804	225,645	225,618	277,853
Exported	63,972	85,976	102,254	83,673
Per cent. export........	48.9	38.1	45.3	30.1

Sec. XXIIj.—*Cleveland:*

It has been shown that the supply of ore for the furnaces of Pennsylvania comes down the Great Lakes and is unloaded at ports on the southern and eastern shore of Lake Erie. It is quite evident that a furnace at the port of entry will have no land freight to pay on the ore, and will haul less than one ton of coke, while the furnaces near the fuel must haul $1^2/_3$ tons of ore. The proposition is quite simple from a mathematical standpoint, but a glance at the map will show that there are some circumstances which disturb the calculations, for a position on the shores of Lake Erie does not increase the sphere of commercial influence as much as might be expected. On the north the tariff of Canada, as well as her limited needs, bars the way, while on the west is the competition of Chicago. There is no reliable communication eastward; the falls at Niagara have given rise to two canals, one on American territory to New York by way of the Hudson River, and one in

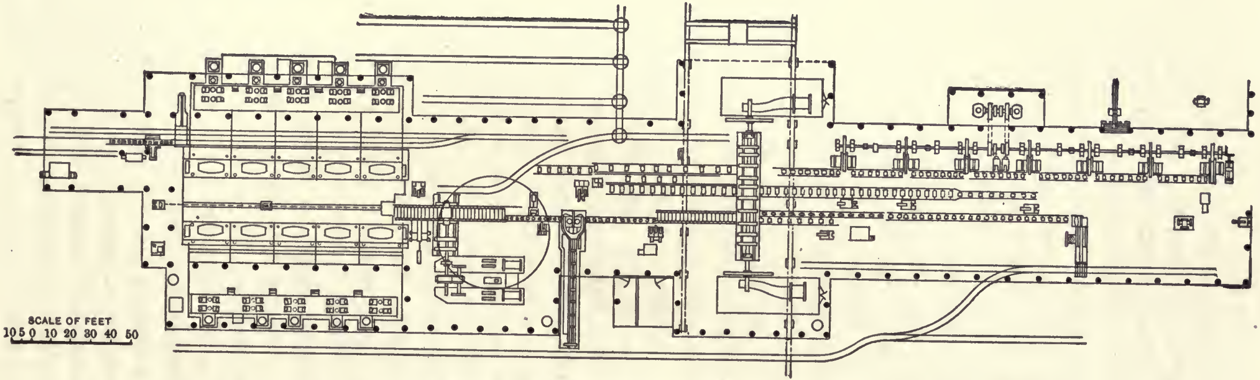

FIG. XXII-M.—RAIL MILL OF MARYLAND STEEL CO., SPARROW'S POINT, MD.

Canada, the Welland Canal, connecting with the St. Lawrence. Great sums have been spent by Canada to create an economical way of shipping by water from her western provinces to the ocean, but she is struggling not only with a commercial but a political complication. The navigation of the St. Lawrence from Quebec to Montreal is not satisfactory, but the latter place will not allow Quebec to get all the trade. Consequently much money is spent to improve the river channel which can be used only a part of the year, when there already exists a subsidized government railway which can carry the freight to Quebec at less cost. The same condition exists to some extent in the United States, where the people are urged to make a ship waterway out of the present Erie Canal, when the interest on the money needed to do this would probably pay the freight by railroad on all the material brought down. In both the case of the Canadian and American canals there is the serious objection that traffic is entirely suspended for three or four months in the winter, while in the case of the St. Lawrence River there is the additional disadvantage that the navigation of the lower bay for several hundred miles is very dangerous on account of the prevailing fogs. Of late years the question of marine insurance has become a serious matter.

All of these matters have an important bearing on the question of locating a steel plant on Lake Erie, as proven by the stress laid on water transportation by canal and by the St. Lawrence when each new project is started. These objections, however, are by no means prohibitory. The advantages are self-evident, and it may be said that the trend of new enterprises is toward this district. One of the first to make the journey was the Lorain Steel Company. There had been for some years a rolling mill near Johnstown, Pa., which bought blooms from the Cambria Company and made rails for street railways. A new company was formed and a new works built near Cleveland, equipped not only for street or "girder" rails, but for standard rails, a complete blast furnace and Bessemer plant being erected on entirely new ground. Since that time Lorain has been one of the centers of steel production in the United States. It divides with Steelton the work of making all the rails and most of the equipment for the street railways of the United States, and both of these plants have taken a part in foreign trade in this line of work.

The more immediate vicinity of Cleveland has played **a** very important part in the steel industry of this country for a long period. The Otis Steel Company was one of the pioneers in the manufacture of open-hearth fire-box steel, and its name has been known all over the land. The Cleveland Rolling Mill Company was a factor in the rail situation twenty years ago, but has long since turned its product into different forms of special work, it being one of the largest producers of wire rod in the country.

SEC. XXIIk.—*Colorado:*

The only great iron or steel producing district west of the Mississippi River is centered in the Minnequa Works at Pueblo, Colo., but its tributary mines cover an area which would overshadow a European empire. The Colorado Fuel and Iron Company owns over 30 mines in the State and 5 mines in New Mexico. The coke used at the steel works all comes from Southern Colorado, about 90 miles from Pueblo, the coal containing about 30 per cent. of volatile matter, and occurring in beds about 6 feet thick. It is washed and then gives a good hard coke containing about 16 per cent. of ash. The steam and gas coals are brought about 50 miles. In Colorado can be found coals of every description from anthracite to lignite, the beds having been exposed to severe geologic disturbances and to the heat of numerous volcanic intrusions.

The iron ore comes mainly from three sections. At Sunrise, Wyo., 350 miles from Pueblo, there is an enormous deposit of red hematite running as high as 62 per cent. in iron, which can be mined with a steam shovel. At Fierro, N. M., 600 miles from Pueblo, is a large deposit of hard magnetic ore running up to 61 per cent. in iron. At Orient, Colo., which is 125 miles from the works, is a deposit of easily reducible limonite containing about 50 per cent. of metallic iron. All of these ores are well within the Bessemer limit of phosphorus.

At Leadville, about 100 miles away, there is a deposit running about 30 per cent. in manganese and in Eastern Utah, about 400 miles distant, one with 50 per cent. of manganese. The spiegel for the steel plant is smelted at the Minnequa plant at Pueblo.

A glance at the map will show that this district is protected by a great distance, and a consequent high transportation charge, from the competition of Eastern works, and that it has an enormous area as its natural market. Unfortunately, most of this country is very sparsely settled and contains few industrial centers, but with the constant westward trend of population, the wants of railroads and of miscellaneous users have increased, and there is a demand not only for a large works but for the local production of a large variety of finished articles.

In answer to this demand very extensive improvements, amounting practically to a new plant, are now under way at Pueblo, and when completed there will be five blast furnaces, a Bessemer plant equipped with two 15-ton converters, an open-hearth plant with six 50-ton basic furnaces, one 40-inch blooming mill, 24-inch reversing structural mill, rod, sheet, tin plate, wire and nail mills.

SEC. XXIII.—*Eastern Pennsylvania:*

In addition to the Steelton district, already described, there are several seats of industry which should be mentioned in the eastern portion of Pennsylvania. Up to the present year the city of Scranton was the center of two old established plants concentrated under one management, and they were a very considerable factor in the rail trade. The whole plant is now being moved to Buffalo, N. Y., where it can receive Lake Superior ores without any charge for railroad transportation. The Scranton Company owns a considerable share in the Cornwall ore property and will make iron at this latter point and transport it to Buffalo for remelting to mix with the iron from lake ores.

The Bethlehem Works was formerly one of the great rail producers, but has not rolled rails for many years. It is now engaged almost exclusively in making open-hearth steel forgings and has the most complete plant in the country for this work. It divides with the Carnegie Steel Company the work on armor plate for the war vessels of the United States, and turns out guns and shafts of the largest size. This plant is now enlarging its open-hearth department and intends to remodel its old rail mill and enter the field as makers of angles, ship shapes and other structural material.

In the neighborhood of Philadelphia are the Midvale Steel Company and the Pencoyd Works, the Phœnixville Iron and Steel Company and the Tidewater Steel Company. The first of these does a large amount of work in the line of special steels and forgings, while Pencoyd and Phœnixville are especially known as bridge and structural shops, making all forms of structural materials for their own use and also for the outside trade. The Pencoyd Works came into general notice beyond the boundaries of the United States on account of its delivery of the well known Atbara bridge in the Soudan.

There are a large number of blast furnaces scattered throughout Eastern Pennsylvania, mainly in the Lehigh and Schuylkill valleys, and a very considerable amount of pig-iron is made. Most of this goes into the general foundry trade, but some is used in the neighboring steel plants. During recent years these furnaces have quite generally used the ores of Lake Superior with Connellsville coke.

In the neighborhood of Chester, Pa., not far from Philadelphia, there is a marked concentration of steel-casting plants, this being one of the greatest centers in this line of work, while Coatesville, Pa., is prominent for its plate mills.

In Table XXII-A I have divided Eastern Pennsylvania in a way somewhat different from that followed by Mr. Swank. He has always put the Schuylkill Valley separate, but has not included Philadelphia, which lies on both sides of this river. I have combined, under the title of Southeast Pennsylvania, the plants of the Schuylkill Valley with those of Philadelphia, Chester and Delaware counties. This is a logical arrangement and brings out more forcibly the importance of this region as a producer of iron and steel.

Sec. XXIIm.—*New Jersey, New York and New England:*

On the shores of Lake Champlain and in the northern basin of the Hudson River there are very considerable deposits of magnetite, which played quite an important part in the early history of the American iron industry, being the base of supplies for the Bessemer plant formerly operated at Troy, N. Y. Owing to the lack of fuel it was necessary to transport either coke or anthracite coal from Pennsylvania, and with the advent of cheap Lake Superior ores the manufacture of steel at this point was abandoned many years ago. An attempt was made in recent years to operate a basic Bessemer plant, but the conditions were not such as to warrant a continuance of the operations. Some of the rolling mills at Troy have been working on stock from Western steel works.

The ores are rather difficult to mine, and the annual output has been decreasing save as a higher price in boom years encourages an abnormal activity, so that the amount raised in New York is only about one-third of the quantity turned out twenty years ago. There are many large beds besides those already developed, but nearly all the ores of this district contain a very considerable proportion of titanium, which gives trouble in the blast furnace as well as in the Bessemer vessel, on account of the infusibility of slags containing titanic acid. This substance is so seldom found in prohibitory quantities in iron ores in other districts that prospectors and investors have many times sunk large sums of money in properties which have proved worthless. This line of magnetic deposits extends in a southwesterly direction across the northern portion of New Jersey and into Pennsylvania, where it appears as the Cornwall ore hills. The character of the ore varies very much throughout its length, its main point of resemblance being in its magnetic property, the titanium being entirely absent in the more southern fields. A great many mines have been worked in New Jersey in years gone by, but either from the exhaustion of the deposits or from the inferior quality or from the high cost of mining, many of them have ceased operation, so that the amount now produced in the State is only half what was raised in 1880.

Taking the whole magnetic field from Northern New York to Southeastern Pennsylvania, it may roughly be said that the Cornwall deposit, which is described under the Steelton district, produces half the total, while New York and New Jersey divide the remainder with an annual production of about 300,000 tons each. The iron made in these two States enters to a limited extent into the steel industry, some of it being sold to open-hearth furnaces, but most of it is used in the general foundry trade. Very much money has been spent on electric concentrating plants throughout this whole region, the most extensive outfit having been erected in Northern New Jersey by Edison, who spent several years in experiments. The ore used by him contained only about 18 per cent. of iron and was a hard compact rock, so that the expense per ton of finished concentrate was very heavy. The operation of bricking was not entirely satisfactory and the whole work was discontinued about two years ago, but in other places less ambitious installations have been worked with more or less success from time to time.

Some of the steel plants of this district are of considerable importance, although some are legacies from the days when the East held the supremacy in the iron trade. (In the iron world the term "East" means the region along the Atlantic seaboard east of the Allegheny Mountains.) A few kept pace with modern improvements, but in no works east of Pennsylvania is there to-day a complete plant of blast furnaces, steel producers and rolling mills, neither is there a Bessemer converter in steady operation, the works being engaged principally in the production of specialties or of supplying the local markets with structural and other material.

Table XXII-P gives information concerning the distribution by States.

Table XXII-P.

Iron and Steel Plants in New England, New York and New Jersey.

State.	Blast Furnaces.		Bessemer Plants.		Open Hearth Plants.		Works making crucible steel.	Works having rolling mills
	Coke.	Char-coal.	Works having standard con-verters.	Works having special con-verters.	No. of works.	No. of furn-aces.		
Maine								1
Massachusetts		3		1	4	14	1	7
Rhode Island					1	2		2
Connecticut		4		1	1	1	2	5
New York	16	3	*		6	11	3	21
New Jersey	11				4	9	5	17
Total	27	10		2	16	37	11	53

*The Troy works is idle.

CHAPTER XXIII.

GREAT BRITAIN.

SEC. XXIIIa.—*General View:*

As far as the coal and iron industry is concerned, the term Great Britain may be considered to embrace only England, Wales and Southern Scotland. These divisions of the Empire cover about 88,000 square miles, an area almost exactly the same as that covered by the States of Pennsylvania and Ohio combined. The population of this island, however, is from three to four times as great as that of these two States, while the pig-iron production in 1900 was about the same, the output of the blast furnaces of Great Britain in that year being 8,960,000 tons, while Pennsylvania and Ohio made 8,837,000 tons. In 1901 Great Britain fell to 7,761,000, while Pennsylvania alone made 7,343,000 and Ohio 3,326,000 tons. In both cases a great part of the ore was brought a long distance by water, to England by the ocean, and to Pennsylvania by the Great Lakes; but Great Britain was compelled to find a foreign output for nearly half her product, while the home demand in America offered a market for all except a small portion of the output.

In Fig. XXIII-A are shown the districts into which the country may conveniently be divided. The statistics of output as given in the figure and in these pages do not agree with the reports of the British Iron Trade Association because I have taken the data from the Home Office Reports, which are published later than the Association Reports and are made up from the sworn statements of the manufacturers. The difference is over one hundred thousand tons in the total production of pig-iron. It must be kept in mind that the figures shown in the enclosures embrace the surrounding district. The enclosure in Durham represents also Northumberland, and the latter division raised one-quarter of the coal credited to the two counties. The lack of room makes it difficult to locate the squares upon the map exactly as statistics would require; it must therefore be remembered that Barrow is in Lancashire, and hence the product of the Barrow Steel Works is included in the enclosing lines shown in the southern portion of the county where there was room for the figures. The map is thus intended as a general guide, but not as an accurate scientific graphical diagram. The statistics shown on the map are for 1899, but the figures for 1900 are given

FIG. XXIII-A.

in Table XXIII-B. The changes do not in any way alter the general outline of results, but in the later table I have tried to improve somewhat on the method of grouping.

FIG. XXIII-B.

Fig. XXIII-B shows a map of the coal fields of Great Britain, taken from an exhaustive treatise on the subject.* A glance will show that fuel is distributed widely throughout the island. More-

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* Les Charbons Brittaniques; Lozé; Paris, 1900.

over, most of the coal gives a good coke, that of Durham being especially noted for its quality. The Home Office reports show that in 1900 the total exports of coal were 44,089,197 tons, of which 18,460,070 tons came from the ports in South Wales, 15,315,091 tons from the ports on the Northeast Coast, and 7,377,094 tons from Scotland, these three districts supplying over 93 per cent. of all the coal exported.

There were 985,365 tons of coke sent over sea, and of this South Wales contributed 112,918 tons, Scotland 131,273 tons, while the Northeast Coast shipped 624,317 tons, the product of Durham and Northumberland. The Durham district therefore supplies only one-third of the coal exported, but furnished five-eighths of the coke.

The coal was shipped to all parts of the world, France taking the most, 8,314,697 tons; Germany next with 5,938,178 tons, Italy 5,115,125 tons, Russia 3,116,099 tons, almost all to her northern ports; while Belgium received 1,152,109 tons. The Pacific Coast of the United States took 34,880 tons, while even the Atlantic coast had 5,265 tons.

The coke also was spread all over the earth; thus out of a total of 985,365 tons, the best customer was Spain and the Canaries with 155,561 tons, probably as return cargo for the ore vessels; next comes Norway with 93,683 tons, Holland 89,293 tons, Northern Russia 86,950 tons, Sweden 79,879 tons. Of the leading iron producing nations Belgium took 39,409 tons, Germany 44,444 tons, France 47,832 tons, Austria 10,203 tons, and the Pacific Coast of America 15,367 tons. The shipments to Spain and to Northern Russia are important, since these two districts depend upon outside sources for their fuel. It will be noticed that Holland received 93,000 tons, but it is quite certain by comparing the statistics of neighboring countries that this coke went mostly to Germany and Belgium. The same confusion is found in the reported exports of pig-iron. Similar serious errors are found in the record of American exports, where shipments to the interior of Europe appear against the port of entry.

The steel industry of the country is largely dependent upon its supply of foreign ore. It was about 1865 that the imports of ore were worth mentioning, but according to Bell* they probably were not over 10,000 tons per year. In 1867 they had risen to 86,568 tons; in 1870 to 400,000 tons, and in 1880 to 3,000,000 tons. Some

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* Principles of Manufacture, p. 453.

ore comes from Greece, Algeria, Italy, Sweden and other countries; but 90 per cent. of the imported ore comes from Spain, where some of the largest English companies have their own ore properties. This ore goes impartially to the north, south, east and west. Scotland gets one million tons a year; the West Coast receives an equal quantity, and both the northeast district around Middlesborough, and Glamorganshire in the southwest, receive double this amount. Table XXIII-A shows the origin of the ores imported into the Kingdom in 1882, 1886, 1890, 1895, 1899 and 1900.

Table XXIII-A.

Imports of Iron Ore into Great Britain from Different Countries.

	1882	1886	1890	1895	1899	1900
Spain	3,072,955	2,533,939	3,627.646	3,807.188	6,186.022	5,551,559
Greece	....	17,969	79,007	193 353	319 759	304,648
Algeria	91,097	201,601	205,670	162.525	231,361	141,624
Sweden	....	....	....	80,904	105,193	98,055
Italy	89,231	35,546	79,312	127,317	94,771	88,532
France	....	....	....	....	38.274	48 165
Other Countries	31,663	33,543	39,630	79.024	79,198	65,380
Total	3,284,946	2,822,598	4,031,265	4,450,311	7,054,578	6,297,963

Almost all this imported ore is transformed into acid steel either by the Bessemer or open-hearth processes. The native ores produced in the Yorkshire North Riding (the Cleveland district), in Lincolnshire, Staffordshire and elsewhere, go into basic steel, or wrought-iron, or into the general pig-iron supply. It must not be forgotten in studying the map that the distances are all small in comparison with those familiar to American conceptions. From the Scotch iron works south of Glasgow to the coal mines of Glamorganshire in South Wales is less than three hundred miles, while across the island from the steel works at Barrow to the coke fields of Durham is only seventy miles. On this account the great works in England have arranged themselves not so much with relation to their raw material as with regard to a market for their output and to subsidiary conditions. Cardiff and Glasgow bring ore across the sea to their coal beds, while Middlesborough brings the fuel to the ore, and Barrow pays freight on a part of both fuel and ore; but in each of these cases the steel works is on tidewater, a most important factor in a nation that depends on foreign trade.

In other cases there are local conditions, as in Staffordshire and South Yorkshire, where, during long years and even centuries, there have grown up industries like those of Sheffield and Birmingham that call for large quantities of steel and iron to be worked up into finished articles of commerce.

In considering the short distances covered by raw material it is necessary to remember that freight rates are much higher in England than in America. The normal charge for carrying a ton of pig-iron from South Staffordshire to London, a distance of 120 miles, is from $2.40 to $2.90, and for carrying coke 100 miles from South Durham to Cumberland the rate is $1.80 per ton.* In the United States the rate on pig-iron from Pittsburg to Philadelphia, a distance of 353 miles, is $1.77. On coke between the same points it is $1.95. It will be found that the rate on coke is considerably over three times as high as in America, while on pig-iron it is four to five times as much.

Both Scotland and Middlesborough have specialties in furnishing supplies to the great shipbuilding industries on the Clyde and on the Northeast Coast. The vessels launched in 1900 in Great Britain footed up about 1,500,000 tons, and we may make a rough estimate that this took about 500,000 tons of steel and iron. This would mean one-twelfth of all the wrought-iron and steel made in the Kingdom and the large share of this business goes to the two districts mentioned.

In Table XXIII-B is given more detailed information concerning the distribution of the iron industry in the year 1900. The statistics of steel output are taken from the report of the British Iron Trade Association, while the figures for coal, ore, blast furnaces and pig-iron are from the Home Office Reports. The tables at the end of each section giving the number of blast furnaces, converters and open-hearth furnaces, are from a supplement of the *Iron and Coal Trades Review,* issued July 5, 1901. A slight but unimportant disagreement may be found in one or two instances between the two sources of information.

In Tables XXIII-C, D and E are given the results of an inquiry into the history of the iron trade during the last twenty years. Through the courtesy of Mr. Swank, of the American Iron and Steel Association, of Philadelphia, I was able to get a file of the Home Office Reports from 1882 to 1900, with the exception of

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* Report of Commissioners of British Iron Trade Association, p. 95.

1885, and the absence of figures for that year in the following pages is thus explained. Under the separate districts I have given detailed statistics, but in the three tables just mentioned I have taken the average for four periods.

Table XXIII-B.

Production of Coal, Ore, Iron and Steel in Great Britain in 1900.

Data on Coal, Ore and Pig Iron from Home Office Reports; on Steel from British Iron Trade Association.

District.	Coal.		Ore.		Pig Iron.		Blast Furnaces.		Wrought Iron.	
	Tons.	P.c.	Tons.	P.c.	Tons.	P.c.	Total.	Active.	Tons.	P.c.
No'h Yorkshire (Cleveland)..	3,742	....	5,493,733	39	2,136,584	24	82	65	198,000	17
Durham and Northumberl'd	46,315,240	21	19,124	....	973 010	11	39	30	....	....
Scotland.......	33,112,204	14	849 031	6	1,156,885	13	102	82	206,000	18
South Wales...	39.083,973	17	29,472	....	841,528	9	68	30	....	....
So'h Yorkshire	28,246,937	13	56,944	....	290,601	3	28	18	137.000	12
West Coast.....	26,865,193	12	1,733,791	12	1,585.925	18	81	50	175 000	15
Staffordshire...	14,227.076	6	1,084,797	8	596,807	7	75	39	379,000	33
North Wales...	3,109,615	1	843	..	66,586*	1	5	4	31,000	2
Eastern Central District.......	2.106,443	1	4,298,145	31	636,653	7	47	32	....	....
Derby and Nottingham.....	23,871,544	11	2,858	....	561,626	6	54	43	36,000	3
Other parts of.. England.....	6,292,012	3	359,506	3	113,486	1	17	8	....	....
Other parts of Wales........	1,822,622	1	323	...	....	....	6	4	....	....
Ireland........	124 699	....	99,641	1	....	....	....	....	....	....
Total.......	225,181,300	100	14,028,208	100	8,959,691	100	604	405	1,162,000	100

*Output in 1899.

District.	Production of Steel.									
	Bessemer.				Open Hearth.				Bessemer and Open Hearth.	
	Acid.		Basic.		Acid.		Basic.			
	Tons.	P.c.	Tons.	P.c.	Tons.	P.c.	Tons.	P.c.	Tons.	P.c.
No'h Yorkshire (Cleveland)..	64,000	1.3	269,000	5.5	975,000	20.0	25,000	0.5	1,333,000	27
Durham and Northumberl'd	....	....	....	....	....	....	....	....	....	....
Scotland.......	....	....	....	....	960,000	19.6	3,000	....	963,000	20
South Wales....	440,000	9.0	....	....	520,000	10.6	....	....	960,000	20
So'h Yorkshire	250.000	5.1	81,000	1.6	210,000	4.3	47,000	1.0	588,000	12
West Coast.....	502,000	10.3	....	....	118,000	2.4	39,000	0.8	659,000	14
Staffordshire...	....	....	142 000	2.9	77,000	1.5	148,000	3.0	367,000	7
North Wales...	....	....	....	....	....	....	30,000	0.6	30 000	...
Total	1,256,000	25.7	492,000	10.0	2,860,000	58.4	292,000	5.9	4,900,000	100

The striking fact is hereby made plain that England in regard

TABLE XXIII-C.

Production of Pig-Iron in Great Britain; one unit=1000 Tons.

Data for 1830, 1860, 1870 and 1880 from Bell; later figures from Home Office Reports.

District.	1830.	1860.	1870.	1880.	Average 1882 to 1884 incl.	Average 1886 to 1890 incl.	Average 1891 to 1895 incl.	Average 1896 to 1900 incl.
Northeast Coast	5	659	1,627	2,416	2,666	2,642	2.638	3.194
West Coast	......	169	678	1,541	1,676	1,589	1,284	1,576
Scotland	37	937	1,206	1,049	1,081	922	826	1.128
South Wales	278	1,019	1,073	927	897	807	734	770
Eastern Central	......	8	75	386	434	505	494	641
Staffordshire	213	617	892	610	551	542	506	586
Central	18	126	180	367	435	388	417	521
South Yorkshire	29	98	78	307	291	197	213	296
Shropshire	73	145	112	88	70	50	45	10
North Wales	25	49	43	58	42	48	40	59
Others	......	...	......	......	166	69	48	108
Total	678	3,827	5,964	7,749	8,309	7,759	7,245	8,889

TABLE XXIII-D.

Production of Iron Ore in Great Britain; one unit=1000 tons.

Data for 1860, 1870 and 1880 from Bell; later figures from Home Office Reports.

District.	1860.	1870.	1880.	Average 1882 to 1884 incl.	Average 1886 to 1890 incl.	Average 1891 to 1895 incl.	Average 1896 to 1900 incl.
Northeast Coast	1,484	4,298	6 528	6,439	5,416	4,700	5,639
Eastern Central	118	1,048	2.765	2,824	2,897	2,974	4,018
West Coast	990	2,093	2,759	2,861	2,569	2,199	1,943
Staffordshire	1.543	1,378	1.798	1,898	1,341	925	1,025
Scotland.	2,150	3,500	2,664	2 172	1,226	785	887
Bristol Channel	828	865	534	314	197	160	120
Central	376	385	153	17	15	11	4
Shropshire	166	338	227	226	92	51	8
South Yorkshire	256	308	287	172	78	72	56
North Wales	85	59	43	8	1	....	1
Ireland, &c	32	99	268	253	193	178	330
Total	8,024	14,371	18,026	17,184	14,025	12,055	14,031

to her iron industry seems to be in a stationary condition. Her output of ore has decreased in the last twenty years, but is now increasing, owing mostly to the development of the lean ore beds of Eastern Central England, including Leicestershire, Lincolnshire and Northamptonshire. There has been a very decided increase in the amount of ore imported and the production of pig-iron has been thus sustained, but the second period shows a smaller product than the first, the third less than the second, and the great increase in the fourth period does not bring the output very far beyond the rate of production from 1882 to 1884.

TABLE XXIII-E.

Imports of Iron Ore into Great Britain at Different Ports.

District.	Average 1882 to 1884 incl. Tons.	Average 1886 to 1890 incl. Tons.	Average 1891 to 1895 incl. Tons.	Average 1896 to 1900 incl. Tons.
Northeast Coast	948,000	1,488,000	1,920,000	2,354,000
Bristol Channel	1,434,000	1,347.000	1,183.000	1,387,000
Scotland	382,000	575,000	694,000	1,394,000
West Coast	294,000	317,000	166,000	882,000
Others	11,000	15,000	15,000	31,000
Total	3,069,000	3,742,000	3,978,000	6,048,000

This stationary character in the total output is true of almost every district, the Eastern Central region being the only one that has increased its output of pig-iron to any notable extent. The other districts have held their own by importing more and more ore, and have maintained a remarkable regularity of tonnage, the order of precedence to-day being practically the order of twenty years ago.

In this lack of development England stands alone. By referring to the tables in Chapter XXXIII it will be found that since 1880 Russia has increased her output of pig-iron 5.66 fold, the United States 4.14, Austria-Hungary 3.13, Germany 3.09, Belgium 1.68, France 1.58, Sweden 1.30, while England in 1901 made almost exactly the same tonnage of pig-iron as she smelted in 1880. The output of steel has been increased as follows: The United States 10.80 fold, Sweden 10.35, Germany 9.62, Austria-Hungary 8.46, Belgium 4.96, Russia 4.94, France 4.03, and England 3.57. It is not my purpose to discuss the causes why England has stood still, but it is necessary to keep the plain fact in mind and to know that it is as true of each district as for the whole country.

SEC. XXIIIb.—*The Northeast Coast:*

I am indebted to Mr. Arthur Cooper, manager of the Northeastern Steel Works, for a careful reading of this section.

The Northeast Coast is the great iron and steel producing district, making more than one-third of all the pig-iron and more than one-quarter of all the steel of the Kingdom, and nearly one-fifth of all the puddled iron. Middlesborough is the center where the coke of Durham meets the ore from Spain, or from the Cleveland Hills, and the finished steel finds an outlet either in the shipyards along the Tees, or by water to other ports of the Kingdom, or of other countries. The Cleveland beds produce 40 per cent. of all the ore raised in the island. This is all smelted in the immediate neighborhood of the mines, and in the annual report of C. E. Muller & Co. of January 14, 1902, it is stated that out of a total of 79 blast furnaces in operation in the Northeast in 1901 there were 43 smelting Cleveland ore, the others presumably being on imported material. A small proportion, about one-seventh, of the Cleveland iron is converted into steel, mostly by the basic Bessemer process, but almost all of the steel made in the district is made from Spanish ore. The Cleveland deposit is not rich enough in either phosphorus or manganese to give a proper iron for the basic Bessemer, and it is necessary to add to the burden a certain proportion of other ores which are richer in these elements; consequently most of the product goes into foundry and forge pig for use both at home and abroad. The output of Middlesborough furnaces, especially those of Bell Brothers, forms the foundation of foundry practice throughout the northern part of the continent; it is often used alone, but is mixed with iron of lower phosphorus

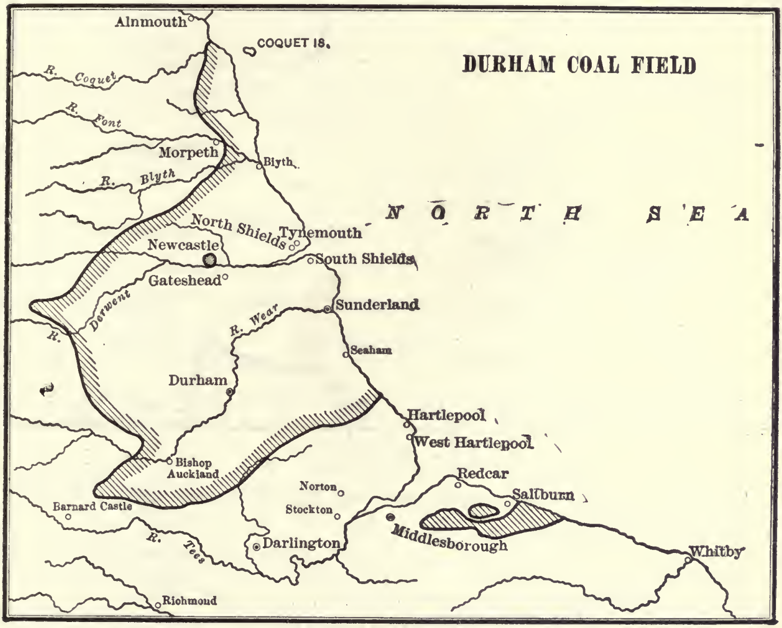

FIG. XXIII-C.

to make the better class of castings. On another page, in the discussion of the ore deposits of Lincolnshire, Leicestershire and Northamptonshire, further remarks will be made on the recent developments in the lean ore deposits of England.

Fig. XXIII-C shows the relation of the coal field of Durham to the district around Middlesborough, while Fig. XXIII-D shows the Cleveland ore deposits.*

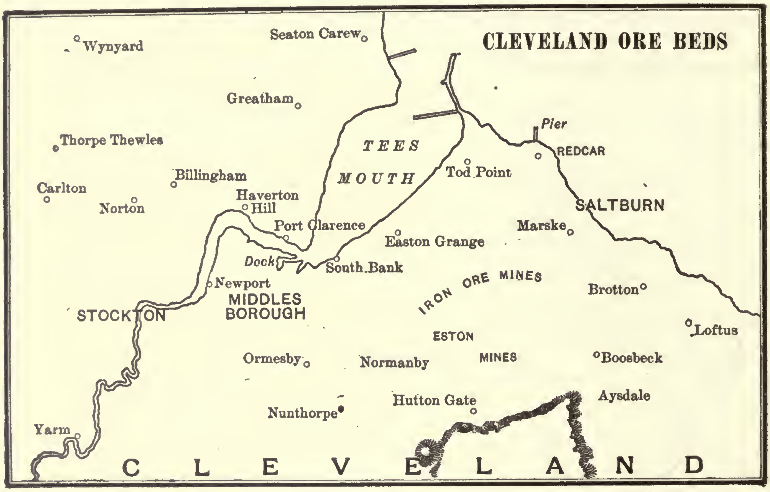

FIG. XXIII-D.

The Cleveland ore is a carbonate and the composition is given by Kirchhoff as follows:

	Per cent.
Protoxide of iron	35.37
Peroxide of iron	1.93
Protoxide of manganese	1.00
Alumina	6.95
Lime	6.63
Magnesia	3.73
Silica	10.22
Carbonic acid	22.02
Sulphur	0.10†
Phosphoric acid	1.15
Organic matter	1.20
Moisture	9.80
Total	100.10

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* These maps are taken from certain letters written by C. Kirchhoff for *The Iron Age*, of which he is editor, and he has kindly granted permission for their reproduction here. I am also indebted to the same letters for much information concerning this district

† From other sources of information I believe that the average content of sulphur is nearer 0.25.

Metallic iron	28.85
Phosphorus	0.50
Loss by calcination	29.58
Iron in calcined stone	40.96

The composition of calcined stone is given by the same writer as follows:

	Per cent.
Peroxide of iron	59.77
Oxide of manganese	0.99
Alumina	9.28
Lime	9.23
Magnesia	5.41
Silica	13.66
Sulphur	0.12
Phosphoric acid	1.41
Total	99.87
Metallic iron	41.84
Phosphorus	0.62

The ore varies considerably in different parts of the field, the above being a fair average. In many cases the content of iron is less and there is consequently a greater proportion of silica and earthy matter so that a larger quantity of fuel and stone is required. For this reason considerable differences in practice and in cost will be found between furnaces very near together in Middlesborough.

The ore deposit, at its northern edge, sometimes contains as much as 32 per cent. of iron and in exceptional cases even 33 per cent. The thickness of the bed is also greatest at this point, measuring 15 feet 7 inches at the mines of Bolckow, Vaughan & Co. Toward the south it grows thinner and at the points marked with a cross upon the map it divides into two seams of about four feet each. The quality also falls, and at the extreme outcrop at Whitby there is only 25 per cent. of metallic iron.

The ore is calcined to expel carbonic acid, and this removes also the water and organic matter, so that the roasted product contains about 40 per cent. of iron. The figures above quoted from Kirchhoff give 41.84 per cent. of iron and 13.66 per cent. of silica. Information from other sources leads me to think that the figures quoted are rather roseate and refer to the best records rather than to the average supply. I have been told that the general run of ore after calcining will carry only 40 per cent. of iron with silica up to 19 per cent.

The average selling price of this ore from 1870 to 1883 is given by Bell as $1.02 per ton at the mines, with 30 cents freight, making a total of $1.32 per ton delivered at the furnace. The value in 1899 is given in the Home Office Reports at $1.01 per ton at the mine. Counting a short haul and the cost of calcining, it can hardly be less than $1.15 per ton for a 30 per cent. ore; this is 3.83 cents per unit, and if the Cleveland pig contains 92 per cent. of iron, the cost of the ore per ton of pig will be $3.52. Kirchhoff gives the cost of the ore delivered at the furnaces of Bolckow, Vaughan as 85 cents per ton, to which must be added the cost of calcining. For a 30 per cent. ore this means a little over 3 cents per unit or about $3.00 per ton of pig-iron.

The composition of the coal from Durham varies somewhat according to the seams from which it comes, but the beds are very much alike and the coals are often mixed. The average of four samples quoted by Bell is as follows:

	Per cent.
C	80.51
H	4.49
O+N	8.03
S	1.26
Ash	5.16
Water	1.01
	100.46

The fixed carbon was 70.32 per cent. and the loss in coking is given by Bell and by Kirchhoff as usually over 40 per cent. in beehive ovens. By far the greater quantity of Durham coke is made in this type of oven, although progressive works in Middlesborough are now introducing the by-product process. Bell states that the coke runs 6.60 per cent. in ash and 0.96 per cent. in sulphur. Kirchhoff gives the detailed composition of four samples, an average of which is as follows:

	Per cent.
Carbon	88.16
Sulphur	1.11
Ash	9.33
Water	1.40
	100.00

The distance from the mines in South Durham to the furnaces in Middlesborough is from 20 to 30 miles, and the freight is about 50 cents per ton.

The coke is hard and strong and is in demand abroad, very considerable quantities being exported. Over 60 per cent. of all the coke sent abroad by England in 1900 was shipped from the Northeast Coast. There were also heavy shipments of coal, the proportion coming from this district being one-third of the total exports. As above shown, the ash in Durham coke is considerably less than is found in some other first-class cokes and this decreases to a slight extent the amount of silicious material entering the blast furnace. The amount of fuel needed for a ton of Cleveland iron is given by Bell as 1⅛ tons, and in exceptional cases it may be lower, but from information received from most excellent authority, I believe this is more often the hope than the actuality. Taking the whole campaign of the furnace and considering the amount actually paid for on board cars, there are probably few furnaces at Middlesborough getting along with less than 1¼ tons, and there are many using more. The cost of this coke is given by Kirchhoff as $1.82 to $2.20 per ton at the mines, and the cost therefore at the furnaces at Middlesborough will be from $2.30 to $2.70 per ton. The selling price is considerably above this, running from $3.15 to $3.50 per ton.

When smelting the Cleveland iron stone, the amount of limestone necessary varies with the character of the ore. Bell gives the amount needed as 1175 to 1350 pounds per ton and the cost as 80 cents per ton delivered at the furnace. The cost of stone under these conditions would be from 43 to 49 cents per ton of iron. Kirchhoff gives also about 1300 pounds of stone per ton of iron, but gives the cost of the stone at $1.20 per ton, making an item of about 70 cents per ton. My own information from authoritative sources agrees with the amount of stone above given, but Cochrane, in a detailed investigation of Cleveland practice and the use of lime, shows a consumption of about 1600 pounds. In this case, however, the ore contained only 26.9 per cent. of iron. From another source I have been given the figure of 1900 pounds of stone at a cost of $1.10 per ton of stone, representing about 95 cents per ton of pig-iron.

We may therefore estimate the cost of Cleveland pig-iron for those who own their own coal mines and ore beds, counting nothing for the money invested, and also the cost for those who do not own their own supplies.

Per ton Pig-Iron.	Minimum. Complete. ownership.	Fair practice. Market prices.
Fuel 1⅛ tons @2.40	$2.70	
" 1¼ tons @3.30		$4.10
Stone 1300 lbs.	.70	.95
Ore	3.00	3.50
	$6.40	$8.55

If we add to these items 60 cents for labor and 25 cents for supplies, which are figures given by Kirchhoff, we have a total of $7.25 for the best managed and best equipped plants owning their own coal and ore mines, and $9.40 for other plants buying their raw material and using somewhat more fuel. There are still other works which show a considerably higher cost. In these totals are not included the item of general expenses and administration, and it does not include the interest and depreciation account, so that they by no means represent the actual cost of making pig-iron in Cleveland. They may, however, be compared with many similar calculations where the cost of pig-iron in different localities is confidently predicted, as in such cases these latter items are always ignored. It may also be pertinent to the question to record that the selling price of Cleveland iron in the winter of 1900-01 was $11.20 per ton, and there is no reason to suppose that money was lost in the transaction.

Thus it is quite clear that Cleveland iron can be made cheaply, but it is also true that it is an undesirable metal. It contains so much phosphorus that it is hard to use in a basic open-hearth furnace, although it is perfectly certain that it can be so used. On the other hand it contains so little phosphorus that it is not well fitted for the basic Bessemer. In order to get iron for the basic converter it has been customary to enrich the phosphorus content by adding a certain proportion of puddle cinder, and to raise the manganese by using manganiferous imported ores. With the diminution of the supply of puddle cinder it is necessary to use a certain amount of basic converter slag in the blast furnaces, and no matter what the mixture may be, the silicon must be kept low, thus requiring a very large amount of lime to flux the high silica in the ore. Taking everything together, the cost of making iron fit for the basic converter is given by Kirchhoff at from $1.00 to $1.50 per ton above the figures just recorded for the ordinary product. For open-hearth work the manganese is not necessary and the phosphorus an injury. It would seem therefore as if a cheap iron could be made for this purpose, while the phosphorus might be lessened if necessary by mixing with foreign ores.

The price of Spanish ore in the winter of 1900-01 was about $2.61 at Bilbao, with the low ocean freight of $1.03, making a total of $3.64 per ton at Middlesborough. As the ore contains about 49 per cent. of iron this gives a cost of 7.43 cents per unit, or about $7.06 per ton of iron. The assumption that the ore contains only 49 per cent. of iron may seem rather pessimistic, but the decrease in the quality of the Spanish ores has been a serious matter. This subject was discussed in the presidential address of William Whitwell before the Iron and Steel Institute, and he gave the composition of Rubio ores as imported at Middlesborough in 1890 and 1900. The comparison is as follows:

	1890	1900
Fe dry	55.50	52.80
Water	9.00	9.10
Fe as received	50.50	47.99
Silica	7.10	10.09

The ocean freight on ore is usually 30 cents higher than the figures just given, which would make the ore cost $3.94 per ton, or a trifle over 8 cents per unit, or about $7.60 per ton of iron. The silica in this ore runs about one-half as high as in the Cleveland stone, and the quantity of limestone needed is much less, and the amount of fuel will be about 0.95 tons per ton of pig-iron. The cost therefore of the ore, fuel and stone for a ton of hematite pig-iron will be as follows:

	Low freight.	Usual freight.
Ore	$7.06	$7.60
Coke	2.66	2.66
Stone (about)	.50	.50
	$10.22	$10.76

Adding to this the same amount for labor and supplies as in the case of Cleveland iron, viz., 85 cents, we have the cost of hematite iron from $11.10 to $11.60, not reckoning the items of general expense or interest. In the winter of 1900-01 the selling price was about $13.85 per ton.

The most important steel works on the Northeast Coast are given in Table XXIII-F. The works of Bell Brothers have not been large producers of steel in the past, but they have lately put in an extensive open-hearth plant. Fig. XXIII-E shows a plan

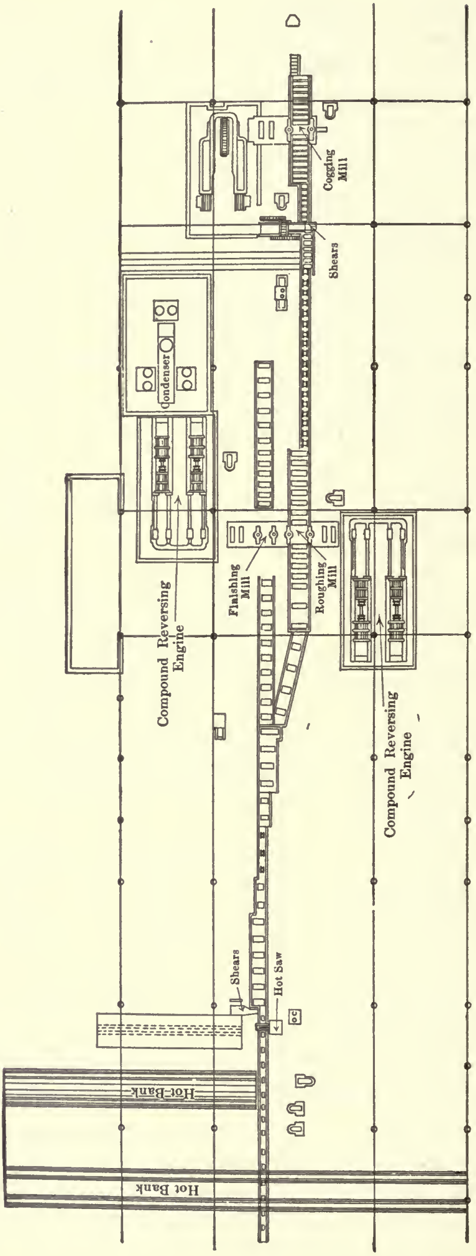

FIG. XXIII-E.—WORKS OF THE NORTHEASTERN STEEL CO., LIM., AT MIDDLESBOROUGH.

of the works of the Northeastern Steel Company, at Middlesborough. In Tables XXIII-G and H are given data concerning the industrial history of the district.

TABLE XXIII-F.

Iron and Steel Plants on the Northeast Coast.

Name of Works.	Location.	Blast Furnaces.	Bessemer Converters.		Open Hearth Furnaces.	
			Acid.	Basic.	Acid.	Basic.
Bolckow, Vaughn & Co.	Middlesbro'.	30	4	6	10	......
North Eastern Steel Co.	"	4	......	4	......	......
Consett Iron Co	Durham	7	......	......	27	......
Britannia and West Marsh	Middlesbro'	......	......	......	11	......
Tudhoe	Spennymoor	......	......	......	10	......
Palmers Shipbuilding Co.	Jarrow on Tyne.	5	......	......	8	......
South Durham Co., 3 Works.	......	......	......	......	23	......
Armstrong, Whitworth & Co. (Elswick)	Newcastle	......	......	......	6	2
Bell Brothers (Clarence)	......	12	......	......	......	6
Darlington Forge	......	......	......	......	4	......
Sir B. Samuelson & Co.	......	8	......	......	......	......
Edw. Williams	......	6	......	......	......	......
Others	......	51	......	......	8	......
Total	......	123	4	10	107	8

TABLE XXIII-G.

Production of Ore and Pig-Iron and Imports of Ore on the Northeast Coast.

See also Tables XXIII-C and XXIII-D for data before 1882.

Year.	Ore Raised.			Ore Imported.	Pig Iron.			
	North Yorkshire.	Durham.	Total.		North Yorkshire.	Durham.	Northumberland.	Total.
1882..	6,326,314	83,726	6,410.040	1,098,000	1,803,508	815,671	93,422	2,712,601
1883..	6,756,055	50,248	6,806,303	951,000	1,867,329	823,659	88,535	2,779,523
1884..	6,052,608	49,091	6,101,699	795,000	1,725,823	779,131*	....	2,504,954
1885..	....	....	....	834,000	....	....	....	....
1886..	5,370,279	1,759	5,372,038	1,015,000	1,735,885	700,836*	....	2,436.721
1887..	4,980,421	2,506	4,982,927	1,475,000	1,841,444	682,797*	....	2,524,241
1888..	5,395,942	40,233	5,436,175	1,426,000	1,856,274	774,984*	....	2,631,258
1889..	5,657,118	3,991	5,661,109	1,660,000	1,915,050	802,267	65,149	2,782,466
1890..	5,617,573	11,488	5,629,061	1,864,000	1,961,328	792,932	83,339	2,837,599
1891..	5,128,303	7,715	5,136,018	1,569,000	1 769,492	814,875	46,816	2,631,183
1892..	3,411,400	9,275	3,420,675	1,522,000	1,333,656	610,892*	....	1,944,548
1893..	4,625,520	....	4,625,520	2,061,000	1,943,404	770,510*	....	2,713,914
1894..	5,048,966	2,679	5,051,645	2,410,000	2,088,299	885,568*	....	2,973,867
1895..	5,285,617	19,064	5,304,681	2,037,000	2.058,279	867,878*	....	2,926 157
1896..	5,678,368	19,277	5,697,645	2,360,000	2,209,074	1,002,852*	....	3,211,926
1897..	5,679,153	16,852	5,696,005	2,337,000	2,134,507	1,063,134*	....	3,197,641
1898..	5,730,413	20,868	5,751,281	2.283,000	2,095,131	1,103,495*	....	3,198,626
1899..	5,612,742	16,960	5,629,702	2.457,000	2.211,222	1,040,174*	....	3,251,396
1900..	5,493.733	19,046	5,512,779	2,330,000	2,136,584	973,010*	....	3,109,594

*Including Northumberland.

TABLE XXIII-H.

Imports of Iron Ore at Ports on the Northeast Coast.

Year.	Middlesborough.	Newcastle.	North and South Shields.	Stockton.	Hartlepool.	Sunderland.	Others.	**Total.**
1882..	498,000	307,000	82,000	114,000	11,000	64,000	22,000	1,098,000
1883..	444,000	295,000	39,000	56,000	30,000	79,000	8,000	951,000
1884..	398,000	179,000	42,000	64,000	64,000	47,000	1,000	795,000
1885..	397,000	179,000	53,000	69,000	58,000	77,000	1,000	834,000
1886..	507,000	240,000	38,000	89,000	76,000	64,000	1,000	1,015,000
1887..	844,000	276,000	48,000	116,000	113,000	69,000	9,000	1,475,000
1888..	724,000	357,000	21,000	116,000	104,000	95,000	9,000	1,426,000
1889..	855,000	374,000	25,000	125,000	181,000	97,000	3,000	1.660,000
1890..	947,000	513,000	80,000	129,000	147,000	47,000	1,000	1,864,000
1891..	778,000	388,000	58,000	148,000	126,000	71,000	....	1,569,000
1892..	886,000	242,000	86,000	123,000	111,000	74,000	....	1,522,000
1893..	1,269,000	268,000	89.000	251,000	90,000	94,000	....	2,061,000
1894..	1,444,000	385,000	149,000	237,000	86,000	108,000	1,000	2,410.000
1895..	1.273,000	358,000	154,000	164,000	46,000	42,000	....	2,037,000
1896..	1,391,000	345,000	218,000	190,000	120,000	94,000	2,000	2,360,000
1897..	1,193,000	319,000	413,000	235,000	94,000	81,000	2,000	2.337,000
1898..	1,103,000	325.000	352,000	252,000	178,000	67,000	6,000	2,283,000
1899..	1,334,000	300,000	377,000	206,000	151,000	87,000	2,000	2,457,000
1900..	1,251,000	252,000	402,000	258,000	116,000	49,000	2,000	2,330,000

SEC. XXIIIc.—*Scotland (Ayrshire and Lanarkshire):*

I am indebted to Mr. James Riley, formerly general manager of the Steel Company of Scotland and of the Glasgow Iron and Steel Company, for a careful review of this section.

The iron industry of Scotland dates back about one hundred and fifty years, and has played an important part for half a century. It was well along in the last century before there was any appreciation or knowledge of the value of the blackband from the coal measures which at that time existed in great quantities throughout Ayrshire and Lanarkshire. This blackband was roasted and gave an ore making 63 per cent. of pig-iron, and it was raised very near the furnaces. In 1870 Scotland produced 3,500,000 tons of ore, but in 1880 this had dropped to 2,660,000 tons. Half of this was blackband, but the price had risen to $3.60 per ton at the pit. In 1900 only 597,826 tons of ore were raised from the coal measures, the price being officially given as about $2.40 per ton at the pit mouth, and this constituted 70 per cent. of all the ore raised in Scotland.

The ore production in 1900 was less than 6 per cent. of the total for the Kingdom, while in 1870 it was about 25 per cent. The figures given on the map refer only to the counties of Ayr and Lanark, which produce two-thirds of all the coal and ore mined in Scotland, and smelt practically all the pig-iron, but in the tables I have used the totals for Southern Scotland.

The pig-iron industry, in spite of the disappearance of the blackband and the importation of foreign ores to take its place, still retains a distinctive characteristic in the use of raw so-called "splint" coal in the blast furnace. The composition of good Lanark coal is as follows:

	Per cent.
C	66.00
H	4.34
O+N	12.03
S	0.59
Ash	5.42
Water	11.62
	100.00
Fixed carbon	53.4

This coal when charged in a raw state into the furnace will not fuse and get sticky, provided the furnace is not more than 70 feet high. The heating value of this coal is only about 80 per cent. of Durham coal, but counting the loss of fuel value in the coking process, there is a slight advantage, ton for ton, in the Scotch coal charged in the furnace over the Durham coal, which must first be coked. When using this raw coal the furnace gases contain quite a quantity of hydrocarbons, and it is found profitable to put up scrubbers and collect the tar and ammonia before the gas passes to the boilers and stoves. The best beds of Lanarkshire coal are approaching exhaustion, and recently some plants have experimented in the making of a poor coke from the local coal and using it as a mixture with the inferior splint coals, but this practice seems to make no progress. A very considerable amount of coke is made in the Kilsyth district, but this is used for foundry purposes. The district of Ayrshire and Lanarkshire produces 9 per cent. of all the coal raised in the Kingdom, and exports large quantities. In spite of the great decrease in the supply of native ore, the production of pig-iron has been sustained by the use of Spanish ores, but there has been very little increase, the amount smelted having remained nearly constant during the last forty years. This statement concerning the stationary production of the district was questioned by Mr. Riley, and I therefore append the statistics in Table XXIII-I; the figures prior to 1885 are taken from a paper by Mr. Riley,* and the later data from the Home Office Reports.

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* *Jour. I. and S. I.*, 1885.

TABLE XXIII-I.

Production of Pig-Iron in Scotland.

Period. Inclusive.	Production per year. Tons.
1861 to 1865	1,122,600
1866 to 1870	1,089,800
1871 to 1875	1,021,600
1876 to 1880	993,600
1881 to 1885	1,084,400
1886 to 1890	922,217
1891 to 1895	826,128
1896 to 1900	1,128,161

Scotland now makes 12 per cent. of the pig-iron and 20 per cent. of the steel made in the Kingdom. As before stated, most of the ore is imported from Spain, and the pig-iron is used on the spot to make acid open-hearth steel for shipbuilding and other purposes.

TABLE XXIII-J.

Iron and Steel Plants in Scotland (Ayrshire and Lanarkshire).

Name of Works.	Location.	Blast Furnaces.	Bessemer Converters.	Open Hearth Furnaces.	
			Basic.	Acid.	Basic.
Steel Co. of Scotland	Newton Glasgow			30	1
David Colville & Sons (Dalzell)	Motherwell			18	
Parkhead Forge	Glasgow			6	
Glasgow I. and S. Co.	Wishaw	4		12	
Lanarkshire	Flemington			8	
Glengarnock	Ayrshire	12	4–10 tons	3	
Clydebridge	Cambuslang			9	
Clydesdale	Mossend			9	
Summerlee & Mossend Co.	Mossend	7		8	
Other open hearth plants				8	
Wm. Baird & Co.	Scattered	26			
Coltness Iron Co.	Coltness	9			
Wm. Dixon	Scattered	11			
Others		26			
Total		95	4	111	1

Scotland makes only a small amount of Bessemer steel and hardly any basic open-hearth, but she makes as much acid open-hearth steel as Cleveland, each of them making one-third of all that kind of metal made in Great Britain. Table XXIII-J gives a list of the principal plants in Scotland. Most of the steel plants make plates and miscellaneous structural bars. In Tables XXIII-K and L are given certain items of statistical information; the importations of ore come mostly to ports on the western shore, but a considerable quantity is brought to Grangemouth and other ports on the Firth of Forth.

TABLE XXIII-K.

Production of Ore and Pig-Iron and Imports of Ore in Scotland.

See also Tables XXIII-C and XXIII-D for data before 1882.

Year.	Ore.		Pig Iron.		
	Raised.	Imported.	Ayr.	Lanark.	Total.
1882	2,404,177	385,000	350,423	775,577	1,126,000
1883	2,228,851	356,000	356,751	772,249	1,129,000
1884	1,883,158	406,000	292,287	695,713	988,000
1885	...	487,000	...	...	...
1886	1,506,731	418,000	301,464	634,337	935,801
1887	1,321,899	545,000	301,652	630‘588	932,240
1888	1,238,597	552,000	320,374	707,400	1,027,774
1889	1,061,734	647,000	320,654	657,549	978,203
1890	998,835	714,000	240,848	496,218	737,066
1891	748,336	360,000	201,063	473,013	674,076
1892	872,435	840,000	276,788	695,705	972,493
1893	847,406	654,000	246,939	546,116	793,055
1894	631,304	598,000	182,546	459,697	642,243
1895	824,673	1,020,000	326,454	722,320	1,048,774
1896	983,670	1,296,000	360,247	753,791	1,114,038
1897	936,850	1,403,000	369,836	766,671	1,136,507
1898	824,219	1,444,000	314,302	748,245	1,062,547
1899	843,585	1,456,000	345,488	825,342	1,170,830
1900	849,031	1,372,000	376,498	780,387	1,156,885

TABLE XXIII-L.

Imports of Iron Ore at Ports in Scotland.

Year.	Glasgow.	Ardrossan.	Ayr.	Troon.	Others.	Total.
1882	251,000	55,000	9,000	14,000	56.000	385,000
1883	280,000	25,000	7,000	2,000	42,000	356,000
1884	265,000	40,000	9,000	3,000	89,000	406.000
1885	292,000	15,000	29.000	5,000	146.000	487 000
1886	246,000	8,000	23,000	2,000	139.000	418,000
1887	303 000	15,000	34.000	6,000	187,000	545,000
1888	323,000	38,000	17.000	2,000	172,000	552,000
1889	358,000	43,000	44,000	11,000	191,000	647,000
1890	330,000	60,000	91,000	31,000	202,000	714,000
1891	241.000	17,000	36,000	4,000	62,000	360,000
1892	516,000	114,000	59,000	31,000	120.000	840,000
1893	355,000	149,000	59,000	42,000	49.000	654,000
1894	302,000	171,000	36,000	31,000	58,000	598,000
1895	521,000	252,000	80,000	51,000	116,000	1,020,000
1896	589,000	410,000	96,000	77,000	124,000	1,296,000
1897	730,000	438.000	100,000	52,000	83,000	1,403,000
1898	655,000	487,000	152,000	71.000	79.000	1,444,000
1899	730,000	402,000	112,000	102.000	110,000	1,456.000
1900	698,000	372,000	92,000	117,000	93,000	1,372,000

Sec. XXIIId.—*South Wales:*

In this district I have included Glamorganshire and the English counties of Monmouth and Gloucester. It is in the latter that we find the ancient district still bearing the title of the Forest of Dean, which was once famous as an iron district, but which, in 1900, produced only 9885 tons of ore, no pig-iron being made in its borders.

The iron industry of South Wales was founded on a local supply of lean clay band running about 30 per cent. in iron. In 1860 the above mentioned counties, together with two or three neighboring ones that are no longer producers, raised 830,000 tons of ore and in 1870 the amount was a trifle larger. From then the production rapidly decreased, being only about half as much in 1880, while now it is a negligible quantity. The production of pig-iron has remained nearly stationary from 1860 until now. Before the local ores failed the hematites of the West Coast were brought in, and then by almost providential dispensation the mines of Northern Spain were developed, and from that time South Wales has run almost exclusively on this imported supply.

In former times the coal from certain districts at works near Merthyr was used directly in the furnace in the same way as in Scotland, but this practice has been discarded and a somewhat richer coal is now coked. The volatile matter in this coal is rather low, running from 16 to 22 per cent., and some seams contain 30 per cent. of ash, but, by washing, this may be reduced so that the coke contains only about 10 per cent. and very good results are obtained. The Spanish hematites imported at Cardiff in 1899 contained only about 50 per cent. of iron and from 7 to 14 per cent. of silica, but they were smelted with about one ton of coke per ton of iron. Some of the older iron works are situated in the interior, a legacy from ancient times, but new plants are being placed on tidewater, thus reducing the freight on both raw material and finished product.

The northern shore of the Bristol Channel produced almost exactly the same quantity of steel in 1900 as Scotland. Unlike Scotland, half of the output is Bessemer, but like Scotland, it is all acid, both Bessemer and open-hearth. This district in 1900 raised 17 per cent. of all the coal mined in the island and furnished 42 per cent. of all the coal exported from the Kingdom, and 11 per cent. of all the export coke. It made about 9 per cent.

of all the pig-iron and 20 per cent. of all the steel. The amount of puddled iron made is very small. This arises from the fact that there are no cheap native ores and it does not pay to put iron from Spanish ores into puddled bar.

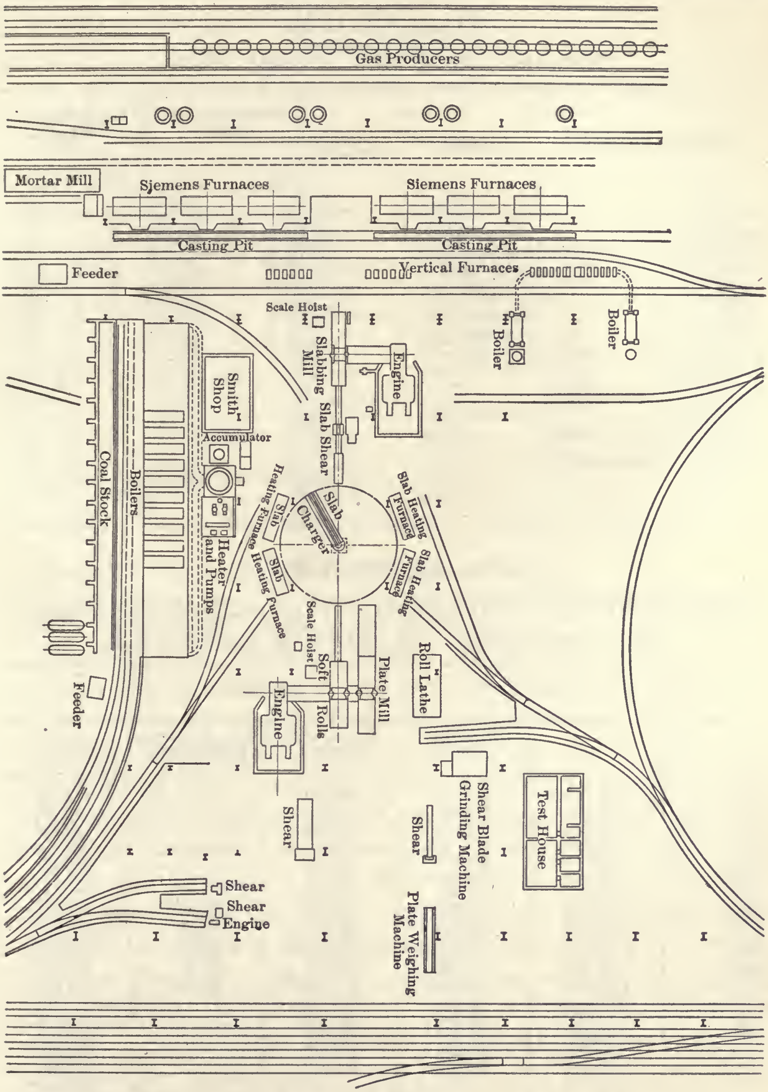

FIG. XXIII-F.—DOWLAIS WORKS, CARDIFF, WALES.

Fig. XXIII-F shows a ground plan of the new open-hearth plant and plate mill of the Dowlais Iron Company at Cardiff, this being

TABLE XXIII-M.

Iron and Steel Plants in South Wales.

Name of Works.	Location.	Blast Furnaces.	Bessemer Converters.		Open Hearth Furnaces.	
			Acid.	Basic.	Acid.	Basic.
Blaenavon Iron Co........	Blaenavon.....	9	2	....	2	....
Crawshay Bros. (Cyfarthfa)	Merthyr Tydfil	9	4	....	....	....
Ebby Vale S. and I. Co....	Ebby Vale.....	6	6	....	2	....
Guest Keen & Co., formerly Dowlais Iron Co ..	Dowlais........	19	6	....	8	....
	Cardiff. ...			....	6	....
Nettlefolds	Newport.......	....	2	....	....	....
Tredegar.................	Tredegar.......	5	2	....	....	....
Elba & Panteg..............	Swansea	....	....	....	8	....
Swansea Hem...............	Landore.........	2	....	....	5	....
Briton Ferry...............	....	2	....	....	6	....
Pontardawe Steel Works..	....	....	....	....	5	....
Upper Forest...............	Morriston......	....	....	....	5	....
Other open hearth plants..	....	....	....	....	37	....
Ryhmney Iron Co.........	....	9	....	....	....	....
Other blast furnace plants.	....	8	....	....	....	....
Total	....	69	....	....	84	....

TABLE XXIII-N.

Production of Pig-Iron and Imports of Ore on the Bristol Channel.

See also Tables XXIII-C and XXIII-D for data before 1882.

Year.	Ore Imported.	Pig Iron.			
		Glamorganshire.	Monmouthshire.	Gloucestershire and Wiltshire.	Total.
1882........	1,481,000	404,350	530,084	....	934,434
1883........	1,575,000	384,128	522,135	....	906,263
1884........	1.247,000	378,275	473.116	....	851,391
1885........	1.275,000	....	....	....	....
1886........	1,134,000	268.828	397,768	....	666,596
1887........	1,335,000	310,000	457,448	....	767,448
1888........	1,342,000	424,681	446,259	....	870,940
1889........	1,447,000	426,854	399.538	38,109	864,501
1890........	1,478,000	416,874	407,848	39,104	863,826
1891........	1,091.000	424,533	336,033	37,944	798,510
1892....	1,170 000	420,710	263,297	34,643	718,650
1893........	1,164.000	444,356	236,089	34,373	714,818
1894........	1,268,000	454,363	254,551	25,459	734,373
1895........	1,221,000	447,715	256,961	....	704,676
1896........	1,297,000	464,486	315,935	....	780,421
1897........	1,554,000	470,443	334,373	....	804,816
1898........	910,000	319,280	176,035	....	495,315
1899........	1,704 000	578,741	350,674	....	929,415
1900........	1,471,000	....	....	....	841,528*

*In the statistics of the Home Office for 1900 the product of Glamorganshire is combined with Denbigh, and Monmouth with Flint, both of which combinations are questionable. To get the total for 1900 I have subtracted the output of Denbigh and Flint for 1899 from the total given for 1900.

one of the best arranged plants in Great Britain. Table XXIII-M gives a list of the principal plants in the district, and Tables XXIII-N and O give certain statistics.

TABLE XXIII-O.

Imports of Iron Ore at Ports on the Bristol Channel.

Year.	Cardiff.	Newport.	Swansea.	Others.	Total.
1882	599,000	738,000	144,000	....	1,481,000
1883	656,000	749,000	170,000	....	1,575,000
1884	481,000	627,000	139,000	....	1,247,000
1885	440,000	673,000	159,000	3,000	1,275,000
1886	443,000	571,000	113,000	7,000	1,134,000
1887	472,000	742,000	112,000	9,000	1,335,000
1888	544,000	694,000	104,000	....	1,342,000
1889	633,000	678,000	135,000	1,000	1,447,000
1890	547,000	778,000	151,000	2,000	1,478,000
1891	486,000	469,000	135,000	1,000	1,091,000
1892	583,000	439,000	146,000	2,000	1,170,000
1893	644,000	377,000	137,000	6,000	1,164,000
1894	640,000	448,000	178,000	2,000	1,268,000
1895	653,000	415,000	152,000	1,000	1,221,000
1896	655,000	453,000	189,000	....	1,297,000
1897	723,000	620,000	210,000	1,000	1,554,000
1898	478,000	247,000	185,000	....	910,000
1890	832,000	619,000	251,000	2,000	1,704,000
1900	780,000	435,000	255,000	1,000	1,471,000

SEC. XXIIIe.—*Lancashire and Cumberland:*

I am indebted to Mr. J. M. While, general manager of the Barrow Works, for reading the manuscript relating to this district.

The county of Lancaster reaches across Morecambe Bay and includes Barrow-in-Furness and the Barrow Steel Works. It is in this detached portion of Lancashire and the neighboring portion of Cumberland that all the ore is raised and a great part of the iron and steel made. It is the custom, however, to keep the records by geographical rather than by natural lines, and the output of Barrow-in-Furness is combined with the output of South Lancashire and sometimes with that of Derby. This last named county produces no ore, but its output of both coal and pig-iron is about two-thirds as much as Lancashire. The figures on the map therefore give a somewhat wrong impression, as it would naturally be inferred that the ore of Lancashire was produced in the southern portion. The enclosure is so placed to indicate the seat of the iron manufacture in that part of the county and in Derbyshire. In Table XXIII-B the county of Derby is joined to Nottingham to make a separate district.

The especial feature of Cumberland and Northwest Lancashire is the deposit of what is known as West Coast hematites. Up to 1830 these beds were little known and no pig-iron was smelted in either Cumberland or Lancashire. In 1854 the production of ore was 579,000 tons, but this was sent to South Wales and South Staffordshire. In 1860 the output had increased to 990,000, in 1870 it was 2,093,000, and in 1880 it reached 2,759,000 tons. With this great development of the ore beds, blast furnaces sprang up both in Cumberland and Northwest Lancashire, and in 1860 there were 169,000 tons of pig-iron smelted. In 1870 this had increased to 678,000 tons, while in 1880 the record was 1,541,000 tons. It will be found that in 1880 the amount of ore mined in these two counties, which as above stated was 2,759,000 tons, is just sufficient to account for the production of 1,541,000 tons of pig-iron, since the ore contained about 54 per cent. of metal; so that although there were over 3,000,000 tons of foreign ore unloaded that year at British ports, it would not seem as if foreign ore was needed in this vicinity. Nevertheless the Home Office Reports for 1882 show that some 300,000 tons were imported on the West Coast. One-third of this came to Chester and Liverpool and hence need not be considered as directly competing with the local ore, but another third was unloaded at Fleetwood, just across the bay from Barrow, while one-third was taken to Barrow, Workington, Whitehaven and Maryport, on the very borders of the ore region.

It was at this time that these hematites were a most important factor in the iron industry. A large quantity of the pig-iron was exported, much of it to America, its low phosphorus content, often about .04 per cent., rendering it especially valuable for acid Bessemer work. That day has passed away and the deposits are thinning out. In 1900 there were only 1,733,791 tons of ore mined, or only five-eighths of the output in 1880. The pig-iron production in the two counties is maintained by the use of Spanish ores. The coke is brought from Durham, a distance of from 60 to 100 miles, or from West Yorkshire.

The supply of ore at one mine has been prolonged by building a sea wall through an arm of a bay and pumping the pond dry. The success of this undertaking led to a larger project along the same line when the newly won territory showed signs of exhaustion. The value of the iron ore is given in the Home Office Reports as $3.95 per ton for a 51 per cent. ore, equal to 7.74 cents per unit, and at this rate the ore will cost $7.35 for each ton of pig-iron containing 95 per cent. of iron. This does not include the transportation from mine to furnace. It must also be noted that the Home Office Reports for 1899 gave the metallic content of the ore as 53 per cent. on the average, while the figure for 1900 is about 51 per cent. The value per ton however is given at a higher figure in 1900, notwithstanding the poorer quality.

The two counties of Lancaster and Cumberland in the year 1900 produced 26,865,193 tons of coal, or about 12 per cent. of the total, almost all of this coming from Lancashire. The production of pig-iron was 1,585,925 tons, or about 18 per cent. of the total, while the steel constituted 14 per cent. of the outturn of the Kingdom. There were also produced 175,000 tons of puddled bar, being 15 per cent. of the total output of the Kingdom. Almost all of this was made in Lancashire.

Table XXIII-P.

Iron and Steel Plants in Cumberland and Lancashire.

Name of Works.	Location.	Blast Furnaces.	Bessemer Converters.		Open Hearth Furnaces.	
			Acid.	Basic.	Acid.	Basic.
Barrow Hem. S. Co.	Barrow in Furness	12	4		7	
London & Northwestern.	Crewe		4		10	
Moss Bay	Workington	4	3			
Cammell, Chas., & Co.	Workington					
Bolton I. & S. Co	Bolton				5	
Wigan C. & I. Co	Wigan	10				6
Salford	Manchester				2	
Millom & Askam Co.	Askham	9				
Carnforth Hem.I. & S.Co.		4				
N'rth Lonsdale I. & S. Co.		4				
Cammell & Co.	Derwent Solway	8				
N'rthwest'rn H.I.& S. Co.		5				
Others		25				
Total		81			24	6

The principal plants are given in Table XXIII-P, the Barrow Works being in Northwest Lancashire, in Barrow-in-Furness, and the other large works in Cumberland. The furnaces of Millom and Askam Company make iron for the open market, and one of them, started in August, 1901, is built on the most modern American lines.

Tables XXIII-Q and R give statistics concerning this district. The imports of ore at Chester, Liverpool and Manchester are grouped separately, as these ports supply quite a different region from the northern points. It is likely that a considerable proportion of the imports at these more southern harbors goes to furnaces outside of Lancashire.

TABLE XXIII-Q.

Production of Ore and Pig-Iron and Imports of Ore on the West Coast.

See also Tables XXIII-C and XXIII-D for data before 1882.

Year.	Ore Raised.			Ore Imported.	Pig Iron.		
	Cumberland.	Lancashire.	Total.		Cumberland.	Lancashire.	Total.
1882..	1,726,235	1,410,116	3,136,351	302,000	790,999	1,001,181	1.792,180
1883..	1,478,062	1,372,815	2 850 877	302,000	796,770	876,445	1.673,215
1884..	1,358,090	1,237,285	2,595,375	279.000	715,328	845.792	1,561.120
1885..	....	....	......	223,000	....	....	....
1886..	1,261,655	1,216,193	2,477,848	308.000	695,048	715.228	1.410.276
1887..	1.480,553	1.192.467	2,673.020	368,000	755,441	945,258	1.700,699
1888..	1,573,804	1.106.013	2,679,817	232.000	745,740	854,238	1.599.978
1889..	1,594,461	1,021.990	2,616,451	272,000	761,748	900,433	1,662.181
1890..	1.431,159	968.467	2.399.626	404.000	737,026	832.614	1,569 640
1891:	1,417,860	977,130	2,394.990	148,000	715.305	724,750	1.440.055
1892..	1,355,007	845 395	2,200.402	237,000	593,245	605.478	1.198.723
1893..	1,352.410	876.672	2.229.082	180,000	584,401	713,052	1,297,453
1894..	1 286.590	870,617	2.157.207	122.000	606,899	688.744	1.295 643
1895..	1 215,410	798,325	2.013.735	143,000	540.298	648,740	1,189,038
1896..	1 279.558	816.570	2.096.128	458.000	680,001	771,420	1,451,421
1897..	1.294,160	783.427	2 077,587	643,000	706.893	819,475	1,526.368
1898..	1,251.764	749,427	2,001.191	806.000	732,853	886,210	1.619,063
1899..	1,137.750	670,924	1.808,674	1.402.000	744,065	954.637	1,698.702
1900..	1,103,430	630,361	1,733,791	1,102,000	729,074	856,851	1,585.925

TABLE XXIII-R.

Imports of Iron Ore at Ports on the West Coast.

Year.	Barrow.	Maryport.	Workington.	Chester, Liverpool, and Manchester.	Others.	Total.
1882....	26.000	13 000	51,000	97,000	115.000	302.000
1883....	5.000	6.000	41,000	129.000	121,000	302.000
1884 ..	....	12,000	27,000	141.000	99.000	279,000
1885....	10,000	27,000	25.000	138,000	23,000	223,000
1886....	21,000	60.000	35,000	156.000	36 000	308,000
1887....	9,000	125.000	48,000	151,000	35,000	368.000
1888....	19,000	126.000	12,000	56,000	19,000	232,000
1889....	21,000	113.000	14,000	111,000	13.000	272.000
1890....	99,000	185.000	7,000	88,000	25.000	404.000
1891....	27.000	61.000	1,000	51.000	8.000	148.000
1892....	47.000	75,000	....	105.000	10.000	237.000
1893....	24,000	67.000	....	85.000	4,000	180 000
1894....	16,000	55,000	....	46.000	5,000	122.000
1895....	33,000	61.000	15,000	32,000	2,000	143,000
1896....	154,000	188,000	37,000	68.000	11.000	458,000
1897....	126,000	381.000	44.000	81.000	11.000	643 000
1898....	203,000	357,000	118.000	83.000	45.000	806.000
1899....	450,000	523.000	219.000	103,000	107,000	1,402 000
1900....	304,000	482,000	145,000	70.000	101,000	1.102.000

Sec. XXIIIf.—*South Yorkshire:*

The district of South and West Yorkshire includes the historic iron works of Bradford, Leeds and Sheffield. It has never been a great producer of iron ore or of pig-iron, but the town of Sheffield was known five hundred years ago as a maker of steel, and it was here that the crucible process had its birth. The present importance of the district comes from the old established works and the subsidiary steel-using establishments and finishing mills that have grown up around some of the landmarks of the iron trade.

Table XXIII-S.

Iron and Steel Plants in South Yorkshire.

Name of Works.	Location.	Blast Furnaces.	Bessemer Converters.		Open Hearth Furnaces.	
			Acid.	Basic.	Acid.	Basic.
Brown, Bayley & Co., Attercliffe.	Sheffield..	....	2	....	4	....
Bessemer, H., & Co., Bessemer	" ..	....	2	....	2	....
Fox, Samuel, & Co....	" ..	....	2	....	....	....
Steel, Peach & Tozer, Phœnix.....	" ..	....	2	....	3	....
Cammell & Co., Cyclops	" ..	....	....	....	6	....
Scott, Walter, Leeds Steel Works..	Leeds......	3	....	4	....	....
Parkgate Iron Co................	Sheffield...	5	....	....	1	5
Brown, J., & Co., Atlas...........	" ...	3	....	....	5	....
Firth & Sons, Norfolk	" ...	....	....	....	4	....
Vickers, Sons & Maxim..........	" ...	....	....	....	4	....
Hadfield St. Fdy Co...............	" ...	....	....	....	3	....
Others..........................	....	....	....	....	7	....
W. Yorkshire Iron and Coal Co....	....	5	....	....	....	....
Lowmoor Co.....................	....	4	....	....	....	....
Others..........................	....	6	....	....	....	....
Total..........................	....	26	....	..... .	39	5

Table XXIII-T.

Production of Pig-Iron in South Yorkshire (Sheffield.)

See also Tables XXIII-C and XXIII-D for data on ore production, and for years before 1882.

Year.	Output.	Year.	Output	Year.	Output.	Year.	Output
1882.....	321,430	1887......	178.455	1892......	261.537	1897......	294.846
1883......	304,381	1888.....	190.846	1893......	155,027	1898......	297,490
1884......	248,313	1889......	229.029	1894......	225.185	1899......	305.583
1885......	....	1890......	248,581	1895......	195 123	1900......	290.601
1886......	137,307	1891......	228,354	1896......	289,497		

In 1900 it raised 13 per cent. of all the coal produced in Great Britain. It produced very little iron ore and made only 290,601 tons of pig-iron, or 3 per cent. of the total output; but it made 588,000 tons of steel, this being 12 per cent. of the total of the Kingdom. It also made 137,000 tons of puddled bar, or 12 per cent. of the total made.

The principal steel works in the district are shown in Table XXIII-S, and the yearly output of pig-iron is given in Table XXIII-T.

Sec. XXIIIg.—*Staffordshire:*

It is customary to divide this county into a northern and southern portion. Forty years ago the south produced more ore than the north and three times as much pig-iron. The ore was a poor ironstone imbedded in the shale of the coal formations, but the deposit has slowly become exhausted and it is necessary to excavate so much shale that the selected ore is very expensive. For these reasons the mining of ore has almost ceased in this southern portion and the furnaces run on hematite from Lancashire, or Spain, blackband from North Staffordshire, or the cheap but silicious ores of Northamptonshire, which need only be hauled 60 miles.

In North Staffordshire the ore consists mainly of blackband. Bell gives the details of the occurrence in one mine as follows:

(1) Blackband 14 inches thick lying on the top of 18 inches of poor coal.

(2) "Red slag ironstone," 16 inches thick, lying above 2 feet of poor coal.

(3) "Red mine stone" 20 inches thick with 18 inches of coal.

There is also a bed of clay ironstone 3½ feet in thickness. The yield of pig-iron from the calcined blackband is about 50 per cent. and the value in 1900 is officially reported as $1.82. The amount raised in that year was 1,083,421 tons, so that this deposit is of no small economic interest.

The whole county in 1900 produced 14,227,076 tons of coal, or 6 per cent. of the total output; 1,084,797 tons of ore or 8 per cent. of the total, almost all being in the northern portion as above stated; 596,807 tons of pig-iron or 7 per cent. of the total, this being nearly equally divided between north and south. It made 367,000 tons of steel, or 7 per cent. of the total. Of this amount 142,000 tons were Bessemer steel, all made in basic vessels.

The county also made 379,000 tons of puddled bar in 530 furnaces, which is one-third of the entire output of Great Britain. Two-thirds of this is made in South Staffordshire. This is the only district in Great Britain where the puddling industry is holding its own.

Table XXIII-U gives the annual output of ore and pig-iron.

TABLE XXIII-U.

Production of Ore and Pig-Iron in North and South Staffordshire.

See also Tables XXIII-C and XXIII-D for data before 1882.

Year.	Ore.			Pig Iron.		
	North.	South.	Total.	North.	South.	Total.
1882........	1,887,120	135,409	2,022,529	275,577	247,667	523,244
1883........	1,682,600	114,644	1,797,244	267,911	285,325	553,236
1884........	1,783,800	89,945	1,873,745	296,256	279,737	575,993
1885........	....	....	....	....	....	....
1886........	1,499,300	91,755	1,591,055	233,500	236,137	469,637
1887........	840,400	97,618	938,018	260,201	240,724	500,925
1888........	1,629,277	60,491	1,689,768	279,169	310,451	589,620
1889........	1,211,496	51,182	1,262,678	276,219	328,489	604,708
1890........	1,183,447	41,063	1,224,510	255,777	289,648	545,425
1891	1,023,885	47,236	1,071,121	232,254	311,816	544,070
1892........	990,895	49,745	1,040,640	241,416	308,194	549,610
1893........	770,607	38,172	808,779	199,010	285,531	484,541
1894........	815,368	31,147	846,515	210,069	282,302	492,371
1895........	828,856	31,205	860,061	193,647	265,411	459,058
1896	901,356	30,096	931,452	236,176	308,459	544,635
9897........	892,421	34,100	926,521	242,688	324,059	566,747
1898........	1,058,349	53,363	1,111,712	268,357	332,869	601,226
1899........	1,020,932	48,826	1,069,758	283,212	338,283	621,495
1900........	1,040,605	44,192	1,084,797	272,617	324,190	596,807

SEC. XXIIIh.—*North Wales:*

In the Home Office Report for 1900 the statistics for North and South Wales are combined in a very curious way, for the pig-iron output of Denbigh in North Wales is included in Glamorganshire in the south, while that of Flint, adjoining Denbigh, is combined with the southern English county of Monmouth. In Tables XXIII-C and D will be found data on the output of ore and pig-iron. In making up the averages I have assumed that the output in 1900 for Denbigh and Flint was the same as in 1899 and have corrected the figures for the southern counties accordingly.

SEC. XXIIIi.—*The Eastern Central District; Lincoln, Leicester and Northampton; and the Central District; Derby and Nottingham:*

The eastern shore of England, just south of the Humber, is not usually regarded as one of the great iron centers of the world, but it is of considerable consequence. The three counties of Lincoln, Leicester and Northampton in 1900 produced over 30 per cent. of all the ore raised in Great Britain, and they made nearly as much pig-iron as South Wales and more than Staffordshire.

The ore of Lincolnshire is an oolite, occurring in a bed measuring from ten to twenty feet thick, and is very easily mined. It is only two or three feet below the surface and is worked in open quarry. It varies very much and Bell gives the composition for each foot in depth for eight successive feet, stating that the results are typical. The figures show that in the wet state the iron was anywhere from 21 to 37 per cent., and in the dry state from 21 to 45 per cent. The ore is sorted more or less by hand-and-eye inspection, and the average product in a dry state carries 34 per cent. of iron with about 6 per cent. of silica and 28 per cent. of carbonic acid and lime, the latter making the ore self-fluxing. It is even a little too calcareous and needs mixing with a silicious ore. Its value is given as 75 cents at the mines. The ore was once undoubtedly a carbonate, but by exposure it has been changed to a hydrated peroxide and it is therefore used without calcining.

Northampton raises an increasing amount of a very lean and silicious iron ore, some of which is smelted nearby, and the rest sent to Staffordshire and elsewhere. The ore gives about 38 per cent. in the pig-iron, and is worked in the open from a bed 18 feet thick. After paying royalty the ore can be delivered at nearby furnaces for 65 cents per ton. This gives a cost of $1.70 for the ore per ton of pig-iron, but the high silica renders the smelting costly.

The deposits in this part of England are related geologically to the Cleveland beds and may be looked upon as the southern outcrop. The use of these lean ores is a rather recent development, just as in Luxemburg the Minette deposit has come only recently into great prominence. In 1830 there were only 5300 tons of iron made from the lean ores of Cleveland and Lincolnshire. In 1860 Cleveland mined 1,480,000 tons of ore and by 1870 this had risen to 4,300,000 tons, and by 1880 to 6,260,000 tons. The increase has not continued in Cleveland, which in 1900 mined only 5,493,733 tons, but the mines of the southern district are coming to the front. In 1860 this region raised only 118,000 tons, in 1870, 1,048,000 tons, in 1880, 2,766,000 tons, while in 1900 the output of the three counties of Lincoln, Leicester and Northampton reached 4,298,145 tons. Thus, although the production of the Cleveland district has fallen since 1880, the total production of the lean ores from this geological horizon has increased from 9,026,000 to 9,818,000 tons. Estimating the average iron content of the ore at 32 per cent. and the iron in the pig at 93 per cent. this amount of ore represents about 3,300,000 tons of pig-iron, or about 37 per cent. of the total pig-iron made in the Kingdom.

TABLE XXIII-V.

Production of Ore and Pig-Iron in Eastern Central England.

See also Tables XXIII-C and XXIII-D for data before 1882.

Year.	Ore.				Pig Iron.		
	Leicester.	Lincoln.	Northampton.	Total.	Lincoln and Leicester.	Northampton.	Total.
1882..	267,802	1,287,289	1,333,085	2,888,186	201,561	192,115	393,676
1883..	294,825	1,107,793	1,290,087	2,692,705	237,068	216,641	453,709
1884..	261,837	1,348,693	1 279,783	2,890,313	259,398	196,212	455,610
1885..	....	....	....	....	....	....	....
1886..	390,687	1,193,621	996,440	2,580,748	242,342	197,853	440,195
1887..	372,773	1,305,929	935,473	2,614,175	251,869	236,390	488,259
1888..	535,831	1,345,101	1,066,746	2,947,678	298,673	236,841	535,514
1889..	582,858	1,560,690	1,257,080	3,400,548	336,175	230,820	566,995
1890	609,964	1,052,409	1,278,381	2,940,754	268,405	225,046	493,451
1891..	646,125	1,214,131	1,043,541	2,903,797	284,766	194,395	479,161
1892	680,985	1,459,404	1,120,365	3,260,754	279,556	177,817	457,373
1893..	471.098	1,039,112	719.071	2,229,281	216,575	143,815	360,390
1894..	568,026	1,554,286	1,130,773	3,253,085	343,616	223,348	566,964
1895..	598,551	1,554,462	1,082,252	3,225,265	349,232	254,744	603,976
1896..	702,842	1,576 779	1,263,650	3,543,271	361,029	274,462	635,491
1897..	714,651	1,765,365	1,264.915	3,744,931	363,487	249,824	613,311
1898..	696.015	1 848.404	1,406.150	3,950.569	381,824	250,835	632,659
1899..	677,667	2,094,330	1,779.710	4,551,707	408,989	279,301	688,290
1900..	750,708	1,924,898	1,622,539	4,298,145	388,745	247,908	636,653

TABLE XXIII-W.

Production of Pig-Iron in Derbyshire and Nottinghamshire (Central England).

Statistics formerly kept separate, but now combined.

See also Tables XXIII-C and XXIII-D for data before 1882.

Year.	Derby.	Nottingham	Total.	Year.	Derby and Nottingham.
1882..........	372,650	73,085	445,735	1892..........	481,449
1883..........	353,474	68,740	422,214	1893..........	343,115
1884.........	359,338	78,175	437;513	1894..........	376,726
1885..........	....	....	....	1895..........	413,454
1886	296,213	50,119	346,332	1896..........	455,487
1887..........	....	....	296,118	1897.........	488,472
1888	....	....	362.744	1898	529,208
1889..........	378.464	91,650	470,114	1899..........	571,994
1890	387.760	75.900	463.660	1900..........	561,626
1891	387.127	83 824	470,951		

In the counties of Lincoln, Leicester and Northampton there are 47 blast furnaces, of which 32 were active in 1900. In Derby and Nottingham there are 54 furnaces, 43 being active. It might seem from a glance at the map that Nottinghamshire should be combined with Lincolnshire and Leicestershire, but in the Home Office Reports its output of pig-iron is joined with that of Derbyshire. Neither Derby nor Nottingham produces iron ore in quantity worth mentioning, so that the apparently arbitrary division is founded on good reason. Tables XXIII-V and W give detailed information concerning these two districts.

CHAPTER XXIV.

GERMANY.

Sec. XXIVa.—*General View:*

The discussion of the German iron industry as it appeared in the former edition was founded principally on knowledge gained by personal inspection. There were also at hand a most valuable series of letters by Kirchhoff, which were printed in *The Iron Age,* of which he is editor. They began in May, 1900, and later were issued in book form. The manuscript for the former edition was submitted both to Dr. Wedding, of Berlin, and Herr Schrödter, editor of *Stahl und Eisen* at Dusseldorf. Since this book was published it has been read by other friends in Germany, and I am indebted particularly to Mr. Franz J. Müller, General Director of The Rheinische Steelworks at Ruhrort, and to O. von Kraewel, Superintendent of the same Company, for a very critical review, and their information has been used in this edition. Much matter has also been derived from a paper by Brugmann.* It need hardly be said that none of my friends can be held responsible for personal or political opinions.

In the matter of statistics Germany is lamentably weak. The Government regularly gathers an immense mass of figures, which are duly published in all the journals and technical papers, but they are worthless. I spent much time and money collecting the records for the former edition, but must state that they were in error. Germany recognizes three kinds of product: (1) Ingots for sale; (2) half finished product; (3) finished product; but if one works sells ingots to another, and the second works makes billets and sells them to a third mill for rerolling, then this steel is put in the total three separate times. A very large amount is actually added twice, because almost all the wire mills in Germany are independent. Within the last two or three years, the total production of ingots in the whole of Germany has been collected. Before that time no statistics were reliable, and even now there are no data published as to the output of separate districts. I am able however to present in this edition for the first time, a reasonably

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* *Jour. I. & S. I.*, Vol. II, 1902.

accurate estimate by high authority of the output by districts for the year 1902-03. The figures will be found in Table XXIV-C. They differ widely from the former statement, but it will be noted that the present figures cover the output of ingots, while the previous edition took cognizance only of finished material, thus excluding billets for export either abroad or outside the district.

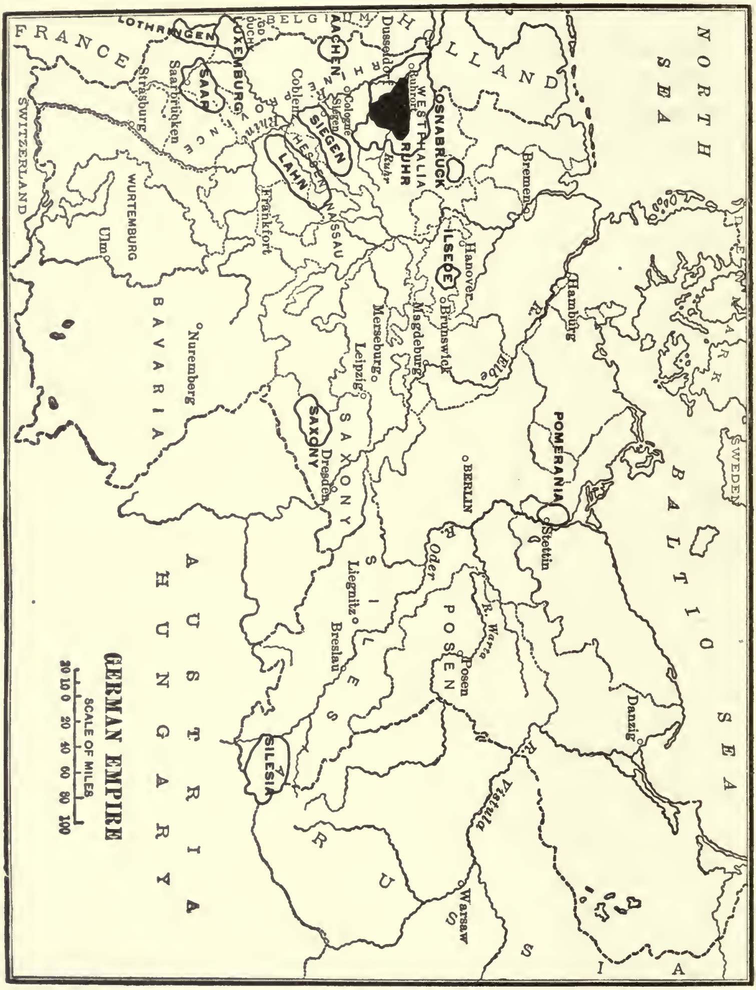

FIG. XXIV-A.

The data on steel works and blast furnaces and puddling plants have been taken from the Gemeinfassliche Darstellung des Eisenhüttenwesens for 1900. The boundaries of each district have been faithfully reproduced from a drawing by Dr. Wedding, but it is impossible to take these limits as true for all the statistics given. For instance, the map shows the area of the Ruhr coal basin, which

TABLE XXIV-A.

Production of Pig Iron, Ore, Coke and Coal in Germany.

Note: Districts are in the order of their pig-iron output.

Data for 1899 from Wedding; for 1900 from Schrödter; details for pig-iron, ore and coal for 1900 are not at hand in the same grouping as given here, but the totals as published for each province indicate that the output is about the same for each division in 1899 and 1900.

District.	Pig Iron, 1899.		Ore, 1899.		Coke, 1900.		Coal, 1899.	
	Tons.	Per Cent.	Tons.	Per Cent.	Tons.	Per Cent.	Bituminous. Tons.	Lignite. Tons.
Ruhr	3,186,704	39	212,794	1	9,644,000	75	55,184,138	none
Lothringen	1,290,264	16	6,972,758	39	none	......	1,071,103	none
Luxemburg	982,930	12	6,014,394	34	none	......	none	none
Silesia	744,672	9	476,823	3	1.947,000	15	27,959,689	609,515
Siegen	656,942	8	2,119,145	12	none	......	none	none
Saar	596,565	7	none	....	894,000	7	9,589,636	none
Aachen	152,736	2	16,584	......	267,000	2	1.764,398	3.927,257
Ilsede	124,156	2	799,728	4	....	......	none	1,544,805
Osnabruck	115,200	1	128,430	1	all others	....	547,822	none
Bavaria	83,321	1	184,020	1	33,000	....	638,153	37,277
Pomerania	80,342	1	none	......	....	......	none	none
Lahn	21,012	......	756,758	4	....	......	none	277,337
Saxony	none	......	8,108	......	74,000	1	4,546,756	1,292,348
Others	95,811	2	28,558	......	....	......	338,058	1,851,542
Cent. Germany	....	......	122,981	1	....	......	none	24,664,585
Total	8,130,655	100	17,989,635	100	12,859.000	100	101,639,753	34,204,666

TABLE XXIV-B.

Movement of Ore in Germany in the Year 1899 in the Districts Importing or Exporting Across the Frontier.

District.	Lothringen and Luxemburg.	Ruhr.	Silesia.	Pomerania.
Ore raised.	12,987.152	212.794	476,823	none
Exported to Belgium	1,807,421	....	....	....
" France.	1,271.052	....	....	....
" Austria	....	....	33,787	....
Imported from Spain	....	1.884,769	....	124,200
" " Sweden	....	1.384,447	275.406	....
" " Hungary	....	....	329,705	....
Sent to the Saar and the Ruhr	1,337,000	....	....	....
Brought from the Siegen, the Lahn and Lothringen	....	4,734,600	....	....

is the foundation of the prosperity of the district, and it shows the outline of the ore deposits in Siegerland, but in the interval along the Rhine are blast furnaces and steel works and countless works, both large and small, some making their own steel and some buying their raw material, but all turning out some of the ten thousand articles "of German manufacture," each shop specialized for something, for bolts, for scissors, for scythes, or for needles, and all contributing to the prosperity of the Rhine province.

The general statistical situation is shown in Tables XXIV-A, B and C.

TABLE XXIV-C.

Estimated Output of Ingots (including castings) in Germany for Twelve Months, 1902-03; metric tons.

District.	Acid Bessemer.	Basic Bessemer.	Acid Open Hearth.	Basic Open Hearth,	Total.
The Ruhr	240,000	2,246,000	176,000	1,667,000	4,329,000
Silesia	55,000	242,000		292,000	589,000
Lothringen		953,000		45,000	998,000
Luxemburg		408,000			408,000
The Saar		867,000	10,000	160,000	1,037,000
Saxony	10,800	40,000	7,200	85,000	143,000
Siegerland				154,000	154,000
Aachen		287,000		46,000	333,000
Ilsede-Peine		239,000			239,000
Osnabruck	29,000			30,000	59,000
Bavaria		100,000		30,000	130,000
Total	334,800	5,382,000	193,200	2,509,000	8,419,000

SEC. XXIVb.—*Lothringen and Luxemburg:*

The province of Lothringen is the old French Lorraine, so familiar to every one as a great arena of war. Following its incorporation into the Empire of Germany not only was its name changed so as to be in accordance with the German language, but almost every town and village received either a new name or a German prefix or suffix. As a matter of fact, this was quite natural, for it is quite impossible for the German or the English speaking people to pronounce correctly many of the French names, and it would have been absurd to have a German city called by a name that nine-tenths of the German inhabitants could not pronounce. English and Americans have committed worse sins without excuse in changing the spelling of Napoli to Naples, Venezia to Venice, and Wien to Vienna. Moreover, it is urged by my German friends that the new spelling is really the original, and that the French were the real offenders in changing the names during their temporary occupation. At present many maps of Lothringen contain the old names, and these are used exclusively in France and Belgium for obvious reasons, and also very widely in England and America, while the term Lorraine is probably known to a hundred Americans where Lothringen is known to one. This change, natural though it is, entails endless confusion upon the traveler, who might be supposed to guess that Hayange means Hayingen, and Differdange, Differdingen, but can hardly be expected to know that Diedenhofen and Thionville are the same.

Lothringen is a fundamental part of the Empire, unlike Luxemburg, which is merely connected with it through a tariff treaty (zollverein). Both districts have the same general characteristics, and rely on the enormous bed of iron ore which extends beyond their borders into France and Belgium, and whose known contents will supply enough iron for many generations. This ore goes by the term "Minette," a contemptuous diminutive once given it by French workmen; this is also the name of one of the French provinces in which it occurs. It is an oolite, consisting of small grains, each one of which is made up of concentric shells of silicious or calcareous matter, and hydrous ferric oxide.

The beds throughout the greater part of Lothringen carry an excess of lime, but near the Luxemburg border is a deposit running high in silica and carrying 40 per cent. of iron, so that by proper mixing a self-fluxing burden can be obtained.

Table XXIV-D shows the composition of different grades of ore according to different authorities.

The map of the Minette region shown in Fig. XXIV-B was originally made by Dr. Wedding, but was much extended and completed by Kirchhoff. The formation is made up of many different beds, and these vary greatly in thickness, the deposit in the north being 180 feet thick, while in the south it is only 20 feet; but there is no regularity at intermediate points, either in thickness or in the arrangement of interstratified rocks, and there is much fault-

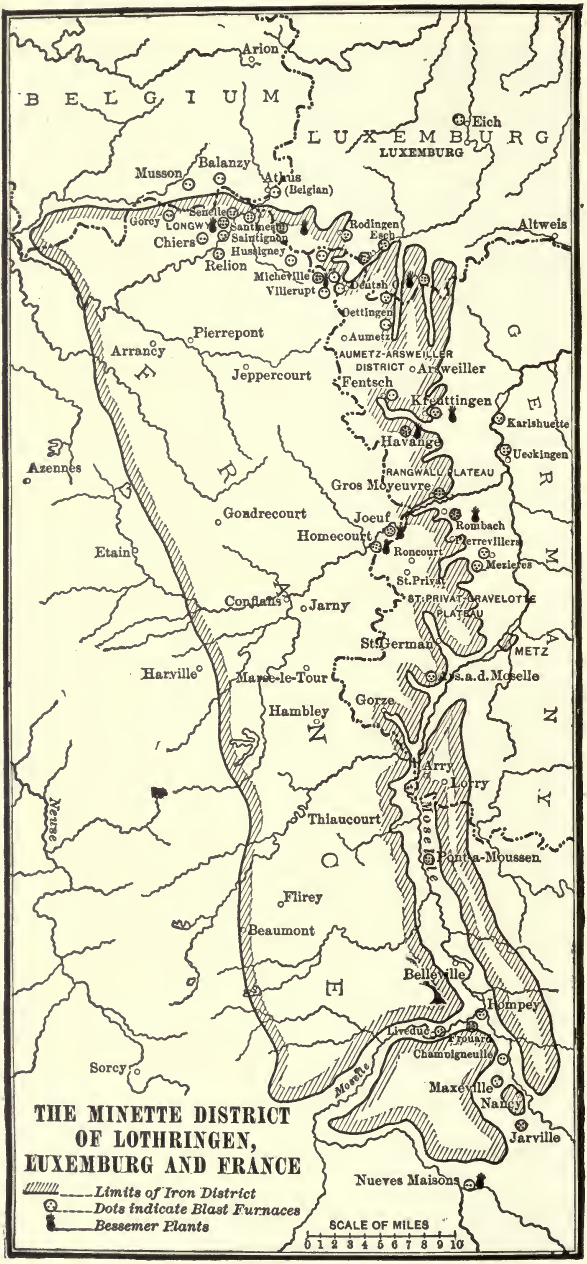
THE MINETTE DISTRICT OF LOTHRINGEN, LUXEMBURG AND FRANCE
Limits of Iron District
Dots indicate Blast Furnaces
Bessemer Plants
SCALE OF MILES
0 1 2 3 4 5 6 7 8 9 10
BELGIUM
LUXEMBURG
LUXEMBURG
GERMANY
FRANCE
Arion
Eich
Musson
Balanzy
Athus (Belgian)
Senelle
Gorcy
LONGWY
Santines
Saintignon
Chiers
Hussigney
Relion
Rodingen
Esch
Altweis
Micheville
Villerupt
Deutsh O
Oettingen
Aumetz
AUMETZ-ARSWEILLER DISTRICT
Arsweiller
Pierrepont
Arrancy
Jeppercourt
Fentsch
Kneuttingen
Karlshuette
Havange
Ueckingen
Azennes
RANGWALL PLATEAU
Gros Moyeuvre
Goudrecourt
Joeuf
Homecourt
Rombach
Pierrevillers
Roncourt
Etain
Mezieres
St. Privat
ST. PRIVAT-GRAVELOTTE PLATEAU
Conflans
Jarny
St. German
METZ
Harville
Mars-le-Tour
Ars. a. d. Moselle
Gorze
Hambley
Arry
Lorry
Meuse
Thiaucourt
Moselle
Pont-a-Mousson
Flirey
Beaumont
Belleville
Pompey
Liveduc
Frouard
Champigneulle
Sorcy
Moselle
Maxeville
Nancy
Jarville
Nueves Maisons

FIG. XXIV-B.

TABLE XXIV-D.

Composition of Ores from Lothringen and Luxemburg and Data showing the Thickness of the Beds, and Thickness of Intermingled Strata of Earth and Limestone, arranged from Schrödter, Stahl und Eisen, March 15, 1896. Also data from Wedding, Eisenhüttenkunde, Zweite, 1897, p. 59; Kohlmann, Stahl und Eisen, Vol. XVIII, p. 593; and Stahl und Eisen, Vol. XX, p. 1266.

Note; the boreholes are at different points in the Aumetz Arsweiler district.

Strata and Thickness in Feet.				Fe	Mn	P	SiO_2	CaO	Al_2O_3	
Schrödter Borehole	Depth from Surface	Thickness of Layer	Character of Deposit							
A	0	16	Red sand....	25.6			33.3	9.4		
	16	10	Red sand....	26.6			31.3	9.5		
	26	41	Lime & clay.							
	67	9	Red Minette.	30.7			7.5	21.5	5.7	
	76	1	Lime........							
	77	1	Red Minette.	38.5			9.2	12.1	6.9	
	78	3	Red Minette.	32.4			10.0	19.8	5.8	
	81	7	Red ore.....	39.4			7.7	11.6	4.9	
	88	19	Earth							
	107	13	Gray ore.....	33.7			7.6	20.0	4.1	
	120	16	Earth							
	136	14	Brown ore...	39.0			15.1	8.0	4.1	
	150	3	Blk. Minette	21.0			21.3	5.3	15.7	
	153	12	Black ore...	41.1			10.7	4.6	6.0	
	165	3	Black ore...	33.0						
	168	3	Black ore...							
	171	2	Black ore...	37.0				7.0		
B	0	13	S. limestone.							
	13	5	R. sandy ore	21.0				15.0		
	18	25	S. limestone.							
	43	4	Red ore.....	24.0		0.53		24.0		
	47	17	S. limestone.							
	64	5	Red ore.....	27.0		0.59		22.5		
	69	6	S. limestone.							
	75	7	Red ore.....	28.0				20.0		
	82	18	Marl							
	100	17	Gray ore....	38.0		0.84		12.0	6.0	
	117	3	Earth							
	120	7	Gray ore ...	35.0		0.91		12.9	6.3	
	127	19	Earth							
	146	10	Brown ore ..	59.3		0.82		6.3	7.7	
	156	9	Earth							
	165	5	Black	36.9		0.86		6.8	6.7	
	170	4	Earth							
	174	4	Ore..........	36.4		0.57		6.2	4.5	
C	0	9	Limestone...							
	9	6	R. sandy ore	26.9				20.0		
	15	27	L'stone.marl							
	42	4	Yellow ore..	21.3				19.5		
	46	8	Blue marl...							
	54	2	Gray ore	35.0				12.0		
	56	6	Gray ore	42.6				6.5		
	62	7	Gray ore ...	31.4				15.2		
	69	3	Gray ore	33.3				12.3		
	72	2	Gray ore	29.8				11.7		
D	0	81	R.sand, marl							
	81	12	Red lime ore	44.5			11.6	6.3		
	93	14	Poor M. & marl......							

Table XXIV-D—Continued.

Strata and thickness in feet.				Fe	Mn	P	SiO_2	CaO	Al_2O_3	
	107	20	Gray ore	45.6	......	......	12.5	4 .5	....	......
	127	12	Blue marl	....	......	......	....	....	....	......
	139	16	Brown ore	39.6	......	......	25.5	3.9	....	......
E	0	95	Lime ores	....	......	......	....	....	....	......
	95	20	Gray ore	37.6	......	......	12.3	10.2	....	......
	115	15	Marl	....	......	......	....	....	....	......
	130	18	Brown ore	35.8	......	......	21.1	6.4	....	......
	148	14	Black ore	42.0	......	......	17.0	3.0	....	......
										CO_2
F	0	8	Red sand	....	......	......	....	....	....	......
	8	38	Earth	....	......	......	....	....	....	......
	46	3	Red ore	29.4	......	......	8.3	20.4	5.9	16.0
	49	19	Earth	....	......	......	....	....	....	......
	68	2	Yellow	34.7	......	......	8.7	15.7	5.8	12.9
	70	12	Earth	....	......	......	....	....	....	......
	82	5	Yellow	28.3	......	......	17.9	14.4	8.3	11.3
	87	6	Earth	....	......	......	....	....	....	......
	93	13	Gray	34.1	......	......	10.7	14.2	6.6	......
	106	21	Earth	....	......	......	....	....	....	......
	127	7	Brown	38.8	......	......	16.2	4.7	7.8	......
	134	8	Earth	....	......	......	....	....	....	......
	142	3	Black	32.7	......	....	21.8	6.9	6.1	......
										H_2O
Wedding.			Red Calcareous	42.9	tr.	0.54	9.9	14.8	4.7	6.3
			Red Silicious	34.5	0.7	0.32	23.6	12.0	5.8	8.6
			Gray	38.9	......	0.92	9.5	12.3	2.3	17.5
			Brown	21.5	......	0.71	16.5	21.0	6.4	25.1
			Green	33.4	0.4	0.88	24.4	2.7	10.3	15.0
Stahl und Eisen.			Rumelange Dudelange	33.2	0.6	0.80	6.8	16.3	5.2	......
				40.7	0.4	1.00	7.5	7.7	4.7	......
			Esch	39.5	0.4	1.00	13.4	6.4	6.1	......
				27.6	0.3	0.72	42.0	4.9	4.6	......
			Differdange la Madelaine	39.2	0.4	0.81	16.1	5.3	6.4	......
				18.2	0.2	0.53	8.5	33.3	2.3	......
Kohlmann.										
			Black; thickness 18 feet	32 to 45	......	......	11 to 22	2 to 7	6	......
			Brown; 6 to 12 feet	36 to 45	......	......	5 to 21	4 to 9	....	......
			Gray calcareous	32 to 41	......	......	5 to 15	4 to 14	4 to 6	......
			Yellow calcareous; 15 feet	32 to 36	......	......	7 to 9	10 to 15	....	......
			Red calcareous; 6 to 12 feet	34 to 40	......	......	8 to 9	9 to 15	....	......
			Red silicious	36	......	.....	26 to 27	2 to 3	....	......

ing, in some cases the throw being 200 feet. It is roughly true, however, that as we go southwest into France the beds go down into the ground, get less in thickness and higher in silica. In Luxemburg the ore mines are owned partly by companies that acquired ownership many years ago, partly by railroads, built in order to get subsidies in the shape of ore lands, partly by farmers and private individuals, while part is still controlled by the government. Much of the ore in Luxemburg is bought and sold in the open market, while in Lothringen nearly all the property is in the hands of iron producers, and the great steel works in both Belgium and Westphalia have acquired title to mineral lands, some of these acquisitions being quite recent, while some date back many years.

The ore supply in Luxemburg is calculated as good for about one hundred years, at the present rate of consumption, but in Lothringen the beds are considered good for eight hundred years. The mineral domain of this latter province covers about one hundred thousand acres, half of which is owned by the local steel companies. A good part of the remainder is owned by the companies operating steel works in Westphalia. Kirchhoff mentions the following as having mines in Lothringen and works in the Rhenish district:

Aachener Hütten Act. Verein, Gutehoffnungshütte, Friederich Wilhelmshütte, Phœnix, Union, Hörde, Hoesch, Rheinische and Krupp. In the Saar district we have Gebrüder Stumm, Röchlings, Burbach and Dillengen. Belgium is represented by the Angleur Company and by Cockerills. This list of course omits the local steel companies of Lothringen, all of which have their own properties.

As above stated, there is a very considerable quantity of ore sold in the open market in Luxemburg, but very little in Lothringen, so that the selling price in the former province will be a better measure of the market. The figures given by Dutreux show that in the five years from 1895 to 1899 the average market price varied from 49 to 57 cents per ton, with a general average for the whole period of 52 cents. The cost of the ore to those who possess their own mines must be less than this, but it is hardly likely that it is less than 40 cents, after allowing for a sinking fund.

The run of mine will average about 31 per cent. in iron, but the ore carried to Westphalia is richer than the average. It will run about 35 per cent. in iron* and costs about 75 cents per ton at the mines. The new freight rate is $1.40 per ton, giving a total of $2.15 per ton of ore delivered in Westphalia, or 6.14 cents per unit.

If the ore is smelted at the mine it is necessary to carry nearly 1¼ tons of coke from the Ruhr to Lothringen, at a cost of about $1.82 per ton of coke at present rates, as the freight on fuel in Germany is about one cent per ton per mile. This, of course, does not include the cost at the ovens, which is estimated by Kirchhoff to be about $2.00 for those who have their own collieries, so that the cost of fuel delivered in Lothringen will be $3.82 per ton of coke or $4.80 per ton of iron. The ore for a ton of pig

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* *Jour. I. & S. I.*, Vol. II, 1902, p. 17.

will cost about $1.30, so that the total for ore and fuel sums up $6.10 in Lothringen and $9.10 in Westphalia. I am afraid that this estimate of Kirchhoff on the cost of coke assumes that a good profit is made on the by-products, but allows nothing for the interest and depreciation of the plant.

Against the obvious advantage of transporting 1¼ tons of coke instead of 3 tons of ore is the disadvantage that Lothringen is nôt a great market. To the southwest is the frontier of France and the French steel works working on the same deposit, while on the northwest are the cheap labor and fuel of Belgium tapping the orefield in Luxemburg. To the south is the mountain barrier of Switzerland, to the east the coal field and iron works of the Saar, and to the north the smoking valleys of the Rhine and the Ruhr. All this means that the steel must be carried a long distance and past the doors of active competitors. A great part of the output of Germany is sent oversea and a large part is consumed in finishing mills in the northern districts, and inasmuch as the coal of Westphalia is right on the road between the mines and the market, it is evident that the northern works are not necessarily destined to succumb to the competition of the Minette district.

There is a chance for both ends working together, since cheap transportation must include ore going in one direction and coke in the other, and there is also great opportunity for reductions in charges. The German railroads are owned by the government, and they offer a very good argument against state control. Like all German official work, they are conducted with perfect honesty, but with an immense amount of red tape. As a consequence of the honesty and of the high freight rates, they pay a handsome profit, but on account of the red tape this money goes into the general treasury and defrays the expenses of the military establishment instead of being used to improve the transportation service. A great deal of money is spent on immense stations for passenger traffic, but the freight service is not what it ought to be, and the transportation of ore from Lothringen to Westphalia costs 1 cent per ton per mile, while coke and finished material are from 30 to 50 per cent. more. Private ownership of railroads in America has resulted in spending money for improvements, for larger cars and heavier engines, and has cut down the rates far below the German tariff, even though the American roads traverse districts much more sparsely settled than the western provinces of Germany.

In addition to the questions of freight which have just been discussed, we have the very important fact that Westphalia possesses large and old established works surrounded by communities of skilled workmen. The task of starting a steel works in a part of the country where such an industry has not existed before is hard enough in America, but in any other part of the world it is still harder, for in our land men are accustomed to move, and very readily break away from old associations. A still more important matter is the absolute destruction of capital involved in a transfer of the iron industry, for a works in Westphalia cannot be transported bodily to Lothringen. If the attempt were made it is doubtful if twenty per cent. of the money would be utilized, and this being so it becomes cheaper to destroy the old and to build anew rather than to attempt to move, and it may be shown by calculation that the interest and depreciation on a steel works, including the blast furnaces, is more than the cost of transporting the ore supply a considerable distance. In the case of a Westphalian works, which perhaps is all paid for and has no outstanding bonds, the depreciation account may be neglected and the interest charges looked upon as profit, while in a new works in Lothringen these items become a direct load upon the cost sheet.

From these considerations it happens that we find many different ways of working. The old plants in the Ruhr are buying properties in Lothringen and are bringing ore to their furnaces and so also are the steel works in the valley of the Saar. Other plants are making pig-iron at the mines and sending it to Westphalia and to Aachen, while still other works are being built at the ore bank, the coke being brought from the Ruhr.

The production of the whole Minette district, including Lothringen, Luxemburg and France, was less than three million tons in 1872, but in 1895 it had risen to eleven million tons. In 1898 it was fifteen million and in 1899 about seventeen million, of which France contributed four millions, Luxemburg six millions and Lothringen seven millions. Of the thirteen million tons mined in Lothringen and Luxemburg about one-fourth was shipped to Belgium and France, leaving about ten million to be used in the Empire. About one-eighth of this latter was sent to the Saar and the

Ruhr, while the remainder, between eight and nine million tons, was smelted at the mines, Lothringen in 1899 producing 1,290,264 tons of pig-iron and Luxemburg 982,930 tons, all this iron being made from local ores.

It has been pointed out by Kirchhoff that the importance of the Minette district is concealed by the accident of its situation. The total output of ore from the whole deposit in 1899 was about seventeen million tons, which would make about six million tons of pig-iron, but this is divided between three different nations and between different provinces, and even the portion which we have considered as German can hardly be called so rightly, since Luxemburg is not an integral part of the Empire. The two provinces together raised very nearly three-quarters of all the ore mined in Germany, Siegerland standing next with 12 per cent. of the total, but the combined production of pig-iron in the Minette field was only two-thirds as much as in the Ruhr.

In 1899 there were seventeen active blast furnaces in Lothringen and twenty in Luxemburg, which were not connected with steel works in those provinces, but which sold their iron in the open market or shipped it to the Saar or the Ruhr, many of these furnaces being owned and operated by steel works in these two districts. The Minette ores give a pig-iron running quite regularly about 2.00 per cent. in phosphorus, and very considerable quantities are sold for foundry work and for puddling. There were twenty-two furnaces in Lothringen and nine in Luxemburg connected with adjacent steel works, so that less than half the furnaces in the district were owned by local steel plants.

The total number of active furnaces as above given was sixty-eight, and the production of pig-iron was 2,273,194 tons for the two divisions, representing an average of a little over 90 tons per day for each furnace. Such a calculation of average capacity is not usually of much value, as an old district is very likely to have a number of small and antiquated plants, but in the official list published by the Verein Deutscher Eisenhüttenleute, from which most of these data are taken, there are no very small furnaces mentioned in these two provinces. The capacity as published in the above mentioned list is considerably in excess of the results above calculated, but it would seem as if the statistics would be more accurate than estimates, and we may say therefore that the average furnace in the Minette district, most of the plants being of rather modern construction, turns out between ninety and one hundred tons per day, some of them of course exceeding this considerably. It is necessary for American metallurgists to consider that this is

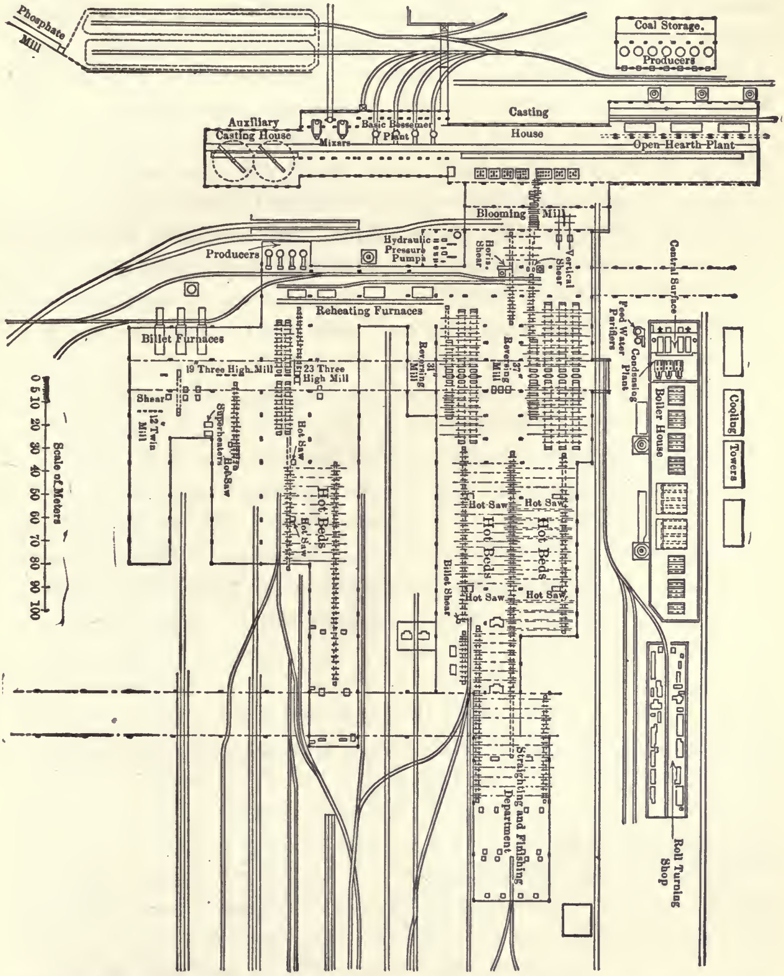

Fig. XXIV-C.—Works at Rombach, Germany.

done on an ore running only 31 per cent. in iron, but on the other hand the mixture is usually self-fluxing, so that for a comparison we must take the ore and limestone together in non-calcareous ores, and figuring in this way we will find that Lake Superior ores when mixed with the usual amount of stone give about 45 per cent. of iron, so that the furnaces working on Minette ores smelt about 50 per cent. more material than American plants, without taking into account the ash in the fuel. It will be noted that the mixture is not always self-fluxing, for near the Moselle River the calcareous beds are scarce and it is necessary to use limestone as a flux.

Most of the blast furnaces in this district use Westphalian coke, the shipments in 1899 from the Ruhr ovens amounting to nearly three million tons, which was nearly 40 per cent. of the total coke output of the northern coal field. Some coke is imported from Belgium by plants in Luxemburg, but the German article is far superior in quality. There are three steel works in Lothringen and two in Luxemburg having between them twenty-six converters, ranging from ten to twenty tons capacity, and averaging about fifteen tons. There were only two open-hearth furnaces, one acid and one basic. All the converters are basic.

Three new plants were started in the year 1900, at Rombach, Kneuttingen and Differdingen. In Fig. XXIV-C will be found a drawing of the first of these. It is representative of the best German engineering practice and is entirely new, having been started in 1900. The engineer is Bergassessor Oswald, of Coblenz, to whose courtesy I am indebted for the drawings. There are seven blast furnaces in the Rombach plant, three of them new, the latter being 90 feet by 23 feet with a 13-foot hearth. The blowing engines are ample, but it is intended to eventually use gas engines for this purpose and thus save the steam for driving the reversing rolling mills. To this end the boiler capacity was made very large, the steam pressure being 140 pounds and economizers and superheaters installed, it being hoped that by this means the rolling mills can be driven by the blast furnace gases. There are two mixers for the iron, each of 200 tons, feeding 4 basic 17-ton converters. The pig-iron runs from 1.5 to 2.0 per cent. phosphorus and 0.5 per cent. manganese, this latter element being obtained from ores from Spain, the Caucasus and from the Lahn district. The mixture is self-fluxing and runs about 31 per cent. in iron.

The blooming mill is a 48-inch reversing, 9 feet 6 inches between housings, and this feeds two large mills without the blooms being reheated. The larger finishing mill is 36-inch with four stands, and rolls large beams, while the smaller is 30-inch for billets, and will finish a bar 400 feet long, this not being an extraordinary length in Germany. There are three other smaller mills, 26-inch, 22-inch and 14-inch, for rails and miscellaneous structural work, and these are to be driven by shunt motors, a very large power plant being provided which eventually is to be run by gas engines. All the machinery is of massive type and the labor saving and mechanical handling devices are worked out with thoroughness. The capacity is now 35,000 tons per month, but this is soon to be much increased.

The Differdingen plant was also constructed with lavish expenditure and a very extensive outfit of blowing engines driven by blast furnace gas was installed. Much trouble was experienced through dust, although these difficulties have since then been in great measure overcome.

The plant operated by De Wendel at Hayingen is an extreme example of the system of spare mills, as four complete mills, each with its modern German multiple cylinder engine, stand waiting their turn to run, for there are only men enough to run at most two mills and only steel enough for that number in spite of the fact that they are operated in a very slow manner. The building covering these mills includes all the hot beds, finishing machines, storage and loading yards, and as a rough guess I should say it is 700 feet by 1000 feet, not including the converting department. The output is about 400 tons per day.

Table XXIV-E gives a list of the steel works and blast furnaces in the district.

TABLE XXIV-E.

List of Steel Works with Blast Furnaces in Lothringen and Luxemburg.

District and Works.	Location.	No. of Blast Furnaces and Daily Capacity in Tons.	Bessemer Converters, Number and Capacity in Tons		Open-Hearth Furnaces Number and Capacity in Tons.	
			Acid.	Basic.	Acid.	Basic.
Lothringen—						
Aumetz Friede..	Kneuttingen	3—130		4—20	1—15	1—15
Rombacher, etc..	Rombach	7—140		4—18		
DeWendel & Co..	Hayingen	7—110		6—12		
	Gross-Moyeuvre	6—110		3—12		
Luxemberg—						
Düdelingen, etc..	Düdelingen	6—110		6—10		
Differdingen	Differdingen	4—120		3—20		

List of Blast Furnaces without Steel Works.

	Location.	Owner.	District.	Blast Furnaces.
Owned by Steel Works Elsewhere—	Feutsch	Aumetz Friede, Lessee	Lothringen	3—120
Lothringen	Redingen	Dillengen	Saar	2— 90
	Diedenhofen	Röchling	Saar	2—150
	Ueckingen	Gebruder Stumn	Saar	4—120
	Deutsch Oth	Acieries Angleur	Belgium	2— 90
Luxemburg	Esch	Rothe Erde	Aachen	5—190
	Esch	Burbach	Saar	2—120
Unattached—				
Lothringen				7—120
Luxemburg				13—120

SEC. XXIVc.—*The Ruhr:*

The Ruhr district embraces most of the province of Westphalia and includes a little of the western shore of the Rhine. It is here that we find the coal that gives the best coke on the continent of Europe, though it is far from being equal to the coke of Durham or of Connellsville. The Ruhr coal district proper is included in an irregular space measuring about fifty miles east and west and a little less north and south, this field being shown on the map in black with Ruhrort on the western end and Hörde on the east, but as a matter of fact, coal is found east of Hörde as far as Hamm and also extends westward across the Rhine, several new mines having recently been opened on the western bank. The great works of Krupp at Essen are almost in the center. The deposit covers an area about equal to the county of Westmoreland in Pennsylvania or the Durham coal field in Northeast England, but Westmoreland raises only about ten million tons of coal per year, Durham about forty-six million and Westphalia over fifty million.

The production of coke in the Ruhr is about the same as in Fayette County, Pennsylvania, which includes the Connellsville beds. The output of Durham is not known accurately, as no statistics are kept in England of this material.

The Ruhr raises one-half of all the bituminous coal raised in Germany, and makes two-thirds of the coke, and, in addition to supplying the wants of Western Germany, sends some coke to other countries. In 1899 Germany exported 750,000 tons of coke to France and 135,000 tons to Belgium, almost all of this coming from Westphalia. Austria received 600,000 tons, but part of this was sent from Silesia. The product of the Westphalian ovens, however, is so much better than the eastern supply that it is carried in large quantities as far as Styria in Southern Austria. In 1892 the Ruhr district made 66 per cent. of all the coke made in Germany, but in 1900 its share had risen to 75 per cent. This increase in relative rank as a coke producer has gone on with remarkable regularity, as will be shown in Table XXIV-F.

Table XXIV-F.

Production of Coke in Germany, by Districts.

Data from Schrödter; private communication. One unit=1000 metric tons.

District	1892	1893	1894	1895	1896	1897	1898	1899	1900
Ruhr	4,560	4,780	5,398	5,562	6,266	6,872	7,374	8,202	9,644
Upper Silesia	1,060	1,060	1,122	1,190	1,269	1,399	1,455	1,516	1,411
Lower Silesia	325	366	416	431	443	424	430	460	536
Saar	587	574	695	713	744	821	887	876	894
Aachen	259	219	207	212	310	251	259	269	267
Oberkirchen	26	27	24	27	27	31	30	33	33
Saxony	82	73	79	70	77	78	72	74	74
Total	6,899	7,099	7,941	8,205	9,136	9,876	10,507	11,430	12,859
Per cent. made in the Ruhr.	66	67	68	68	69	70	70	72	75

The exports of coke to Belgium are counterbalanced by coke brought into Luxemburg from that country, the amount so imported being greater than the amount going from Westphalia to Liège. It is only a small proportion of the furnaces in Luxemburg that thus import coke, and the amount sent from the Ruhr to Lothringen and Luxemburg in 1899 amounted to 2,783,000 tons, or nearly 40 per cent. of the total coke production of Westphalia.

The coal occurs in a great number of beds, of varying thickness, the number of workable seams being over two hundred, but none of them is over six feet thick and the average only about half that. The total thickness of the coal measures is between seven and eight thousand feet and they are much folded and faulted. In the southern portion of the field the outcropping beds have been nearly worked out, and as mines have been opened more and more to the north it has been necessary to sink deeper to reach the coal, one shaft going down 2500 feet, and all through strata heavily charged with water. When it is considered that there is more trouble from gas in the deeper mines it will be evident that conditions do not indicate any future decrease in the price of coal or any likelihood of any extraordinary development in capacity. The upper beds give a coal containing from 35 to 45 per cent. of volatile matter, the middle region from 15 to 35 per cent. and the lowest seams not over 15 per cent. It is from the so-called "fat" coals of the middle region that most of the coke is made, the ash in the product running about 10 per cent. The sale of coal and coke is controlled by a syndicate which embraces 90 per cent. of the coal output, and the price of fat coal has risen during the last few years from $2.00 in 1895 to $2.44 in 1900, these figures being at the mine.

Kirchhoff gives quotations from the annual reports of many collieries, and I find from these figures that the larger collieries, producing between them one-third of all the coal and coke of the district, show a cost ranging from $1.31 to $1.69 per ton of coal, with an average of about $1.55, some of the smaller collieries running up to $2.00 and even to $2.50.

The wages of miners have advanced very much in recent years. In 1878 day laborers received only 56 cents and the miners 67 cents, but there was then an advance through many years so that in 1891 the wages were 71 cents for common labor. A reaction followed and then another rise, and in 1898 common labor commanded 76 cents per day and the miners earned $1.14. The mining situation in Westphalia is much as it is in the United States, for the rapid development of industry has gone ahead of the natural increase in population and nearly one-third of the working force in the mines come from Poland, Eastern Prussia and Italy. These alien communities are less common in Europe than in our own land.

The average selling price at the oven of blast furnace coke in the Ruhr basin varied from $1.96 per ton in 1887 to $4.95 in 1890. It dropped to $2.75 in 1893, 1894 and 1895 and then rose to $3.50 in 1900 and $4.25 in 1901. A great part of this coke is made in by-product ovens, and it is well known that responsible coke oven builders will agree to build ovens and operate them free of cost for a term of years, taking their pay in the by-products, and turn over the plant at the end of the period to the party of the second part. This being so, it is quite evident that the price of coke in Westphalia includes a very good profit, and the figure given is no measure of the cost of fuel to those steel works that own their own mines and ovens, among which are the following:

Hoerde, Union, Hoesch, Schalke, Bochumer Verein, Krupp, Gutehoffnungshutte, Phœnix, Rheinische, and Deutsche Kaiser.

In the matter of iron ore, Westphalia occupies a very subordinate position. A small amount of blackband is raised, containing about 35 per cent. of carbon and about 28 per cent. of iron, mainly in the form of carbonate, but the quantity is inconsiderable compared with the output of pig-iron and steel. Sixty per cent. of the ore supply comes from the Siegen, the Lahn and Lothringen, and the remainder from over sea. Spain contributes over 20 per cent. of the total ore smelted in the district, and Sweden about 15 per cent. The supply brought from the Siegen is spathic ore, which is roasted before using; it contains about 35 per cent. of iron and is more fully described in the account of that district. The ores from the Lahn and from Lothringen are also described in the proper place, but it has already been stated that the Minette ore brought to the Ruhr is richer than the average. The composition runs about as follows: Fe, 32 to 38 per cent.; SiO_2, 6 to 8 per cent.; CaO, 10 to 18 per cent. The usual blast furnace burden in Westphalia carries from 35 to 40 per cent. of this ore, about 35 to 40 per cent. of Swedish (Grangesberg or Gellivare) and about 10 per cent. of spathic ore from Siegerland or brown ore from Nassau, the remainder being cinder, pyrites residue, etc.

Many of the well known steel works of this part of the country are not of the type familiar to American metallurgists. They are produced by slow accretions rather than by one comprehensive plan, and it is seldom that any contemplated improvement involves the destruction of any part of the existing plant. Oftentimes there is complete discordance between the equipment or the management of separate departments of the same plant, and a new and up-to-date blast furnace will be running alongside a legacy of 1840. A massive new blooming mill will be found supplying small finishing mills that hold together only by the force of habit, while the most carefully built and most economical steam engine, equipped with every possible fuel saving device, will be operated in conjunction with one abandoned by James Watts. These conditions obtain sometimes in America, but they are merely incidental and temporary, existing only during a period of reconstruction, while on the Continent they are typical and are almost universal in the old plants of Westphalia. The contrast between the new and the old is oftentimes a journey from the sublime to the ridiculous, and in a steel works on the Ruhr there is not the excuse for such conditions that exist in some other sections. In the newer plants of Lothringen it is openly stated that complicated methods of work and new machinery cannot be introduced owing to the stupidity of the local laborer, but in Westphalia generations of steel making have bred a class of workmen quite superior to those of the country districts, and it is probable that they would handle new machinery in a short time. The work turned out of the machine shops at Essen show that the workmen and the foremen could use better apparatus than they have, and that possibly a little less patting on the back and a little more shaking up would be a good thing, and the engineering skill and thoroughness evinced in the new armor department render it difficult to understand how the same minds can patiently contemplate from day to day the heirlooms of Tubal Cain that are on every side. It should be stated, however, that a revolution is in progress, for it is recognized that the Essen works are a back number. There are no blast furnaces there and we have the singular phenomenon of the largest works in the country with ancient blast furnaces scattered all over the region and bringing iron together from all directions to be converted into steel. This is all to be changed, however, for a new works is now constructing on the banks of the Rhine, where water transportation will cheapen the costs of both incoming and outgoing material, and where new methods and mills will be up-to-date and in accord with modern German engineering. This new plant is at Rheinhausen near Ruhrort, and ocean going vessels of 2000 tons burden now come up the river to this latter port, and the advantages of what is practically an inland tidewater situation will be manifest when we consider the large quantities of Spanish and Swedish ores used and the amount of steel exported.

The cost of pig-iron made from Spanish ores is given by Kirchhoff at $13.75 per ton. The large quantity of ore imported of this kind would lead to the conclusion that the cost of basic pig-iron is nearly as high, but as a matter of fact this ore is used almost entirely by two works, Krupp's and Bochum, these being the only large producers of acid Bessemer steel in Germany. The product is used for special steels, the acid metal being considered preferable.

Kirchhoff gives the detailed figures obtained from the annual reports of several companies to show the profits of the industry. It is of course impossible to make any clear statement of profits and losses for these old plants, which have their own sources of raw material and sell everything from coal to machinery, but I have made a rough calculation that in the year 1898-99 the profits of Gutehoffnungshütte represented $6.00 per ton on a production of 300,000 tons of steel. At Phœnix with an output of 330,000 tons, and at Bochum with 227,000 tons, the profit was $4.00 per ton.

The taxes at Gutehoffnungshütte amounted to 44 cents per ton, and the funds put aside for workmen's pensions, etc., footed up 48 cents per ton, while at Phoenix the taxes were 53 cents and the pensions 30 cents. It must again be remarked that these taxes and pensions include the mines, coke ovens, etc., and that the profits include all the subsidiary branches of the plant, but I have calculated the results on the output of steel, as these plants are miscellaneous steel producers and may rightly be compared with many works in America and other countries.

In Krupp's works there are fifteen acid-lined Bessemer converters, each of 5 tons capacity, and at Bochum there are 3 of 8 tons, a total of 18 acid vessels with an average of 5½ tons capacity. The output of acid Bessemer steel in 1899, in the Ruhr district, was 118,000 tons. It is quite certain that all these converters were not worked to their full capacity and this is particularly true of those in works outside of Essen, but if we assume that all the acid Bessemer steel was made at Krupp's the production will be only 660 tons per converter per month. In America we do not have many converters of this size, as they have been relegated to the scrap heap, but twenty years ago, when the steel industry was in its infancy and when the old methods of hydraulic cranes and pit casting were in vogue, it was considered that 120,000 tons per year was just about the proper output for two converters of this size, supplied with one ladle crane and pit. In other words, the product for each acid converter in Westphalia to-day is just one-tenth what it was in America twenty years ago. The reasons for this condition may be sufficient or may not be, but the facts are of record.

The works of Krupp are not the only ones by any means that are branching out in improvements, for the Rheinische has built what is practically a new works, and the Deutscher Kaiser is a completely new establishment. No attempt has been made, however, either in Westphalia or in Lothringen to change the general system of operation, there being little tendency to specialization and little thought of steady operation for large production, the controlling idea being that it is impossible to change rolls quickly, and that it is necessary to have spare mills lying idle, ready to start on a different section. The weak point of this plan is that it is almost out of the question to have the same heating furnaces supply two or three different mills and handle the stuff economically, and quite difficult to arrange the hot bed and finishing part of the mills so as to serve two different trains of rolls. In one of the new plants working on different structural shapes, at the time of my visit in 1899, the chaotic condition of the hot bed and cold bed and loading department was something which cannot be described. This branch of rolling mill work is the weakest feature of German practice, while the operation of heavy blooming and reversing mills is the strongest.

There are a large number of steel works not possessing blast furnaces at all and one of these at least operates Bessemer converters, but the greater part of the steel, as might naturally be expected, is made by the steel works having blast furnaces either near the steel works or elsewhere, this being true of both Bessemer and open-hearth product. All the basic Bessemer plants use "direct metal."

The output of acid Bessemer steel is small as explained above, being only one-tenth part of the basic tonnage and the acid open hearth also contributes only one-tenth part as much as the basic furnaces. About half the steel is made in what we may call the large steel plants, meaning by this that they operate both blast furnaces and a Bessemer plant, while the rest was made in small plants and in steel casting works, the latter having 21 furnaces averaging 9 tons each.

I am informed by Mr. Schrödter that "there are several works which turn out 32,000 to 35,000 tons in a month, from either two or three basic converters of 18 to 20 tons capacity, using one vessel at a time." I have received personal communications from four German works giving me the actual output of their converters and the data are given herewith. The first four plants in the list are in the Ruhr district, while Rothe Erde is at Aachen.

Works.	Size of converter.	Tons per month per converter.
Phœnix	12½ tons	7,000
Hoesch	11 tons	8.000
Hörde	18 tons	8,000
Rheinische	15 tons	6,500
Rothe Erde	15 tons	7,500

A basic lining in a converter is considered to do well if it lasts 220 heats, while the bottoms average from 45 to 50 heats. It is the practice to run one vessel at a time, and this one vessel will make three heats per hour, since the actual time of blowing is about twelve minutes. Every sixteen hours the bottom must be changed, while delays occur occasionally from repairs to tuyeres. When such a delay does occur, another vessel is immediately brought into use until the repairs are completed. Sometimes the vessels are used alternately when the iron is blowing very hot, and sometimes heats are made out of turn to keep the lining hot on an idle vessel, as a basic lining suffers from becoming too cold.

At the end of three days the first vessel will be worn out and the relining takes fifteen hours and the firing about six hours more. While this is going on the second and third vessels must be working and of course there are many times when a fourth unit is needed, the best and newest plants being designed on this basis. Under this system it is easy to see that the output will not increase in proportion to the number of the converters, but each unit renders possible a more uniform output per hour, which tends to economies in the rolling mills.

This regularity is of more importance in Germany than in America on account of the use of unfired soaking pits, the use of coal for heating being almost unknown. In some works the Sunday iron is melted in the blast furnaces during the week, no cupolas being provided. The first round of ingots on Monday morning is kept in the pits only twenty minutes, and then rolled into blooms, as it is not hot enough to finish into rails or billets. The next round stays forty minutes, and the next sixty minutes, after which the mill goes on throughout the week finishing billets, rails, beams, or other shapes at one operation.

During a roll change in the finishing mill, the blooming mill may make blooms or large billets. Moreover it is the general practice to have at least two finishing mills supplied from the same blooming mill, and these run alternately so that one is always ready. One of these is generally equipped to roll small billets. In this way the converting department and the soaking pits are kept running steadily and the loss from oxidation in the heating furnaces, which is so costly a thing in America, is unknown. To the average observer a German plant, turning out from 1000 to 1500 tons per day, seems to be operating at a very low

TABLE XXIV-G.

List of Westphalian Steel Plants and Blast Furnaces, Giving the Number of Furnaces and Converters and Their Rated Capacity.

Note :—Figures on blast furnaces are estimated daily capacity; all the steel plants having blast furnaces at the steel works, use direct metal.

Name of works.	Location.	Blast Furnaces.	Bessemer Converters.		Open Hearth Furnaces.	
			Acid.	Basic.	Acid.	Basic.
Bessemer steel works with furnaces at works—						
Hörde Bergw	Hörde	7—160	....	4—18	1—18	7—18 2—7
Union	Dortmund	9—160	....	4—18	....	4—25 1—8
Hoesch	Dortmund	3—200	....	3—11	....	4—18
Bochum	Bochum	4—140	3—8	3—3½	....	7—25
Gutehoffnungshütte	Oberhausen	8—140	....	4—12	....	6—15 1—4
Phœnix	Ruhrort	3—100 3—150	....	3—12	1—12	4—20 1—12
Rheinische	Ruhrort	3—270	....	4—15	....	4—10
Deutcher Kaiser	Bruckhausen	4—300	....	4—18	1—15	7—15
Bessemer steel works with blast furnaces elsewhere—						
Krupp	Essen	....	15—6	....	9—10	18—21
Furnaces at	Duisburg	....	....	....	....	....
	Hochfeld	3—100	....	....	....	....
	Rheinhausen	3—200	....	....	....	....
	Neuwied	2—80	....	....	....	....
	Müihofen	4—75	....	....	....	....
Furnaces at	Eschweiler	....	....	....	....	4—14
	Berge Borbeck	2—150	....	....	....	....
	Kupferdreh	1—125	....	....	....	....
Bessemer Plants without blast furnaces—						
Haspe	Haspe	....	....	3—6	....	....
Stahl Industrie	Bochum	....	2—8	....	....	2—12
Steel works without blast furnaces	....	....	....	....	6—12	64—15
Blast furnaces without steel works	....	20—110	....	....	....	....

cost, in spite of there being a few more men than would be found in America.

There were 147 basic open-hearth furnaces in the Ruhr district in 1899 with an average rating of about 17 tons. Three-fifths of the estimated capacity was in the plants operating Bessemer converters, the remainder being scattered in many different establishments, six furnaces being used for steel castings. The district is also the great producer of wrought-iron, there being nearly 500 puddle furnaces at work, or nearly half the total number in the empire. Table XXIV-G gives a list of the principal producers of steel and iron, but it will be understood that the estimated capacity of blast furnaces represents a maximum hoped for, rather than a regular production. Thus the seven furnaces at Hörde are rated at 160 tons when the figures for 1898 show an average product of 90 tons, and the same reports give 90 tons for the furnaces belonging to the Union Works, 130 tons for the Hoesch, and 110 tons for Gutehoffnungshütte. The data for both blast furnaces and steel producers are taken from official sources.

SEC. XXIVd.—*Oberschlesien, Upper Silesia:*

In the extreme southeastern end of Germany, surrounded on the north, east and south by Russia and Austria, lies a little district about fifty miles square, which produces half as much coal as the Ruhr Valley, one-fourth as much coke, and which stands second among German districts in the production of steel. Isolated by the political frontier lines and by the mountainous character of the country, it forms a factor not only in the industrial world, but in the general political situation, for tariff measures and expenditures for internal improvements by railway or canal must be arranged to give this district its share in the benefits, in order that it may not pay taxes to assist a competitor.

Coal is found in both Upper and Lower Silesia, by which is meant both eastern and western, but the iron industry exists only in the east. The character of the population is quite different from that of Western Germany, for Eastern Silesia formed part of the old dismembered province of Poland, as might be inferred from the names of the towns. It is more provincial; wages are lower; the standard of living is not as high, and the proximity of Russian Poland, Austria and Hungary gives rise to a great deal of floating foreign labor. The primitive character of the population is indicated by the traveling bazaars, temporarily established in the market places of the towns. The wares are the crudest handmade articles, ranging from shoes to augers, and could not be sold in an up-to-date community except to a museum. Gangs of Russian women travel around in search of work exactly as Croatian or Austrian workmen go from one place to another in America, and these women as well as others from Austria and from the home villages, work in the steel works, on the railroads, or any place where there is work to be done, beginning this drudgery at the age of sixteen. Their wages are about 25 cents per day, while men earn from 50 to 62 cents.

The principal advantage possessed by Silesia is its coal supply. In 1899 it raised nearly 28,000,000 tons of coal, which was over half as much as Westphalia produced, and it made 1,777,000 tons of coke, nearly one-quarter of the amount turned out in the Ruhr. The coal is very rich in volatile matter, running from 30 to 35 per cent., but it gives a very poor coke. The quality has been much improved in some places by stamping the coal, this being done both wet and dry at different works, but it is even questioned by some whether any good is done by this compression, the burden of evidence, however, seeming to be in its favor. The Silesian coal field reaches over the boundary into Moravia and Poland and will be further referred to in the discussion of Austria and Russia. Formerly considerable ore was mined in Silesia, but the supply is decreasing, for in 1894 there were 600,000 tons raised, while in 1899 there were only 477,000 tons. This ore is very poor stuff of the following composition:

	Per cent.
Iron	25
Manganese	2 to 3
Silica	30 to 40
Zinc	0.8
Water	30

In the dry state this would figure out Fe, 36 per cent.; Silica, 43 to 57 per cent.; Zn, 1.1 per cent.

The foregoing data were given me on the spot by the manager of one of the blast furnace plants, and they agree with results recorded by Bremme, Stahl und Eisen, Vol. XVI, p. 755. The figures given by Wedding are as shown in Table XXIV-H.

Table XXIV-H.

Composition of Ores from Upper Silesia.

Wedding: Ausführliches Handbuch der Eisenhütten Kunde, 1897; Zweite Auflage; Braunschweig, Fr. Vieweg & Sohn, p. 59.

	Tarnowitz.	Tarnowitz (very rich.)	Trockenberg
Fe_2O_3	47.05	50.43	49.06
H_2O	12.00	8.11	13.01
MnO	4.30	4.52	7.23
SiO_2	24.89	25.47	21.29
Al_2O_3	8.88	7.80	5.99
CaO	0.96	1.02	1.18
MgO	0.04	0.50	0.36
P_2O_5	0.49	0.76	0.63
ZnO	2.20	2.21	1.50
Total	100.81	100.82	100.25
Metallic iron wet	32.9	35.3	34.3
Metallic iron dry	37.4	38.4	39.4

The ore is very fine and there is an immense amount of flue dust mixed with much troublesome sublimate containing the zinc. About 35 per cent. of lime is needed as a flux. The local furnaces are gradually ceasing to use this ore, but I found the works at Donnersmarckhütte carrying it to the extent of 50 per cent. of the burden. Foreign ore is now used in the blast furnaces, the amount brought to the district in 1899 being 330,000 tons from Hungary and 275,000 tons from Sweden, the amount of foreign ore smelted being 40 per cent. greater than the domestic product. The Hungarian ore is a carbonate and is roasted before using. It comes from Kotterbach, south of the Tatra Mountains, some of the mines there being owned by the works at Friedenshütte. A small amount of ore is sent across the border into Austria, but this is a mere local condition. It is rather singular that Friedenshütte should have been one of the first works to install gas engines driven by furnace gas, when the local conditions of dust would make the trial almost a crucial test, and when coal for firing boilers can be had for $1.00 per ton.

The steel works of this district are of the usual German type. They are troubled like a large proportion of Continental and English plants for lack of water. In America most works have been placed in some advantageous position, but in Europe they "just grew," and they seldom are near a sufficient water supply, as a good sized river, according to foreign standards, carries just about enough water to cool two or three blast furnaces, and condensers are a luxury. This disadvantage is overcome partly by the use of central condensing plants, which are much more common than with us, and by cooling towers, where the water is pumped up about fifty feet and allowed to trickle down over brush or similar devices. The cooling is not enough to give a good vacuum, and the clouds of water vapor are a nuisance in summer and winter, but it is the best that can be done. Many plants use the condensed water to return to the boilers and elaborate settling and skimming tanks are installed to separate the oil, but much remains to be done to give clean water.

The statistics for 1899 show that there were 33 blast furnaces in operation, making 745,000 tons of iron, which is an average of 22,600 tons per furnace, or 62 tons per day. There were two acid Bessemer converters of 8 tons capacity, and 7 basic vessels of 10 tons capacity. There were 30 basic open-hearth furnaces, averaging 16 tons capacity, in the larger steel works, and a few others in steel casting plants. There are no acid open-hearth furnaces in the district. Silesia is a large producer of wrought-iron, there

TABLE XXIV-I.

List of Steel Works and Blast Furnaces in Upper Silesia.

	Location.	Blast Furnaces.	Bessemer Converters.		Open Hearth Furnaces.	
			Acid.	Basic.	Acid.	Basic.
Steel works with blast furnaces—						
Friedenshütte	Friedenshütte	4—110		4—12		2—17
Königshütte	Königshütte	7—80	1—8	2— 8		4—12 1—10
Bethlen Falva	Schwientochlowitz	3—75				2—15
Borsigwerk	Borsigwerk	3—75				4—15 4—20
Hubertushütte	Oberlagiewnik	3—70				2—20
Steel works without blast furnaces—						
Huldschinsky'che	Gleiwitz		1—8	1—8		2—15 1—20
Baildonhütte	Kattowitz					3—15 1—20
Bismarckhütte	Schwientochlowitz					1—20 3—15
Blast furnaces without steel works—						
Julienhütte	Bobreck	7—60				
Donnersmarckhütte	Zabrze	3—75				
Three others, one each						

being 287 puddle furnaces in operation, or 30 per cent. of the total for Germany.

In Table XXIV-I is a list of the steel works and blast furnaces.

SEC. XXIVe.—*The Saar:*

The Saar district is about 40 miles square, with an underlying bed of coal. It includes the neighborhood of Saarbrucken and the western extremity of Bavaria. The coal is not of the best quality and gives a poor coke, which would hardly be used in America, but that it can be used is proven by the steel works at Volklingen and Burbach. There are four plants in the valley, and three of them make most of their pig-iron at the steel works, but these three, and the fourth also, operate furnaces in Lothringen or Luxemburg and bring the pig to the Saar.

The coal varies considerably, and Wedding states that it contains about 7.7 per cent. of ash, but at one works which I visited it ran from 22 to 30 per cent. of ash, and in another from 18 to 20 per cent. In both places it was crushed and washed and the ash

TABLE XXIV-J.

List of Steel Works and Blast Furnaces in the Saar District, with the Number of Furnaces and Rated Capacity.

	Location.	Blast Furnaces.	Bessemer Converters.		Open Hearth Furnaces.	
			Acid.	Basic.	Acid.	Basic.
Steel works with blast furnaces—						
Burbach	Burbach	5—130	....	4—11	....	3—15
also at Esch, Luxemburg	....	2—120	....	....	....	....
Röchling'sche	Volklingen	5—120	....	4—15	....	....
also at Didenhofen Lothringen	....	2—180	....	....	....	....
Gebruder Stumm	Neunkirchen	6— 60	....	4—12	....	1—12
also at Ueckingen Lothringen	....	4— 30	....	....	....	....
Steel works with furnaces elsewhere—						
Dillingen	Dillingen	....	....	3—15	1—15	1—30 2—25
Furnaces at Redingen Lothringen	....	2— 60	....	....	....	3—15
Steel works without furnaces—						
Weber	Hostenbach	....	....	....	....	3—15
Eisenwerks Kramer	St. Ingbert	....	....	3—12	....	....
Blast furnaces without steel works—						
Halbergehütte	Brebach	4— 30	....	....	....	....

reduced to about 10 per cent., giving a coke with 12 to 14 per cent. The coal is charged into the coke ovens in a saturated state holding about 11 per cent. of water, and is rammed with an electric rammer before charging, this preliminary ramming compressing the mass so that the coke is much more dense and the amount used for smelting is decreased 10 per cent. By-product ovens are used and the yield of coke is about 70 per cent. of the weight of dry coal. Scarcely any of this coke is carried outside the valley of the Saar, but the local blast furnaces use it exclusively.

The ore is all brought from the Minette district, and the mixture is self-fluxing, containing about 31 per cent. of iron, and the pig carries about 2 per cent. of phosphorus, the practice being the same as in Lothringen, save that the coke is inferior to the Westphalian fuel used in the latter place. There are 20 blast furnaces in the Saar, and in 1899 they smelted nearly 600,000 tons of pig-iron, or 30,000 tons each, being a little over 80 tons per day, reckoning them as all in operation. There were no acid converters and only three acid open-hearth furnaces, two of these being used for steel castings. There were four basic Bessemer works with 18 converters of an average capacity of 13 tons, and 16 basic open-hearth furnaces of an average capacity of 16 tons. Three of these basic furnaces were in steel casting plants.

Table XXIV-J gives a list of the steel works and blast furnaces.

Sec. XXIVf.—*Aachen* (*Aix la Chapelle*):

The immediate neighborhood of Aachen possesses a bituminous coal field which in 1899 raised 1,764,000 tons of coal. Some of this gives a fair coke and the output of the ovens in the above year was 337,000 tons. There is also a deposit of lignite from which nearly 4,000,000 tons were mined. The output of this kind of coal is rapidly increasing for use in making steam and similar purposes, a large proportion of the total being made into briquettes. The ore production is very small, being only 16,580 tons in 1899. There are some scattered blast furnaces which made 153,000 tons of iron during the year. The district is important as a steel maker on account of the works at Rothe Erde, on the outskirts of Aachen. This plant makes no pig-iron at its works, but operates five furnaces at Esch in Luxemburg, all the pig-iron going to Rothe Erde for remelting. There are three basic converters of 15 tons each, which made 287,000 tons in the year 1902, or 8000 tons per month for each vessel. There are also three open-hearth furnaces of 25 tons capacity.

The Rothe Erde works are very progressive and have a very extensive system of cranes, commanding their storage and shipping yards, quite unusual in foreign works and not at all common in American plants. A conspicuous feature is a very high crane covering traveling cranes of ordinary height and span and transferring material or the smaller and lower cranes themselves.

SEC. XXIVg.—*Ilsede and Peine:*

In the southeast corner of the province of Hannover, between the towns of Hannover and Brunswick, is a deposit of brown iron ore which is mined by open cut, the bed varying from 6 to 41 feet in thickness. The composition of this ore is given in Table XXIV-K, the material called "washed ore" being obtained by washing the clay from the fine ore produced in mining, thus obtaining clean grains of ore.

The ore is used raw and is self-fluxing, giving a pig-iron containing about 3 per cent. of phosphorus, which is the best for basic Bessemer practice of any iron made in Germany. It is smelted at Ilsede in three blast furnaces of 200 tons each, and the fuel ratio is about 1 to 1. The records of manufacture for 223,000 tons of pig show that 2.925 tons of ore were used per ton of pig-iron, while the coke was 1.008 tons. The coke is brought from the Ruhr, a distance of over 150 miles, with a freight rate of $1.58 per ton, but it has been estimated by Schrödter that the cost of pig-iron

TABLE XXIV-K.

Composition of Ilsede Ores.

(Wedding: Eisenhütten Kunde; 1897, Zweite; p. 33.)

	Aluminous.	Calcareous.	Washed Ore.	Phosphoric.
Fe_2O_3	58.26	44.16	62.73	16.41
MnO	7.31	4.72	5.26	1.00
SiO_2	10.70	3.90	4.87	3.09
Al_2O_3	4.76	1.00	1.02	1.16
CaO	5.09	21.61	8.90	31.50
MgO	0.44	....	....	0.91
P_2O_5	2.46	2.15	4.08	25.96
H_2O+CO_2	10.98	22.46	13.14	19.97
Total	100.00	100.00	100.00	100.00
Metallic Iron wet.	40.8	30.9	31.3	11.5

was only about $6.75 per ton, in an era of low prices a few years ago. In 1899, owing to high cost of fuel and supplies, the pig-iron cost $9.10 and in 1900 it was $10.10. A local supply of lignite helps keep the wolf from the door.

In 1902 the output of ingots was 239,000 tons, about 20,000 tons per month. The pig-iron is converted into steel at Peine, only about three miles away, where there are four basic converters of 15 tons capacity.

Sec. XXIVh.—*Kingdom of Saxony:*

The Kingdom of Saxony, which must not be confounded with the province of the same name, is on the border of Austria, touching Silesia on the east, while Bavaria lies on the west. Leipzig is in the extreme northwest and Dresden, the capital, is in the center. It contains a very good supply of fuel, and in 1899 raised 4,500,000 tons of bituminous coal and 1,300,000 tons of lignite. Some of this coal will make coke, and 72,000 tons were so used in the year mentioned. There are some deposits of ore, but the amount raised is unimportant. No pig-iron is smelted, but pig-iron is brought in from outside and the district around Chemnitz shows quite a development of the steel industry. A very small amount of puddled iron is also made in the Kingdom.

There are four steel works altogether. One of them has two acid converters of six tons capacity, which in 1902 made 11,000 tons of steel, and another works has three basic converters of 15 tons, which made 40,000 tons.

There is one acid open-hearth furnace of eight tons and eleven basic furnaces of thirteen tons. There are also some small steel casting plants.

Sec. XXIVi.—*The Siegen:*

Siegerland includes the southern portion of Westphalia and the eastern arm of the Rhine province. It has no coal within its borders, but raises a large amount of ore, most of this latter being a carbonate occurring in mammoth fissure veins, the limits of which are unknown, but which are certainly of great extent.

The ore is mined by shafts averaging about 700 feet in depth, and is roasted before smelting, the loss in weight being about 30 per cent. About two-thirds of the output is smelted in the district, the rest going to the furnaces in the Ruhr or along the Lower

Rhine. In 1899 there were 2,120,000 tons of ore raised, which was about one-eighth of the total for Germany.

The composition of the ore as given by Wedding indicates about 38 per cent. of iron and 7.5 per cent. of manganese in the raw ore, but this is richer than the average. The calcined ore according to Brugmann* runs from 47 to 48 per cent. in iron, 8 to 10 per cent. in manganese and 9 to 12 per cent. in residue. The distance to the Ruhr is about 90 miles and the freight 70 cents per ton. The cost delivered is about $4.40, the low phosphorus and high manganese making the ore desirable.

There are 32 blast furnaces in the district, four of them being operated by steel works. These four have a daily capacity ranging from 70 to 110 tons, but the others are much smaller, the average rated capacity being only 60 tons. The total pig-iron production in 1899 was only 657,000 tons, which is only about 30 tons per day for each furnace, but it should be said that many of the old furnaces are making spiegeleisen, a considerable proportion of the output running 20 per cent. in manganese. Much pig is used for puddling, there being over one hundred furnaces in the district, or 10 per cent. of the total for Germany.

There are four steel works in the district, concerning one of which the German records give no information beyond a question mark. The other three make only basic open-hearth steel, having 12 furnaces of an average capacity of 13 tons. The output of steel in 1902 was 154,000 tons.

SEC. XXIVj.—*Osnabruck:*

The district of Osnabruck lies at the junction of Western Hannover and Northern Westphalia; being only 50 miles in a straight line from the Ruhr it might be included in that district, but it possesses its own coal and ore beds and thus stands partly by itself. In 1899 it raised 550,000 tons of bituminous coal and 128,000 tons of ore.

The ore comes from the Hüggel and though low in phosphorus is very friable. Wedding states that it carries from 37 to 47 per cent. of iron, but Brügmann gives its content as from 15 to 25 per cent., with much moisture.

The iron industry is centered in the Georgs-Marien-Bergwerks, at Osnabruck. There are four blast furnaces, and in 1899 the

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production of pig-iron for the district was 115,000 tons, which would give about 80 tons per day for each. There are two acid converters of seven tons, and three basic open-hearth furnaces of twenty tons each.

SEC. XXIVk.—*Bavaria:*

The iron and steel industry of Bavaria consists mainly of the Eisen. Ges. Maximilianshütte, at Rosenberg in Oberpfalz. It has two blast furnaces, three basic converters of five tons capacity and two basic open-hearth furnaces of fifteen tons. A small amount of wrought-iron is also credited to this province. The quantities of coal and ore raised and the amount of finished material made are unimportant.

SEC. XXIVl.—*The Lahn:*

The district known as the Lahn begins at Coblenz and stretches northeastwardly through Hessen Nassau, south of the Westerwold range. It has no good coal, but a small deposit of lignite, and produces a little foundry pig-iron, wrought-iron and steel from local ores and Westphalian coke. It is known, however, for its deposits of red and brown hematites, large quantities being sent to Westphalia. In 1899 the Lahn raised over 750,000 tons of ore, this being about one-third what was mined in the Siegen.

The average commercial run of red hematite is about 50 per cent. in iron. The ore is carried 130 miles to Westphalia, with a freight rate of 97 cents; the delivered price is $3.80 or about 7.6 cents per unit. This neighborhood also supplies ore, carrying 22 to 38 per cent. of iron, 7 to 8 per cent. of manganese, and 18 to 25 per cent. of residues. This is laid down in Westphalia for $3.50 per ton.

SEC. XXIVm.—*Pommerania:*

This district is mentioned on account of the new tidewater plant of three blast furnaces of the Eisenwerk Kraft, near Stettin on the Baltic Sea, which is built to smelt imported ore. Coal is brought from England and coked in by-product ovens, the ammonia forming a source of revenue. The iron is all for foundry use and by its situation this plant has easy access to Berlin, this city being one of the greatest markets in the world for such iron on account of the immense business done in miscellaneous castings.

SEC. XXIVn.—*Other Districts:*

In the table herewith, showing the output of fuel and iron, figures are given for Central Germany, indicating the large amounts of lignite raised in Merseburg and Magdeburg in Saxony, and in Frankfurt in Brandenburg, but these mines have little bearing on the iron industry. The lignite of this region is not as good as that mined in the Rhenish district, for it contains a very large amount of water, the vaporization of which absorbs such a large amount of heat that the calorific value per ton is greatly reduced. Ordinary lump bituminous coal will drain after being soaked so that it will carry only two or three per cent. of moisture, but this lignite can and does carry over one-half of its total weight in water, and yet feel reasonably dry to the hand. A carload may contain four tons of fuel and six tons of water, and this fact renders it far from economical to transport it any distance.

CHAPTER XXV.

FRANCE.

I am indebted to my friend, Mr. August Dutreux, of the Cie. des Forges de Chatillon, Commentry et Neuves-Maisons, for a careful reading of the manuscript of this article.

SECTION XXVa.—*General View:*

The iron industry in France is spread over the whole country, as will be seen in the map in Fig. XXV-A; many of the seats of industry date back a great many years, but viewed from the standpoint of to-day the control of the situation rests in the ore beds of the Minette district on the borders of Luxemburg and Lothringen. This deposit has been fully described on another page in the discussion of the latter province in the article on Germany, and it was there stated that the ore extended into French territory and is found in the province of Meurthe et Moselle, but other parts of the country must be considered either as furnishing the fuel, or as being the seats of old established industries. The position of the iron business was discussed in *Journal I. & S. I.*, Vol. II, by H. Pinget, secretary of the Comité des Forges de France. This article is principally a condensation of his work, with such additions as have been suggested by subsidiary information; but through the courtesy of M. Pinget I am in possession of the statistics for 1900, and he has also given me in detail the number of converters and open-hearth furnaces in each province and their output. I have grouped these provinces in the way usually followed by French writers, the results being shown in Table XXV-A. The map in Fig. XXV-A gives the output for 1899, as the later data were not available when it was made.

Early in 1900 I was able, through the intercession of Hon. M. E. Olmsted with the State Department, to enlist the services of the American Chamber of Commerce in Paris in the collection of very full statistics concerning the production and consumption of fuel and iron in the different provinces of France. The information so collected was deemed of great value by the Department, and

I very gladly agreed that the report should appear as a government publication, which may be consulted by those desiring fuller information on many points. I sent to the Chamber of Commerce

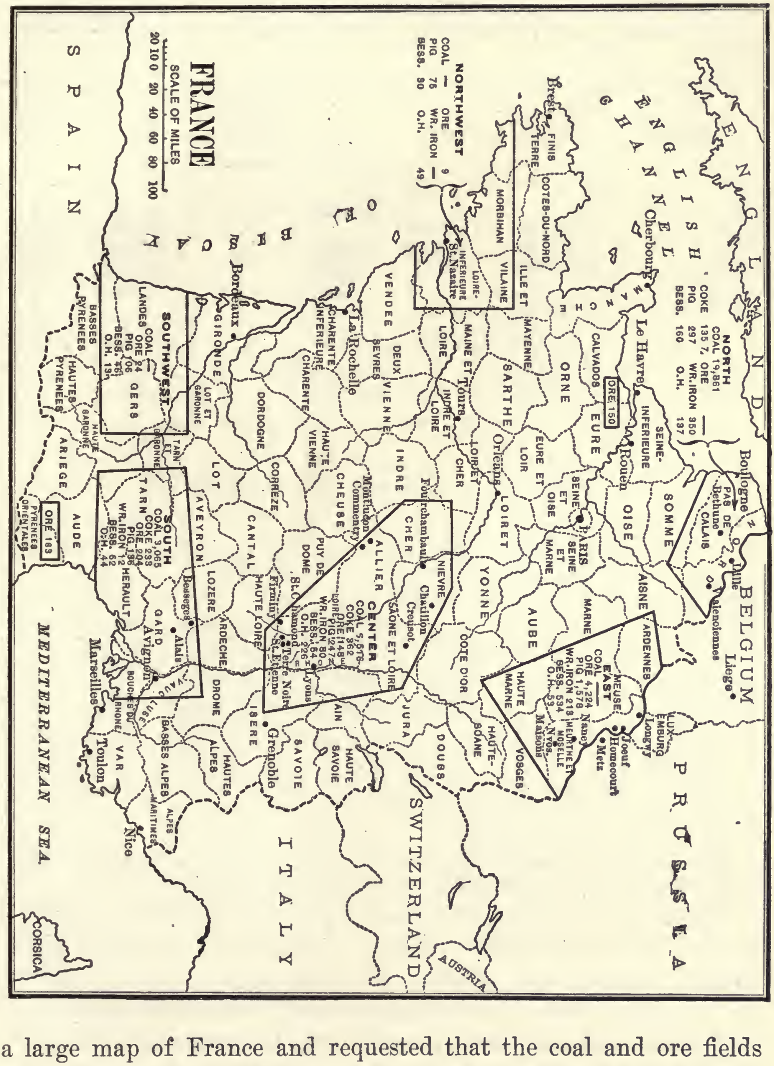

Fig. XXV-A.

a large map of France and requested that the coal and ore fields be marked upon it. The results are shown in Fig. XXV-B, while the following pages embody many facts obtained through the same source.

TABLE XXV-A.

Production of Fuel, Ore, Iron and Steel in France; metric tons.

Data on fuel, ore and pig-iron, private communication, Struthers, *Eng. and Mining Jour.*

Data on steel and rails from Pinget. Comite des Forges.

Data marked thus* are for 1898. Totals disregard data for 1898 and are official.

Production in 1899.	Coal	Coke.	Ore.	No. of Blast Furnaces in Operation.	Pig Iron.	Wrought Iron.
East	....	....	4 224,000	61*	1,576,000	213,000
North	19,861,000	1,357,000*	....	12*	297,000	350,000
Centre	6,516,000	362,000*	148,000	16*	247,000*	80,000*
South	3,065,000	233,000	204,000	11*	136,000*	12,000
Southwest	....	....	24,000*	8*	106,000*	....
Northwest	....	....	9,000	2*	75,000*	....
Others	3,421,000	....	377,000	1*	....	61,000
Total	32,863,000	1,952,000	4,986,000	111*	2,578,000	834,000
Imports	13,370,000	....	1,951,000	....	....	....
Exports	1,026,000	....	....	....	....	....

Production. in 1900	No. of Steel Works.		Bessemer.		Open Hearth.		Total Steel.	Rails in 1901.
	Total.	With Bessemer Converters.	No. of Converters.	Product.	No. of Furnaces.	Product.		
East	9	6	19	554,890	8	71,104	625,994	119,873
North	4	3	9	232,329	13	138,548	370,877	72,289
Centre	10	1	2	52,128	43	261,788	313,916	....
South	3	1	2	33,326	10	59,769	93,095	48 793
Southwest	1	1	2	45,579	2	15,434	61,013	33,000
Northwest	2	1	3	32,909	5	54,602	87,511	17,859
Others	5	....	....	....	10	68,542	68,542	....
Total	34	13	37	951,161	91	669,787	1,620,948	291,814

SEC. XXVb.—*The East:*

Much of the information regarding this district is appropriated from Kirchhoff's letters, before referred to in the discussion of Lothringen.

The eastern division embraces the great ore deposit in the province of Meurthe et Moselle and the neighboring districts of Haute Marne, Ardenne and Meuse. The map of the Minette district, given in connection with Lothringen, will indicate the position of both mines and steel works. All of the basic Bessemer plants in the Minette district are in the province of Meurthe et Moselle, but the other three make the greater part of the open-hearth product, and their output is constantly increasing. The fuel must be brought quite a distance and a glance at the map will show that the Belgian coal fields are as near as those of Northern France, and since the coke made from the French deposit is not of the best, and since it has been impossible during recent years to get a sufficient supply, there is a large amount of coke brought from Germany and Belgium in spite of the tariff. The Pompey Company has coke ovens at Seraing, Belgium, but as a rule the companies do not control their fuel supply, although very lately the furnaces around Longwy have united to form a coke company, a plant of 500 ovens being projected.

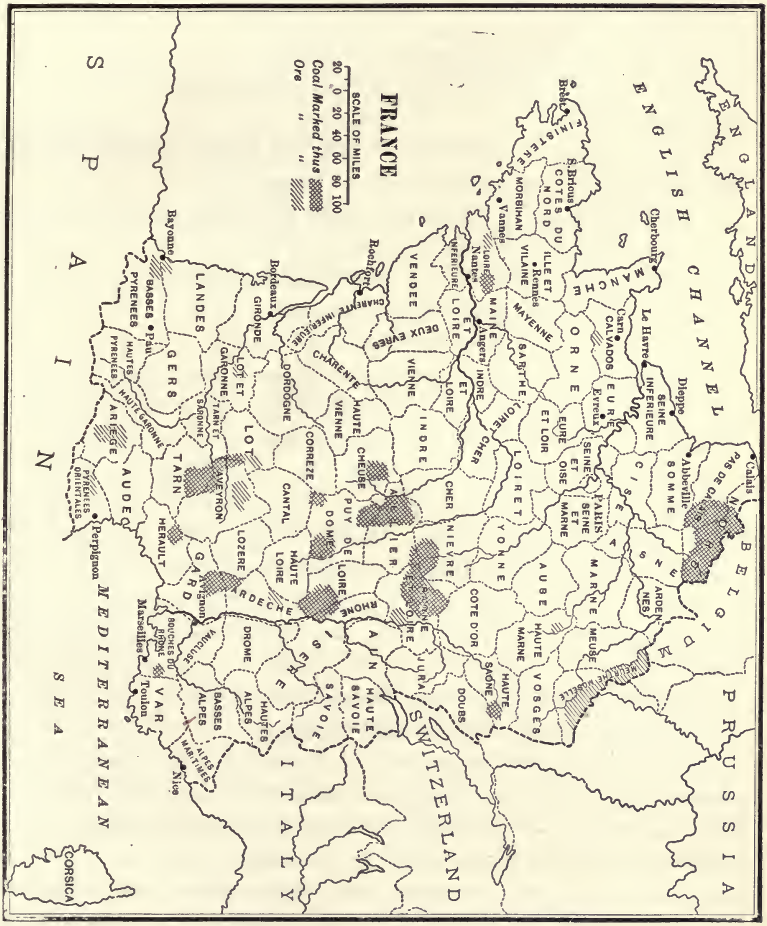

FIG. XXV-B.—COAL AND ORE FIELDS OF FRANCE.

In 1898 this district produced 60 per cent. of all the basic Bessemer steel made in France, and at that time there were only four works in operation, the Longwy, Micheville, Joeuf and Pompey. Other works are building or have already started which will overshadow these completely, from which some idea may be formed of the complete supremacy of this district as the great producing center. It is customary to consider Meurthe et Moselle as made up of three districts, Longwy, Joeuf and Nancy; but in reality they are exactly alike in metallurgical conditions.

In the Longwy division there are three steel plants of moderate capacity as follows:

(1) The Longwy Company, which in 1899 produced 186,463 tons of pig-iron and 158,910 tons of ingots.

(2) The Micheville Company, which in 1899 made 172,138 tons of pig-iron and 156,989 tons of ingots.

(3) The Société des Forges de Montataire, with a new works at Frouard, with three eight-ton converters.

In the Joeuf district are two steel works:

(1) The Soc. An. de Vezin-Aulnoye has a new plant at Homecourt, near Joeuf, with six blast furnaces and four eighteen-ton converters, with an estimated capacity of 1200 tons per day.

(2) The old plant of De Wendel, in which Schneider & Co., of Creusot, are interested, has a rated capacity of 500 tons per day, but is of an antiquated type. Owing to the relations existing between France and Germany no railroad connection is allowed with the works, since it brings its ore by rail from German territory, and all its products are hauled by cart to the existing French railroad.

The third district of Nancy has two steel plants:

(1) The Pompey Company at Pompey.

(2) A new works being built at Neuves-Maisons by the Compagnie des Forges de Chatillon, Commentry et Neuves-Maison. This company is one of the oldest and largest in France and has operated works for many years in the central district at Montluçon, Commentry and elsewhere, and it is very significant when such a new departure is taken and a very large works projected in a district so entirely disconnected with all preceding operations. The new plant is intended to include five blast furnaces and four 18-ton converters.

In addition to the blast furnaces connected with steel works above mentioned, there are many others making iron for the general market and on January 1, 1900, there were 65 furnaces completed, with 54 in blast, the total capacity of all being estimated at 5000 tons per day. It is unnecessary to discuss the metallurgical situation in this locality as it has been covered by the description of Lothringen. Table XXV-B gives a list of the works in this district.

TABLE XXV-B.

List of Steel Works in the East of France.

Those marked (B) have Bessemer converters.

Province.	Companies.	Location.
Meurthe-et-Moselle	Société anonyme des Aciéries de Longwy (B)	Mont-Saint-Martin
	Société anonyme des Aciéries de Micheville (B)	Micheville
	MM. de Wendel et Cie, Maitres de Forges (B)	Joeuf
	Société anonyme de Vezin-Aulnoye (B)	Homecourt
	Société anonyme des Hauts-Fourneaux, Forges et Aciéries de Pompey (B)	Pompey
	Société anonyme des Forges et Fonderies de Montataire (B)	Frouard
Meuse	Société anonyme des Forges et Aciéries de Commercy	Commercy
Haute-Marne	Compagnie des Forges de Champagne et du Canal de Saint-Dizier a Wassy	Marnaval-Saint-Dizier
Ardennes	MM. Boutmy et Cie, Maitres de Forges	Messempré-Carignan
	MM. Lefort et Cie, Maitres de Forges	Mohon

SEC. XXVc.—*The North:*

The great coal field of France lies in the provinces of Nord and Pas-de-Calais. It is an extension of the Belgian deposit and extends from the border to beyond Bethune; the city of Valenciennes may be regarded as a center. The coke made is not of the best quality, but the Belgian is little better, if at all, and the demand has been far ahead of the supply owing to the remarkable development of the iron industry in Meurthe et Moselle, so that although there are now 2000 coke ovens in operation and many more in process of erection, the price of fuel in France has been almost prohibitive. In the year 1900 coal retailed in Paris at $15.00 per ton and coke for foundry use as high as $10.00. These prices, which were exceptionally high even for France, of course encouraged imports in spite of a duty of 25 cents per ton, and coal from the United States entered Mediterranean ports, while England sent 6,000,000 tons of fuel, including coal and coke, and Germany supplied considerable coke. Much Belgian and English fuel is imported into the coal region itself, for in 1899 the foreign coal used in the provinces of Nord and Pas-de-Calais amounted to one-sixth of the total consumption. In the province of Calvados in the northwest, a comparatively short distance from the French coal fields, nearly all the fuel consumed was brought from England. It is the intention of French coke makers to increase the number of ovens so as to render foreign imports unnecessary, but it is doubtful if this increase can affect some of the northwestern and southwestern works, which are close to the sea and which will find English coke cheaper, as well as better. The cost of mining in the Nord and Pas-de-Calais field is enhanced by the depth of the shafts and by the numerous dislocations and contortions of the strata, and the coal must compete on the east with the product of Belgium and Germany and on the west with English fuel.

A certain amount of iron has been made in this district, but the great drawback has been the absence of any ore deposit, the supply having been drawn from Meurthe et Moselle, or from Spain and Sweden. For many years there has been a small amount of hematite mined in the province of Calvados, but the amount produced has been unimportant. I am informed that there has now been discovered the mother lode of spathic ore in large quantities and of good quality. The freight on this will always be low owing to the continual march of empty cars returning northward to the coal districts, and it is thus possible to establish an iron center in the District of the North. To what extent this may develop remains to be determined. Table XXV-C gives a list of the steel works in the district.

TABLE XXV-C.

List of Steel Works in the North of France.

Those marked (B) have Bessemer converters.

Province.	Companies.	Location.
Nord	Société anonyme des Hauts-Fourneaux, Forges et Aciéries de Denain et d'Anzin (B)	Denain
	Société anonyme des Forges et Aciéries du Nord et de l'Est (B)	Trith-Saint-Leger
	Société anonyme des Usines de la Providence	Hautmont
Pas-de-Calais	Société anonyme des Aciéries de France (B)	Isbergues

SEC. XXVd.—*The Center:*

The central district embraces the provinces of Loire, Saone et Loire, Allier, Rhone, Cher, Isere and Nievre. It includes the works at Creusot, Montluçon, Commentry, St. Chamond, Firminy and St. Etienne. Notwithstanding this array of names familiar to metallurgists, the output of this part of France may be briefly passed over. It is of small amount and the existing works have gradually become specialized, making certain lines of finished high grade products for a limited market, as, for instance, armor plate, guns and tool steels. The fuel supply is not good, the blast furnace coke of St. Etienne in the Loire basin containing an average of 14 per cent. of ash. The supply from Allier, which goes to Commentry, Montluçon, etc., is no better, while much of the fuel for the Creusot works comes from the Burgundy basin in Saone et Loire, and for the making of coke must be mixed with one-third of the coal from St. Etienne. Ore is wanting, over one-third the supply being brought from Spain, and there seems to be no future development possible as far as international metallurgy is concerned. The whole district in 1899 made only 4000 tons of rails, which was but a little more than one per cent. of the total output of steel. The Creusot works still turn out a very fair product, but much of their pig-iron is brought from more favored districts. This plant makes almost all the few rails made in this part of the

TABLE XXV-D.

List of Steel Works in the Center of France.

Note: Those marked (B) have Bessemer converters.

Province.	Companies.	Location.
Allier	Compagnie des Forges de Chatillon. Commentry et Neuves-Maisons	Montlucon
Isere	MM. Ch. Pinat et Cie, Maitres de Forges	Allevard
Loire	Compagnie des Forges et Aciéries de la Marine et des Chemins de fer	Saint-Chamond et Assailly
	Compagnie des Fonderies, Forges et Aciéries de Saint-Etienne	Saint-Etienne
	MM. Claudinon et Cie, Maitres de Forges	Le Chambon-Feugerolles
	Société anonyme des Aciéries et Forges de Firminy	Firminy
	MM. Jacob Holtzer et Cie, Maitres de Forges	Unieux
Nievre	Société anonyme de Commentry-Fourchambault et Decazeville	Imphy
Saone-et-Loire	MM. Schneider et Cie, Maitres de Forges. (B)	Le Creusot
	MM. Campionnet et Cie	Gueugnon

country, and quite a little material for ships, and claims attention on account of its miscellaneous business in machinery, ordnance and structural work; but there is little danger that the establishments of Central France will make many conquests in international trade in the lines of heavy machinery or structures until their present methods of hand labor are completely revolutionized. In the southern part of this division Algerian ore is used, as well as some from the Pyrenees. In 1888 there were 24 blast furnaces reported in blast, but ten years later in 1898 only 16 were in operation. Table XXV-D gives a list of the steel works in this district.

Sec. XXVe.—*The South:*

The southern district covers the provinces of Gard, Aveyron, Ardeche, Bouches du Rhone and Ariege, and includes the coal field of Alais in Gard, which gives a coke that is used in the blast furnaces of Besseges and Tamari. There is also a deposit in Aveyron, which, though poorer than the Alais coal, will run over 18 per cent. in volatile matter and will give a marketable coke in Coppée ovens. In the southeast there are deposits of lignite, the province of Bouches du Rhone raising 490,000 tons in 1899, and neighboring districts contributing 117,000 tons. Some of this is sent to Switzerland and Italy. The quality of this fuel, however, is not good and the supply is scant, so that about one-quarter of all the coal consumed in this part of the country is imported from England, principally for steam purposes. The iron industry has received an impetus from quite recent developments in the Pyrenees; these mountains have long supplied ore in moderate quantities, but it is likely that the output will be largely increased. Some ore is also brought from Algeria. In 1888 there were nine blast furnaces in operation, while in 1898 there were eleven in blast, some

Table XXV-E.

List of Steel Works in the South of France.

Note: Those marked (B) have Bessemer converters.

Province.	Companies.	Location.
Ariege..........	Société Metallurgique de l'Ariege....................	Pamiers
Aveyron.........	Société anonyme de Commentry-Fourchambault et Decazeville......................................	Decazeville
Gard............	Compagnie des Mines, Fonderies et Forges d'Alais. (B)	Besseges and Alais

of these in the region near the Pyrenees being small and using charcoal for fuel. Table XXV-E gives a list of the steel works in the district.

SEC. XXVf.—*The Northwest (Loire Inferieure) and the Southwest (Landes):*

Both of these divisions fall under the same head, as both of them import Spanish ores from the north of Spain and smelt with English coke. The works in Loire Inferieure also bring some pig-iron from other provinces of France. The production of neither district is of great importance from a general point of view, although both contribute quite largely to the rail output. At the works at Trignac, near St. Nazaire, there are three blast furnaces, three 10-ton converters and four open-hearth furnaces, the production of Bessemer steel being about 2500 tons per month. The names of the works in the two districts are given in Table XXV-F.

TABLE XXV-F.

List of Steel Works in the Northwest and Southwest of France.

Note: Those marked (B) have Bessemer converters.

Province.	Companies.	Location.
Loire-Inférieure	Société anonyme des Acieries, Hauts-Fourneaux, Forges et Aciéries de Trignac. (B)	Trignac
	Société anonyme des Forges et Acieries de Basse-Indre	Basse-Indre
Landes	Compagnie des Forges et Aciéries de la Marine et des Chemins de fer. (B)	Le Boucau

CHAPTER XXVI.

RUSSIA.

I am indebted to Mr. A. Monell, formerly of the Carnegie Steel Company, for a careful reading of the manuscript in conjunction with a naval attaché of the Russian Government, whose services he kindly requisitioned. Mr. Monell has visited many of the Russian works and his approval of the text renders it of much greater value. The manuscript has also been read by Mr. Julian Kennedy.

The information has been gathered from many sources. Much of it has been taken at first hand from the Russian *Journal of Financial Statistics* and *The Mining Industries of Russia,* and some from Consular Report No. 555 of the British Foreign Office. A paper by Bauerman, *Jour. I. and S. I.,* Vol. 1., 1898, and articles in "Stahl und Eisen," by Neumark and Gouvy, furnished very much in the way of detail, and many other papers were consulted. In the matter of statistics, it often happens that the published figures are contradictory, but the data given here are in accord with those issued from official sources.

In consulting statistics concerning Russia, the weights are usually given in poods and the values in roubles. It may be convenient therefore to record that one pood is about 36.14 pounds, and hence 62 poods are one gross ton, or for practical purposes, 60 poods=1 ton. A rouble is 51.5 cents and this is one hundred kopecks or copecks.

SEC. XXVIa.—*General View:*

Within the last ten years Russia has trebled her production of pig-iron and increased her output of steel fourfold. No other nation can show such a record. The reason, however, is not hard to find, for all the force of an autocratic government has been applied to the building up of home industries in the same way that America and Germany have developed the manufacture of iron by high tariffs. In Russia ore is admitted free, a bounty is paid on all pig-iron exported, and the freight rates are very low.

The government owns the railways, and their requirements, together with the supplies for the war equipment of both army and navy, absorb four-fifths of all the iron produced. This abnormal condition arises from the fact that the one hundred million peasants in Russia use scarcely any iron implements or tools of any kind. They are an undeveloped, mediæval people, and like the rest of the human race, must learn to know their own needs. As a result there is a very low limit to the capacity of Russia to absorb iron and steel and the government may fix its own price in buying material.

The policy in the past has been to encourage manufacture, especially in South Russia, and the large dividends regularly proclaimed attracted large amounts of foreign capital. The New Russia Company, for instance, the oldest and largest steel works, has declared dividends since 1889 of from 15 to 125 per cent. In 1899 the aggregate share capital of foreign companies in Russia was over seventy million dollars, more than half of this being in mining interests, foreign money representing one-quarter of all the mining industry of the Empire. In addition to this proportion in mines there is a very large investment in iron and steel works; the Belgians especially, and the French also, have built many extensive plants, oftentimes without inquiring into local conditions at all and relying on the government to buy whatever was made at such a price that big dividends could be declared. The Bourses of the Continent swallowed anything with a Russian name, and the public contributed from its hoardings. The inevitable crisis came in 1899 and 1900, the government refusing to pay exorbitant prices, and a process of natural selection is now in progress. The situation of many concerns is indicated by the official report of a French company, which pathetically but almost humorously states that the plant they have built in the lonely forests of the Ural is suffering from "the absence of mines and railways near the works."

Naturally, this great crisis has had its effect on the imports of iron and steel and this will be shown in Table XXVI-A.

TABLE XXVI-A.

Imports of Iron, Steel and Fuel into Russia; tons.

	1897	1898	1899	1900
Pig iron	100 000	113 000	139.000	50,000
Iron	300.000	320,000	270,000	97,000
Steel	90,000	74 000	48,000	20,000
Iron and steel goods.	270,000	280.000	300,000	220.000
Coal	2,150.000	2,500.000	4,000,000	4,000,000
Coke	400,000	450,000	550,000	540,000

It will be noted that importation of iron and steel fell off remarkably owing to the necessity of finding a market for the home production. The imports of coal and coke did not decrease, because they are brought in to the plants in Northern Russia and Poland which depend entirely on outside sources of supply.

Everywhere in Russia the iron manufacturer has two great troubles: If he is near coal, the ore is uncertain or being rapidly exhausted. If he is near good ore, there is no fuel. In either event the available labor is unreliable and inefficient, for the great majority of the men come from the agricultural class and seldom break off all connection with their native village, many of them working in the factories only during the winter and going back to the farms in the spring. The government watches over them with paternal care. No man can work continuously for twelve hours, and if he works at night the hours must not exceed ten. On days preceding holidays the day work must not be over ten hours, and work must cease at noon the day before Christmas. There are fourteen holidays, in addition to all Sundays, obligatory on all members of the Russo-Greek Church, and there are many other regulations about the making of individual written contracts with each laborer, to violate which is a serious offense for either workman or employer. For joining a strike a man may serve more than a year in prison, as this would involve a violation of a written agreement. It should be stated, however, that these rules, although enforced with autocratic completeness, are tempered by regulations that allow for accidents and for extraordinary repairs.

The government also insists on very complete arrangements regarding the health and welfare of the workmen in their home life. The New Russia Company, in Southern Russia, employs 14,500 workmen. Only 150 of these are women, a showing which compares more than favorably with conditions across the Austrian border. The company supports a hospital with 106 beds and a dispensary with six doctors, five surgeons' assistants, two midwives, one apothecary and two assistants, the cost of this department amounting to $36,000 per year. It also supports a system of schools costing $75,000 per year, and tea houses, baths, etc., etc. That all this is good cannot be questioned, but that it is a regulation of the State bespeaks a paternal government, and bespeaks also a people who need a paternal government, and this is a people who are in a certain stage of sociological evolution and who must develop for more than one generation before the common peasant becomes the industrial equal of the artisan of America.

As might be expected in a country so great, there are several different centers of production, and owing to the undeveloped condition of transportation the distances intervening between these centers acts as a sort of commercial protection. This is true in every country to a greater or less extent, but Russia presents extreme examples. The Moscow district, in the center of Russia, is 600 miles from the works in Poland, or from those in Ekaterinoslav, while Poland and South Russia are separated by an equal distance. The Ural district is still more isolated, being nearly 900

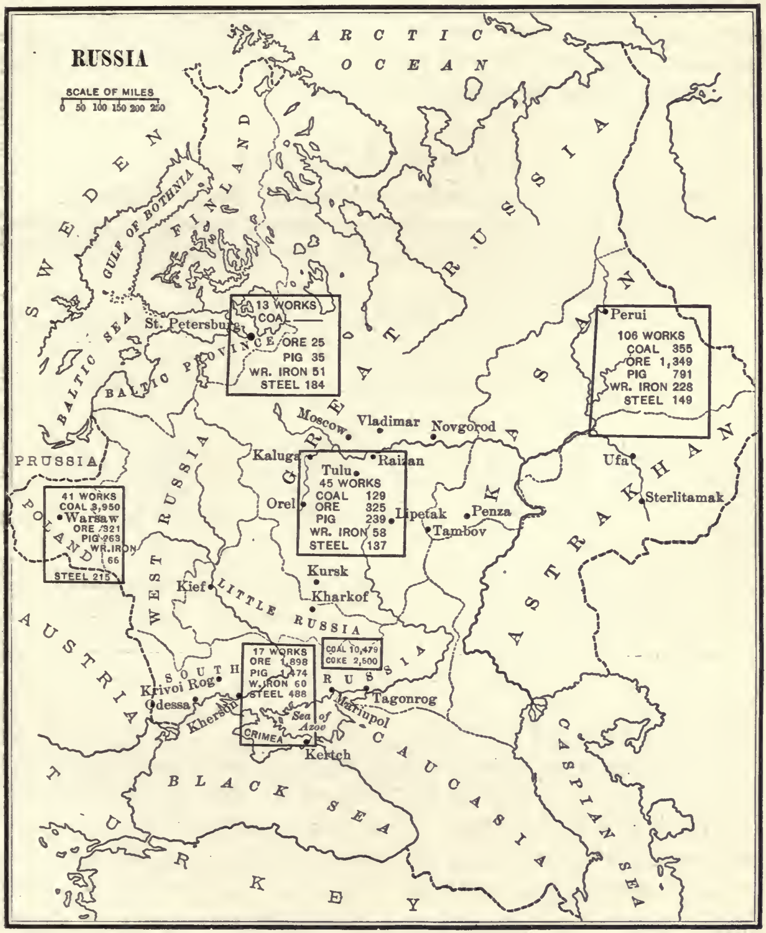

FIG. XXVI-A.

miles from Moscow, 1200 miles from the Sea of Azov and more than that from Poland. Fig. XXVI-A will give an idea of the general distribution of the iron and steel industry, while Table XXVI-B gives more definite statistics. The total output of steel in 1899 was 1,939,000 tons, one-third of this being made in the Bessemer converter and two-thirds in the open-hearth furnace. The output of rails was 530,000 tons, about one-quarter of the total being made by the New Russia Company.

TABLE XXVI-B.

Production of Coal, Iron Ore, Iron and Steel in Russia.

Data for 1899 from The Mining Industries of Russia, published by The Mining Scientific Committee of St. Petersburg, 1901. Data for 1900 from British Consular Report, No. 555, June, 1901.

District.	Coal in 1900.		Ore in 1900.		Blast Furnaces in 1899.			Pig Iron in 1900.		Steel in 1899.		Wr. Iron in 1899.	
	Tons.	Per Cent.	Tons.	Per Cent.	Cold Blast.	Hot Blast.	Total.	Tons.	Per Cent.	Tons.	Per Cent.	Tons.	Per Cent.
South....	10,479,000	69	3,117,000	52	3	37	40	1,474,000	52	982,000	50	57,000	11
Ural......	355,000	2	1,612,000	27	33	102	135	791,000	28	291,000	15	246,000	47
Poland...	3,950,000	26	488,000	8	2	83	35	263,000	9	282,000	15	66,000	12
Moscow..	129,000	3	649,000	11	9	45	54	239,000	9	190,000	10	54,000	10
North....	....	....	32,000	1	4	5	9	35,000	1	178,000	9	87,000	16
Siberia and Finland	....	....	91,000	1	3	17	20	30,000*	1	16,000	1	19,000	4
Total..	14,913,000	100	5,989,000	100	54	239	293	2,832,000	100	1,939,000	100	529,000	100
Imports..	4,000,000	....	....	....	....	....	....	50,000	....	48,000	....	270,000	....

* Output in 1899.

SEC. XXVIb.—*The South:*

The predominant factors in Russian development to-day are the South Russian coal fields in the basin of the Don and the ore beds of Krivoi Rog and Kertsch. The coal deposits cover an area of about 90 miles by 200 miles and are estimated to contain fourteen thousand million tons of fuel. There are nearly three hundred mines opened, some shafts going down 1300 feet, but over three-quarters of the total product comes from fifteen openings. The seams are of only moderate thickness, not exceeding seven feet, rarely over five feet, and as a rule from twenty-four to thirty inches. One seam which is worked is only sixteen inches.

The cost of mining is therefore high and during recent years the supply has been far behind the demand. In the year 1900 the price of coal at the nearest railroad station to a Donetz mine was $5.00 per ton, although good authority gives the average cost at $1.00 to $1.70 per ton at the pit's mouth. The district in 1888 produced 2,205,000 tons, 6,686,000 in 1897 and 10,479,000 tons in 1900, this being 69 per cent. of all that was raised in Russia. The coal varies from lignite to anthracite the same seam being quite different in places a few miles apart. The anthracite beds are much more extensive than those furnishing the soft coal, but the furnaces at Salin are the only ones using hard coal for smelting. The bituminous varieties are generally high in sulphur, ranging from 1 to 4 per cent. The coke is of poor physical structure and most of the coal needs to be washed, several plants for this purpose having recently been put in operation. The best beds give a coke containing 8 per cent. ash and 1.1 per cent. sulphur, but other coals give a product up to 25 per cent. ash and 4 per cent. sulphur. In 1900 there were made 2,500,000 tons of coke, but not more than one-third the coal used for this purpose could be called true coking coal. The percentage of volatile matter at some plants is 18 to 21 per cent., while in other places the proportion is higher. In 1900 there were 4000 ovens, two-thirds of which were of the Coppée type, no by-product plants being in use.

The ore found in the basin of the Don is poor and of little importance, the nearest deposits of any size being in Krivoi Rog in Kherson, on the border of Ekaterinoslav. The deposit is of limited extent and varies greatly in composition and character, the richest ore being pulverulent and giving considerable trouble in the blast furnace on account of this fine condition. Ores below 40 per cent. are considered worthless, the composition of eight samples in the general market supply varying as follows:

Fe.	47 to 66
P	.01 to .04
SiO_2	4 to 26
CaO	0.5 to 2.7
S	0.36
Water	5.0

Neumark gives the following as an average:

Fe	60
SiO_2	5 to 8
Al_2O_3	1 to 2
P	.03 to 1.01

The most striking feature is the great variation in the content of phosphorus. The amount of ore in sight is very limited and most of the good deposits are owned by companies that smelt their own output and sell no ore. At times the end has seemed very near, but it is now estimated that there is a supply for the next twenty or thirty years at the present rate of production. It is evident that this is not a bright outlook, as a diminishing ore supply always means a higher cost.

To help out in this time of trouble, very large deposits of ore have been opened at Kertsch, about 300 miles to the south across the Sea of Azof, the beds being near the surface so that they can be worked open cut by steam shovels. The layer is about 30 feet thick, but the upper and lower portions are poor and only the middle strata, constituting two-thirds of the whole, are used. The composition is as follows:

Fe	40 to 46
Mn	0.3 to 3.0
SiO_2	15
Al_2O_3	5 to 6
S	0.1 to 0.2
P	1.5

Neumark considers that this will give the cheapest iron in Russia, and places the cost of pig-iron at from $11.00 to $12.50 per ton. The ore will be used in works now building at Kertsch, and it is also carried to the furnaces in the Krivoi Rog district in spite of its low content of iron.

In 1899 the production of ore in South Russia was as follows:

	Tons.
Krivoi Rog	2,650,000
Local Donetz	180,000
Kertsch	190,000
Manganese ores	100,000
Total	3,120,000

South Russia in 1887 produced only 161,000 tons of iron ore, but in 1897 the output had risen to 1,898,000 tons, and in 1899 to 3,120,000 tons or over half the entire output of the Empire. In 1900 it was estimated that the Kertsch peninsular would raise 600,000 tons. The tonnage of wrought-iron and steel produced in 1899 was twelve times what it was ten years before. In 1888 this district made only 13 per cent. of the pig-iron and 18 per cent. of the steel made in Russia; in 1899 it made over 50 per cent. of both pig-iron and steel.

In 1900 there were 17 works, the most important being given in Table XXVI-C, the new works in Kertsch not being included. The plants are scattered considerably, one large works, the Providence Russe, with three blast furnaces, being at Mariupol, one at Taganroth and others nearer the ore in the vicinity of Ekaterinoslav.

TABLE XXVI-C.

Principal Iron and Steel Works in South Russia in 1900.

	Pig Iron. Tons.	Finished Iron and Steel. Tons.	No. of Men Employed.
New Russian Company, Limited........	270,000	153,000	8,319*
South Russian Dnieper Met. Co..........	210,000	170,000	6,636
Petrovski, Russo-Belgian Met. Co..... .	148,000	107,000	2.689
Alexandrovski, Briansk S. Russian Co..	145,000	90,000	7,174
Donetz-Yurieff Met Co..................	110,000	32,000	3,240
Donetz Ironworks and Steel Co.	95,000	76,000	2,371
Taganrog Met. Co.......................	80,000	65,000	3,122
Olkovaia Furnaces and Works Co.......	80,000	....	458
Nikupol-Mariupol Min. & Met. Co......	76,000	23,000	1,619
"Russian Providence" at Mariupol....	70,000	40,000	1,841
Sulinski (Pastukhoff)..................	40,000	25,000	3,091

*It has been previously stated, on the authority of the Russian Journal of Financial Statistics, that the number of workmen in 1899 in all the works of the New Russian Co. was 14,500. It is stated in a British Consular Report that the number is 8,319. It is probable that the latter figure omits some of the mines or associated industries.

SEC. XXVIc.—*The Urals:*

The Ural district presents some problems of peculiar interest to the metallurgists. The ores have long been known and the iron made from the beds of Mount Tagil has been famous all over the world. The deposits are scattered over quite a distance north and south, both on the eastern and western slopes of the range, and lie mostly between 54° and 60° north latitude and 56° and 62° east longitude, an area about 240 by 420 miles. Some of the beds are brown ore, occurring in strata 130 feet thick and containing 60 per cent. of iron after roasting, while other deposits are of magnetite and are among the most important in the world.

The chief center of the Eastern Urals is near Nisjne Tagual, where the hill known as Wissokaia Gora offers a deposit about a mile square, in which the best ore runs from 60 to 65 per cent. in iron. The famous iron mountain of Blagodat is thirty miles north of Nisjne Tagual and three miles from the Kouchwa Station on the Ural Railway. This mountain is seamed with ore running from 52 to 58 per cent. in iron. The more northern deposits in the Ural district are difficult of access, but the southern, as above indicated, are on the line of the railway from Perm to Ekatevinburg.

In 1888 this district produced over one-half of all the pig-iron made in Russia. Since then the proportion of both has decreased, but the production of pig-iron has doubled in tons and the output of steel increased nine fold. This development has gone on in spite of the fact that good fuel is scarce. There are very large deposits of coal, but the quality is very bad, the ash running from 17 to 23 per cent, and it gives a very poor coke. The whole district in 1900 raised only 339,000 tons, or much less than half a ton for each ton of pig-iron. From this it may easily be seen that the almost universal fuel is charcoal, and this is not always of the best. In the southern part pine wood is used and the blast furnaces are built as much as 59 feet high, this being considered the maximum allowable, but as we go northward the charcoal becomes poorer and the possible height of the furnaces less, so that in the Central Urals they are only 50 feet and in the northern part only 42 feet, the average production for one furnace per day being twenty tons.

To the average metallurgist it may seem impracticable to carry on metallurgical operations on a vast scale when charcoal is the only available fuel, but certain things must be taken into account. First: The great iron district of South Russia is 1200 miles away as the crow flies, rather far for Russian railways, and when it comes to water transportation the advantage is all the other way, for the Ural iron works would be shipping *down stream.* This is an important matter in Russia where there is an immense commerce in the transportation of products down river on rafts and barges which are broken up for lumber at the end of the journey, there being no need of a return cargo.

Second: The Russian government prohibits the destructive deforesting of lands, so that the same area may be reckoned as affording a sure supply of charcoal in a given number of years.

Third: After allowing for the growth of population and its needs, the Urals will have 40,000,000 acres of perpetual forest land, equal to a space 250 miles square, and it is estimated that this will produce charcoal sufficient to make 4,700,000 tons of pig-iron per year. It is also calculated that this charcoal can be made for $4.25 per ton.

Fourth: The ore is abundant and some of it of the best quality.

These facts are not disputed and it therefore becomes a question why there is not a more rapid development in the region. This subject was made the occasion for an investigation by the government. It was shown that onerous restrictions and routine imposed by branches of the government itself were responsible for much of the trouble, these being in great contrast to the encouragement given to industries in South Russia. Possibly quite as serious a matter was the system of land tenure, for it was pointed out that a great part of the land has not yet been allotted to the serfs set free a generation ago, and as no man knows what land he will have or how much he will get, it can hardly be expected that he will take much interest in any part of it, or spend money on improvements. Another factor in the problem is the law providing that the landed proprietors must furnish steady work to the people living on the estate, and under these circumstances it can hardly be expected that labor saving machinery will be introduced.

A most peculiar feature in the situation is the status of what are styled "Possession Works." These are owned by the government and are leased to individuals or companies. These properties embrace 6,000,000 acres of forest land, equal to an area 100 miles square, and the blast furnaces produce 200,000 tons per year, or one-third the total production of the Urals. The terms of the lease prohibit the proprietor from making any improvements or changes without special authority from the State. There are also numberless petty prohibitions, as for instance, the sub-letting of leaseholds, etc., that render an efficient liberal management entirely out of the question. Coupled to these conditions is the natural opposition of mediæval feudal landed proprietors to changing the existing order. Some day the spirit of enterprise which is now transforming Russia may take hold of this remote corner of the empire, and when the great plains of Siberia and Eastern Russia are more thickly peopled we may have the curious condition of an immense iron and steel producing district with charcoal as the only fuel.

It may also be possible that some of the best ores may be transported 1200 miles to the Donetz coal basin, or that the coal may be taken to the ore. The prohibitive distances intervening between outside countries and the center of the Continent make many things possible when the time comes that the plains of Asia are covered with cities, or when they will be laid out with railway systems as the Great Desert of our own West has been reconstructed in a generation.

At the present time one solution to the transportation problem in the Urals is being given by a company which is building a plant of six 15-ton open-hearth furnaces at Tsaritain on the Volga. The pig-iron will be made in charcoal furnaces in the Urals and be brought 900 miles on barges by river, and it must all be brought on the summer freshet, as the upper tributaries are only navigable at that time. The fuel is naphtha, which will be brought 700 miles from Batoum by way of the Caspian Sea and the Volga.

One of the principal works in the Urals is the Nijni Tagual, owned by Demidoff, Prince San-Donato. This is near the ore deposits of Blagodat and Vissiokaia and has eleven blast furnaces, twelve open-hearth furnaces and a Bessemer plant. The largest works in the Southern Urals is near the ore mine of Komarowo, but its output is only 2000 tons of pig-iron per month. This ore deposit is a brown hematite, but a little distance to the eastward is an immense deposit of magnetite at Magnitnaja or the "Iron Mountain."

Sec. XXVId.—*Poland:*

The prominence of Poland as an iron center rests solely on the fact that with the exception of Ekerinoslav it is the only part of Russia where extensive deposits of coal are found. In 1888 the Dombrova field, in the Bendzin district, province of Petrokov, in Poland, produced 2,376,000 tons of coal, being slightly more than Southern Russia, but in 1899 Poland had increased only to 3,950,000, while South Russia raised 6,686,000 tons. The coal of the Dombrovski basin is an extension of the Silesian deposit and gives a much poorer coke than is made from the coal in German and Austrian territory. The blast furnaces therefore bring almost all their supply from Austrian Silesia and Moravia. This condition has caused a very slow development of the coal industry, the increase in output in the three years from 1897 to 1900 being only 6 per cent. In this latter year Poland produced 26 per cent. of all the coal raised, the South contributing 69 per cent. and all other portions of the Empire only 5 per cent. A small amount of lignite is raised, but in 1900 the output was only 95,000 tons.

There are some deposits of iron ore in Poland, and there are nearly one hundred mines where brown hematite and spherosiderite are found, but the ore is very lean and variable, holding 20 to 50 per cent. of iron and the amount produced is unimportant. In 1899 only 488,000 tons were raised, half of which came from the province of Radom. The composition reported was 30 per cent. of iron in the raw stone and 35 per cent. when roasted. In recent years the ores of the Krivoi Rog have been brought 700 miles to replace the local supply. There are about 40 iron plants in the district, but they are as a rule very small and almost all the iron is made in four works, of which the principal is the Huta Bankowa, operated by French capital, possessing three blast furnaces making together about 250 tons of iron per day and eleven open-hearth furnaces. There is also quite a forge and tube plant at Warsaw, which has had open-hearth furnaces running on imported pig-iron, though blast furnaces are now building. The Briansk Company, which has already been mentioned as having a works in South Russia at Ekaterinoslav, also has a plant in Poland at Grodno.

In 1888 Poland produced 51,000 tons of steel and in 1899 it made 282,000 tons, and yet owing to the great advance in South Russia the percentage of total production made in this province was much less at the later period.

SEC. XXVIe.—*The Center:*

The district of Central Russia is one of the oldest in the Empire and includes an area about two hundred miles square, with Moscow at its northwest corner. There is a little coal found here, but it is the worst in Russia, being high in ash and sulphur and of poor structure and of little use in the iron industry. Formerly there were large forests, but two-thirds of this area is now denuded and charcoal has risen to prohibitory prices. There is a limited amount of brown and spathic ores, the latter in the best beds averaging about 50 per cent. of iron, giving 59 per cent. in the roasted ore. The silica is about 10 per cent. The home supply of raw material is so poor that coke is now brought 350 miles from the Donetz basin, and ore from the Krivoi Rog and Kertsch, the distance for the latter being about 600 miles. The principal works are at Tula, about 75 miles south of Moscow, and at Lipetzk, about 100 miles southeast of Tula. At the first named place there are three blast furnaces, each making 120 tons per day, while Lipetzk has two furnaces of larger capacity.

SEC. XXVIf.—*The North:*

The district of North Russia includes the provinces of Petersburg, Olonetz and Courland. There are some deposits of magnetites and lake ores, and works have been operated here for a long time, using charcoal as fuel. The present output of ore and pig-iron is small, but by the importation of fuel and pig-iron, mostly from England, a very considerable amount of steel is made.

TABLE XXVI-D.

Imports at St. Petersburg in 1899.

	Tons.
Pig-iron	9,000
Coke	128,000
Coal	1,639,000

There are several works of some size in the north, the Poutiloff, Nevski, Alexandrovsky, Kolpino and Obeuhoff being in the neighborhood of St. Petersburg. The Poutiloff is the largest of these, having two converters and twelve open-hearth furnaces. Another works, the Petrozavodsk, is situated about one hundred miles away at Ladogua.

CHAPTER XXVII.

AUSTRIA-HUNGARY.

I am indebted to my friends, Ernest Bertrand, general manager at Kladno, and Cari Sjögren, engineer at Donawitz, for reviewing this manuscript and giving much information.

SECTION XXVIIa.—*General View:*

The dual Empire of Austria-Hungary is often treated as a unit and often as two distinct entities, and it is sometimes difficult to tell whether statistics relate to Austria proper or to Austria-Hungary. This is due to the peculiar political relations existing between the two countries, which it is beyond the scope of this article to discuss.

The steel production of Austria demands attention on account of the energetic way in which improvements have been made in recent years, and because her metallurgists have always been progressive. It was as far back as November, 1863, that acid Bessemer steel was made at Turrach, in Styria, and this was followed in the next year by Neuberg, and by eight others soon afterwards. The Thomas Gilchrist basic Bessemer process was ushered into the world in 1878 and only one year later the first charge was made at Kladno, in Bohemia. In the same year both Teplitz and Witkowitz adopted the practice.

The steel industry of Austria, as far as it is here necessary to consider it, exists in three districts shown in Fig. XXVII-A: Moravia and Silesia in the north and east; Bohemia in the northwest, and Styria and Carinthia in the southwest. Not one of these possesses all the essentials for cheap production, for Bohemia and Styria have no coke, and Moravia no ore. Moreover, the situation of Austria does not facilitate international trade, especially as Russia, which would be a natural outlet for manufactures, has adopted a very decided protective tariff system. For this reason the Austrian industry is not specialized and cannot tend toward a heavy production of one line of work, but toward a diversified output, and for this reason also the basic open-hearth is rapidly becoming the general method of manufacture. Quite a considerable amount is made by the basic Bessemer, but very little by the acid open-hearth,

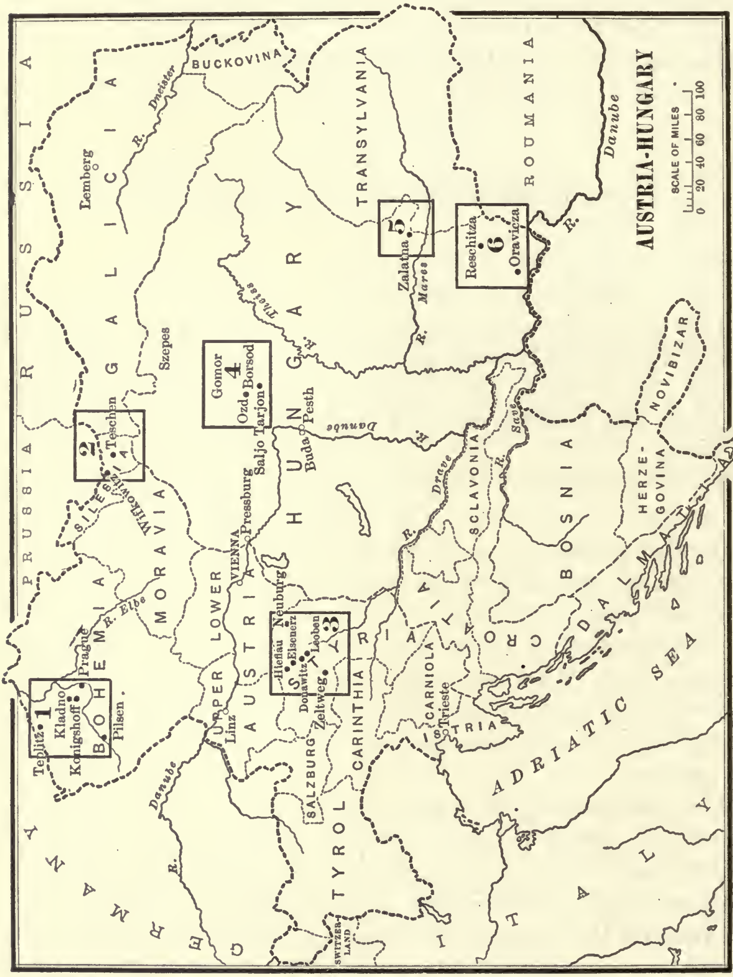

FIG. XXVII-A.

while during January, 1901, there was blown what will probably be the last heat of acid Bessemer steel. The statistics of production as far as available are given in Table XXVII-A and XXVII-B the latter showing how the basic process has supplanted the work on acid linings.

TABLE XXVII-A.

Production of Fuel, Ore, Iron and Steel in Austria-Hungary in 1900; metric tons.

Index of Authorities; see Table XXX-A.

Province.	Bituminous Coal.	Lignite.	Ore.	Pig Iron.	Steel.
Bohemia	3,590,670[9]	17,359,952[9]	667,946[9]	281,639[9]	214,000[19]
Styria	....	2,802,891[9]	1,151,173[9]	275,901[9]	205,000[15]
Moravia	1,478,957[9]	190,213[9]	8,582[9]	271,304[9]	235,000[15]
Silesia	4,697,091[9]	1,101[9]	70[9]	41,819[9]	
Gallicia	1,166,633[9]	76,792[9]	....	2,062[9]	
Triéste	....	....	....	54,604[9]	
Other Provinces	59,194[9]	1,108,968[9]	66,687[9]	72,878[9]	127,000
Austria	10,992,545	21,539,917	1,894,458	1,000,207	781,000[14]
Hungary	1,238,855[9]	4,292,584[9]	1,567,860[9]	451,647[9]	353,000[14]
Austria Hungary	12,231,400	25,832,501	3,462,318	1,451,854	1,134,000[14]

TABLE XXVII-B.

Production of Steel in Austria (not including Hungary).

From Kupelweiser; Oesterreichischer Zeitschrift, XLIX., 1901. In 1879, the first basic steel was made. In January, 1901, the last acid Bessemer heat was blown.

Year.	Bessemer Steel.			Open Hearth Steel.			Total Steel.
	Acid.	Basic.	Total.	Acid.	Basic.	Total.	
1879	76,348	3,500	79,848	19,697	....	19,697	99,545
1880	75,027	17,835	92,862	20,481	....	20,481	113.343
1881	88,279	31,889	120,168	29,846	....	29,846	150,014
1882	101,230	57,714	158,944	39,740	....	39,740	198,684
1883	101,254	88,429	189,683	43,797	....	43,797	233,480
1884	86,855	70,987	157,842	40,009	....	40,009	197,851
1885	88,288	76,821	165,109	41,021	....	41,021	206,130
1886	60,016	105,839	165,855	25,861	11,204	37,065	202,920
1887	67,620	118,379	185,999	18,309	29,631	47,940	233,939
1888	76,533	139,127	215,660	25,572	50,962	76,534	292,194
1889	72,849	126,502	199,351	32,121	77,516	109,637	308,988
1890	76,684	103,180	179,864	29,204	133,808	163,012	342,876
1891	60,713	95,061	155,774	27,800	150,493	178,293	334,067
1892	50,379	100,841	151,220	20,114	180,951	201,065	352,285
1893	48,657	108,104	156,761	19,794	203,894	223,688	380,449
1894	47,784	133,131	180,915	17,729	254,835	272,564	453,479
1895	46,502	127,816	174,318	18,576	304,747	323,323	497,641
1896	46,931	157,216	204,147	21,587	356,973	378,560	582,707
1897	38,713	167,688	206,401	14,754	405,098	419,852	626,253
1898	41,963	184,650	226,613	15,952	480,125	496,077	722,690
1899	38,538	186,643	225,181	18,314	540,894	559,208	784,389
1900	18,214	182,809	201,023	23,196	557,110	580,306	781,329

Owing to the high freight rates and the long distances from the northern coal districts to the southern parts of the Empire a large quantity of coal is imported at southern ports. In the year 1899 the total coal raised was 41,000,000 tons, but only 11,450,000 was bituminous, the remainder being lignite. In the same year the imports amounted to 17,000,000, so that much more bituminous coal was imported than was used. The local gas works at Trieste sell coke for domestic use at $9.30 per ton. A large quantity of Westphalian coke is brought to the blast furnaces of Bohemia and even to Styria, since the coke districts of Moravia and Silesia are as yet unable to meet the demand. There is one large blast furnace at Trieste which uses coke from England and sometimes ocean-borne coke from Westphalia, and some of the smaller charcoal furnaces in the south often use a certain proportion of imported coke. I was informed by one of the great iron masters of Austria that he had seriously considered the use of American coke in the blast furnaces of southern Austria, but the high prices and high freights of the last two years have been prohibitory. The total production of coke in Austria in 1900 was 1,227,918 tons, almost all of which was made in Moravia and Silesia. The production of Hungary was only about 10.000 tons.

To balance the very considerable quantities of coke coming into Austria from Germany, there are large amounts of brown coal (lignite) carried from the region around Teplitz in Bohemia into Germany. It goes northward by water transports on the Elbe to Magdeburg, and even to Hamburg, meeting there the competition of English and Westphalian fuel.

SEC. XXVIIb.—*Bohemia* (*see No. 1 on Map*):

This province is well supplied with fuel although there is no good coking coal. In 1889 it raised 4.070,000 tons of bituminous coal, or nearly as much as Austrian Silesia, while it produced 17,960,000 tons of brown coal (lignite), or over 82 per cent. of the total for Austria, most of the latter coming from the immediate vicinity of Teplitz. Bohemia also has a supply of iron ore which is quite well suited for the basic Bessemer. It carries from 0.6 to 0.8 per cent. of sulphur and is roasted and leached with water to dissolve the sulphates, after which treatment it averages about as follows:

	Per cent.
Fe	42.00 to 48.00
P	1.2
Mn	0.1
S	0.3

The coke is brought from Silesia and Westphalia.

The principal works are those of the Prager Eisen Industrie

Gesellschaft at Kladno and Teplitz, and the Böhmische Montan Gesellschaft at Königshof. Kladno has four large modern blast furnaces, a basic Bessemer plant with three converters of 13 tons capacity, a basic open-hearth plant and mills for rolling rails, structural shapes, wire, etc. The blooming mill is strong and ingots of three tons are rolled into rails and beams in one heat. Teplitz has three basic converters, two heavy plate mills and a beam mill. It receives pig-iron from Königshof, where there are four modern blast furnaces, a foundry and one basic converter. Until quite recently there was considerable business done in making small ingots and great quantities were made only four inches square, which were rolled directly into small shapes, but this practice is now carried on only at Königshof and in very small amount. It is found more economical to roll billets from large ingots than to cast small pieces, this being the trend of experience throughout Europe where many plants are giving up the old practice. It is at Kladno that Mr. Bertrand has developed the Bertrand Thiel open-hearth process which has been discussed in Chapter XII. The ore used in the open-hearth furnaces is partly Gellivare (Swedish), and some of this is also used in the blast furnace to reduce the content of phosphorus in the pig-iron to about 1.5 per cent.

It is also necessary to mention the steel casting plant of the Skoda Company at Pilsen, which has a high reputation for difficult stern posts, etc., for large ships, and is also equipped with hydraulic presses for guns and armor.

Table XXVII-C gives a list of the principal works in Bohemia.

TABLE XXVII-C.

List of Steel Works in Bohemia (Böhmen).

This district is marked on the map as No. 1.

Name of Plant.	Location.	No. of Bessemer Converters.		No. of Open Hearth Furnaces.		Annual Output; tons.
		Acid.	Basic.	Acid.	Basic.	
Prager Eisenindustrie	Kladno		3		2	160,000
	Teplitz		3			
Boemische Montan, etc.			2			40,000
Skoda Steel Works.	Pilsen			4		14,000

SEC. XXVIIc.—*Moravia and Silesia* (*see No. 2 on Map*):

The coal field which has already been described as covering a large part of Upper German Silesia extends over Austrian Silesia and into Moravia. As before explained, the coal is rich, but does not give the best of coke. Immediately around Ostrau, where Witkowitz is situated, the quality of the coke is quite good, but in Silesia it is poor. It is however the only coke district east of Westphalia, and forms the nucleus for a considerable iron industry. The coke is used not only in Moravia, but in adjoining Bohemia and is shipped across the Russian frontier to the blast furnaces in Poland, which are almost entirely dependent upon this district for their supply. Some is sent to Styria, but the southern works use much coke from Westphalia on account of the better quality of the German product. The relative importance of the Silesian coal district as it affects the different nations will be seen from Table XXVII-D, which shows the output of bituminous coal from this international field.

TABLE XXVII-D.

Output of the Silesian Coal Field.

	Tons in 1899.
Germany; Silesia	23,527,000
Austria; Moravia and Silesia	6,252,000
Russia; Poland	3,905,000

The province of Silesia produced three times as much coal as Moravia, but the latter division made the most coke, as the southern portion seems to give the best material for smelting.

The one predominant iron and steel producer in this region is the works at Witkowitz in the province of Moravia. This plant draws much of its ore from its own mines in Hungary, the deposit being a carbonate, which is roasted. It makes about one-quarter of all the pig-iron that is made in Austria, the output being about 25,000 tons per month. There are six blast furnaces and two acid lined converters and eight twenty-ton basic open-hearth furnaces, which are operated by the duplex process, the pig being first blown in an acid converter, and then transferred to a basic open-hearth furnace. In this way the wear on the converter lining is minimized and the output of the open-hearth furnaces is about doubled; the blast furnaces are not confined to narrow limits in the composition of the iron and the whole process is a very attractive solution of a metallurgical problem. Apparently also the financial solution is attractive, but I believe that the work is more expensive than other methods. The works produces large quantities of all forms of rolled steel and has a large steel casting plant which has a wide reputation. In the coal region of Silesia are the works at Trynietz with two acid converters, and seven basic open-hearth furnaces, and mills for the making of rails, structural shapes and merchant iron. Table XXVII-E gives a list of the principal works in Moravia and Silesia.

TABLE XXVII-E.

List of Steel Works in Moravia (Mähren) and Silesia (Schlesien).

This district is marked on the map as No. 2.

Name of Plant.	Location.	No. of Bessemer Converters.		No. of Open Hearth Furnaces.		Annual Output; tons.
		Acid.	Basic.	Acid.	Basic.	
Witkowitz Bergbau, etc..	Witkowitz.	2*	....	....	8*	150,000
	Witkowitz.	....	....	....	4	25,000
Archduke, Frederic.......	Teschen...	2	....	....	7	60,000

SEC. XXVIId.—*Styria (see No. 3 on Map):*

A journey to a steel plant, whether it be in America, Germany or Russia, is not usually looked upon as a pleasure from an æsthetic point of view, but there is one exception in a visit to the beautiful valley where the ancient town of Leoben and the steel works of Donawitz lie peacefully hidden in the shadow of the Alps. At the end of the valley, only a few miles away, is a mountain towering in a huge cone nearly 5000 feet above the sea and 3000 feet above the hamlet below. This is the Erzberg or Ore Mountain. The whole surface is a layer of spathic ore from 200 to 500 feet thick and it is mined by a succession of terraces all the way up the mountain side.

This deposit has been known from the most ancient times, the present province of Styria being a part of the Roman province of Noricum, from whence came a large portion of the weapons of the Roman legions and other iron instruments of the Empire. In fact, Styria and Carinthia both claim the "rather doubtful honor," as Tunner expresses it, of supplying the nails for the cross that was erected on Calvary. Certain it is that the mines were worked

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*These converters and furnaces are worked by the "combined" or "duplex" process.

tens of thousands of years before that, for the remains of primeval man have been found beside the unburned charcoal of prehistoric forges.

To-day some of the ore is brought to Donawitz, near Leoben, while a large amount is smelted in a new furnace plant erected at Eisenerz, nearer the Erzberg, and there are furnaces also at Hieflau. It is a spathic carbonate of about the following composition:

	I.	
	Crude.	Roasted.
FeO	34.97	.....
Fe_2O_3	16.75	74.04
Mn_3O_4	2.98	4.01
SiO_2	8.20	11.04
Al_2O_3	2.09	2.81
CaO	3.06	4.12
MgO	2.92	3.93
CO_2	27.60	.....
P_2O_5	0.04	0.05
SO_3	tr.	.....
	98.61	100.00

	II.	
	Crude.	Roasted.
Fe	38.93	51.80
Mn	2.15	2.84

When weathered it is a brown hematite containing about 54 per cent. of iron, but the proportion of weathered ore is small. The ore is roasted in kilns, giving an average of about 50 per cent. in iron. It is smelted with coke brought from Westphalia and Austrian Silesia, the first of these being 500 miles away in a straight line. The transportation moreover is very expensive from both fields owing to the very heavy grades on the picturesque route through the Steiermark Alps.

Many of the blast furnaces of Austria are built upon a plan which is different from the usual American construction. The whole structure rests not upon solid ground on the general level, but on a pier formed of arches, so that one may walk directly underneath the bottom. At Donawitz the tap hole is at least fifteen feet above the general level. The mere elevation is nothing unusual, as many American furnaces are built high in the air to allow the iron and slag to be carried away in cars, but in Austria it is claimed that the bottom of the furnace must be kept cool in order to prevent the cutting away of the lining and the breaking out of the iron. This difference in construction is due very much to a difference in the work to be done. When running on ordinary Bessemer iron for the acid converter, the temperature is high, and graphite is deposited as a protective covering in the interior of the hearth; but when a very low silicon iron is desired the conditions are quite the reverse. It is safe to say that no American furnaceman will agree to make iron regularly with as low a content of silicon as that which is considered the standard product at Donawitz. I have been given the following as typical:

C	4.00
Si	0.10 to 0.30
S	tr to 0.03
P	0.08 to 0.10
Mn	2.0 to 2.5

This iron is taken to a basic open-hearth furnace in a molten state, and the value of the low silicon need not be dwelled upon. The linings are of magnesite, for in Styria this mineral is abundant and it is as cheap as almost any other refractory material. Taken all in all, it may be considered a fortunate thing for the rest of the world that good coking coal does not exist in the Steiermark.

There is a deposit of brown coal nearby, and Styria in 1899 raised 2,624,000 tons or about ten per cent. of the total output of Austria. It is the only province besides Bohemia that does produce a large quantity, but there is no bituminous coal found in the empire except in the northern provinces.

The predominant steel producer in the district is the Alpine Montan Gesellschaft and mention has already been made of the furnace plants smelting the ore of the Erzberg. The one great steel works is at Donawitz, near Leoben, which has lately been entirely rebuilt. There are also modern plate and universal mills at Zeltweg. Table XXVII-F gives a list of the principal works in Styria.

TABLE XXVII-F.

List of Steel Works in Styria (Steiermark).

This district is marked on the map as No. 3.

Name of Plant.	Location.	No. of Bessemer Converters.		No. of Open Hearth Furnaces.		Annual Output; tons.
		Acid.	Basic.	Acid.	Basic.	
Oesterreichische Alpin Montan, etc.	Donawitz				13	160,000
	Neuberg			3	2	20,000
	Zeltweg				2	25,000

SEC. XXVIIe.—*Hungary:*

The iron industry of Hungary is considerably scattered, but more than half of all the pig-iron of the country is made in the northern portion in the counties of Szepes, Gomor, Borsod and in their immediate neighborhood. (See No. 4 on map.) Considerable ore is found in this district, the deposit being a spathic carbonate which must be calcined. In 1899 there were 1,337,000 tons of ore raised in this field, about 30 per cent. of this being exported. The steel works at Witkowitz in Moravia owns mines here and in 1899 took 200,000 tons of ore from Borsod County, which was nearly all it produced, while a considerable quantity is sent from other mines to Bohemia and German Silesia, the works at Friedenshütte owning mines near Kotterbach. Out of 67 blast furnaces in all Hungary there are 37 in this Szepes Iglo district. Most of them are small, some use charcoal, but many bring coke from Silesia, as good coking coal is not found either here or in any other part of Hungary.

There is a very considerable steel plant of the Rimamurian Salgo Tarjan Ironworks Company at Salgo-Tarjan, this company owning mines in Gomor County and having blast furnaces and rolling mills. About 75,000 tons of steel are made per year from three 7-ton basic converters. There are also smaller works at Ozd, while the Austrian-Hungarian State Railway operates a plant of two basic converters and several open-hearth furnaces, making together about 50,000 tons per year. Another small Bessemer plant it situated at Sohl. In the South is the old established plant at Reschitza, where there are three basic converters and three 20-ton open-hearth furnaces with a capacity of about 40,000 tons per year. The iron for this is made in the immediate neighborhood.

These two districts in the north and in the south make three-quarters of all the pig-iron smelted in Hungary and a larger proportion of the steel. The only other district worth mentioning is in the southeast in Transylvania, where a larger amount of pig-iron is made than in Reschitza. The great drawback throughout all Hungary is the absence of coking coal and only 10,000 tons are produced per year, this being made in the vicinity of Buda Pest. The Hungarian works therefore are on a moderate scale, and being protected by the government in every way content themselves with supplying the wants of the state railways and of the general home market. Table XXVII-G gives the output of fuel and iron in 1899, while Table XXVII-H gives the records of steel production.

TABLE XXVII-G.

Production of Coal, Ore and Pig-Iron in Hungary in 1899 by Districts; in metric tons.

From Struthers: Eng. & Min. Journal; private communication.

	Szepes-Iglo (Northern Part).	Zalatna (Transylvania).	Orvicza (Southern Part).	Budapest.	Others.	Total
Designation in Fig. XXVII-A.	4	5	6			
Active blast furnaces	32	9	7	....	6	54
Idle blast furnaces	5	2	2	....	4	13
Pig Iron	259,698	107,575	76,060	....	8,314	451,647
Iron Ore	1,337,451*	270,882	135,793	186,230	22,823	1,567,860
Bituminous Coal	....	7,648	470,018	761,189	....	1,238,855
Coke	....	....	....	10,036	....	10,036
Lignite	....	785,010	53,819	1,883,114	1,570,641	4,292,584

TABLE XXVII-H.

Production of Steel in Hungary.

From Kupelweiser; Oesterreichischen Zeitschrift; XLIX, 1901.

Year.	Bessemer Steel.			Open Hearth Steel.			Total Steel.
	Acid.	Basic.	Total.	Acid.	Basic.	Total.	
1880	12,854	....	12,854	8,021	....	8,021	20,875
1885	61,269	....	61,269	11,384	....	11,384	72,653
1886	51,106	....	51,106	3,201	2,740	5,941	57,017
1887	47,163	....	47,163	4,199	13,891	18,090	65,253
1888	72,687	....	72,687	3,100	24,832	27,932	100,619
1889	60,152	14,914	75,066	3,800	28,658	32,458	107,524
1890	72,976	34,841	107,817	4,700	44,207	48,907	156,724
1891	57,475	41,262	98,737	525	52,709	53,234	151,971
1892	54,030	45,448	99,478	....	59,380	59,380	158,858
1893	68,493	51,313	119,806	....	69,421	69,421	189,227
1894	69,968	57,496	127,464	....	79,483	79,483	206,947
1895	80 579	65,518	146,097	....	100,809	100,809	246,906
1896	73,172	66,542	139,714	1,413	153,563	154,976	294,690
1897	66,567	65,778	132,345	3,529	176,436	170,965	303,310
1898	66,081	71,310	137,391	4,298	189,862	194,160	331,551
1899	41,894	62,136	104,030	2,410	226,195	228,605	332,635
1900	49,842	62,336	112,178	11,387	229,199	240,586	352,764

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* Of this total, 385,319 tons were exported, mainly to Moravia, but some to Bohemia and German Silesia.

CHAPTER XXVIII.

BELGIUM.

This article has been submitted to M. H. de Nimot, secretary of the Association des Maitres des Forges, at Charleroi, Belgium, who has been kind enough to go through it very carefully and give me some figures for 1900 not otherwise obtainable. M. de Nimot objects to my statement that the working people of Belgium are "bound to the vocations of their fathers." I deem it merely justice to him to offer his protest, but I believe that while it may not be absolutely and universally true, as no such generalization can ever be, the argument as herein given portrays a real condition and a real difference between the workmen of Belgium and America.

Belgium is essentially a fuel producing country. In 1900 she raised 23,462,817 tons of coal, which is about one-tenth of the production of the United States or of Great Britain. The production of coke was 2,434,678 tons. Table XXVIII-A gives the main facts about the country, from which it may be seen that about three-fourths of all the coal and also of the coke comes from the province of Hainaut on the border of France, and almost all the remainder from Liège. The Belgian coal mines have reached a great depth, which materially increases the cost of operation, and there is much trouble from the great amount of gas in the beds, causing fearful explosions which seemingly no care can prevent. The average working depth in Hainaut is 1600 feet, while some mines run from 3400 to 3800 feet. It is estimated that the coal supply will last from one hundred to two hundred years longer, this period being the same as that assigned to the deposit of Central France, the North of England and Central Bohemia.

The average cost of coal at the mines for the whole country for 1899 was officially given at 10.72 francs =$2.07 per ton, and the average selling price $2.40. In 1900 the cost was $2.78 and the selling price $3.48. The average price of coke was $3.96 at the ovens in 1899, but in 1900 the price averaged $4.18, although blast furnace coke was sold at an average of $3.40 per metric ton. About one-fifth of all the coal raised, and over one-third of all the coke made, is exported, most of these shipments going to France. On the other hand, the imports of coal amount to one-seventh as much as is raised and a very considerable quantity of coke is brought in, these imports coming from Westphalia across the eastern border while the exports go southward. The Westphalian coke is far superior to the Belgian product, but it is economical for the French works to buy the poorer article on account of the short haul.

TABLE XXVIII-A.

Production of Coal, Coke, Iron and Steel in Belgium in 1900; metric tons.

	Hainaut.	Liège.	Namur.	Luxemburg.	Total.
Coal raised	16,532,630	6,190,892	739,295		23,462,817
Imported from Germany					1,573,697
" " England					1,173,917
" " France					497,088
Exported to France					3,917,765
Coke made	1,748,450	686,228			2,434,678
Imported from Germany					220,753
" " England					40,559
" " France					25,688
Total exports					1,073,313
Exported to France					646,369
Ore raised				247,890	247,890
Imported from Luxemburg					1,564,579
" " Spain					321.478
" " France					291,783
" " Sweden					98,539
" " Others					252,236
Pig iron made					1,018,561
Imported from England					155,873
" " France					73,603
" " Germany					53,674
" " Un. States					12,259
Steel made	225,945	429,254			655,199
Rails					134,428
Puddled iron					333.981
Finished iron					358,163
Exports of finished iron & steel					415,802
Total number of blast furnaces	16	17		6	39
Active in 1901	8	12		5	
Number of Bessemer converters					47
Number of open hearth furnaces					18
Av. wage in steel works per day	77 cents	78 cents			

Belgium formerly raised quite a considerable quantity of iron ore, but her maximum production was reached in 1865 with a total of 1,019,000 tons, the output since then having decreased until now it is only about one-fifth of that amount. Some ore is raised in the province of Luxemburg, which just touches the great Minette deposit that spreads out over the adjoining Grand Duchy of Luxemburg, now in commercial alliance with the German Empire. It is from the Grand Duchy and from Rhenish Prussia that Belgium draws most of her ore, although a very considerable amount is brought from Spain to Liège, very little foreign ore going elsewhere in the country except some containing manganese. The pig-iron from these Spanish ores makes about one-sixth of all the iron produced in Belgium, and it is used almost entirely for the manufacture of acid Bessemer steel.

The ores from the Minette district give an iron running from 1.3 to 2.0 per cent. in phosphorus and large quantities are used for puddling and for foundry purposes. In making iron for the basic Bessemer it is a common practice to use a certain proportion of manganiferous ores and slags so that the iron will contain from 1.5 to 2.0 per cent. of manganese.

The pig-iron used in Belgium is almost all of domestic manufacture, about one-sixth of the total output being made in the province of Luxemburg, the remainder being equally divided between Liège and Hainaut. The total production of the country at its maximum is about one million tons per year or just about what would be made by ten furnaces making three hundred tons per day. Three-quarters of all the pig-iron made in the Kingdom is smelted at eight plants, a list of which is given in Table XXVIII-B.

TABLE XXVIII-B.

List of Important Blast Furnace Plants in Belgium.

Province.	Name of Works.	Location.	Number of Blast Furnaces.	Capacity per Furnace per Day.
Hainaut	la Providence	Marchienne	3	....
	de Coullet	Near Charleroi	4	90
	de Monceau Sur Sambre	Near Charleroi	2	90
Liège	Soc. John Cockerill	Seraing	6	....
	L'Esperance Longdoz	Seraing	2	....
	Angleur	Tilleur	4	....
	Ougrée	Ougrée	4	....
Luxemburg	d'Athus	Athus	2	70

The steel is made almost entirely in the two provinces of Liège and Hainaut. The production in 1899 was 718,000 tons or about 60,000 tons per month, but in 1900 this fell to 655,000, while in 1901 it was about 500,000 tons, owing to the great depression in business throughout Europe. Out of 47 converters only 25 are in operation and only 12 open-hearth furnaces are working in the whole country. Over 60 per cent. of the steel was made at Liège, and the works of John Cockerill made most of the rails that were rolled, amounting in 1900 to 134,000 tons, or about 11,000 tons per month.

The great advantages possessed by Belgium are the short distances through which material must be carried, as will be shown in

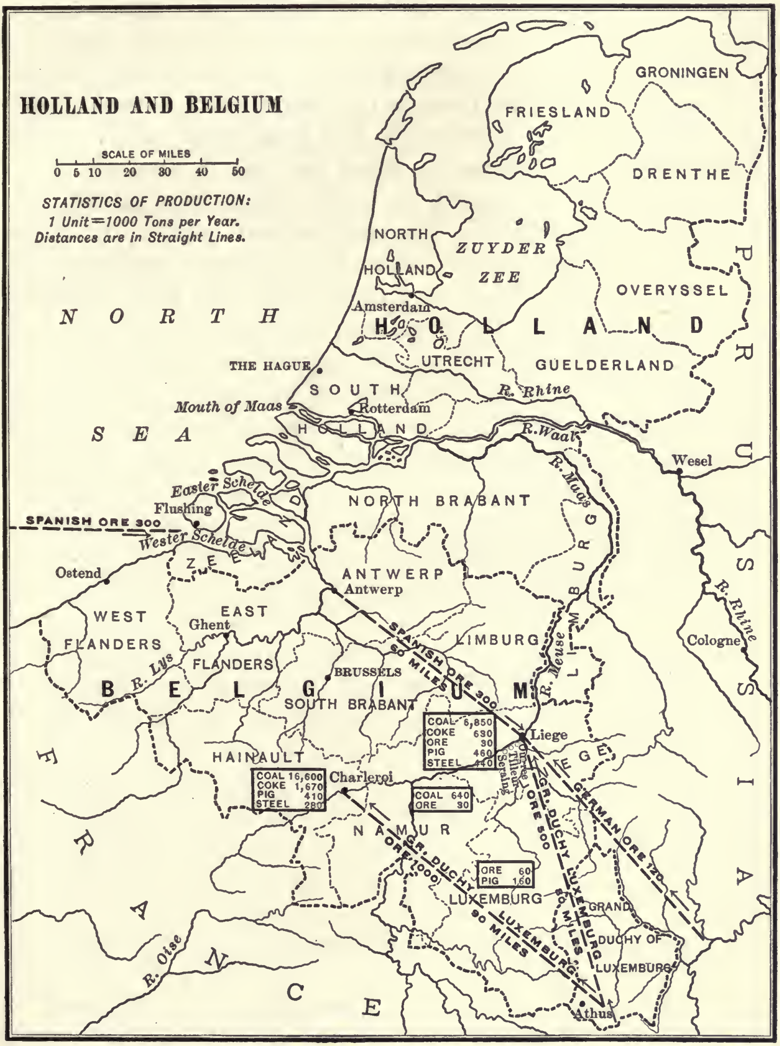

FIG. XXVIII-A.

Fig. XXVIII-A. A circle of less than a hundred miles radius takes in the coal and ore mines and a seaport, while the average haul is much less than this. The wages of labor are also very low, and although it is a common saying that a man works just in proportion to the way he is paid, this saying is not always mathematically exact. It is perfectly true that a man working for 60 cents a day in Liège does not do as much work as an American laborer receiving twice as much, but it does not follow that he is only half as efficient. It is true that a woman loading coke and ore buggies and pulling them on the blast furnace hoist for thirty cents a day may not do the work done by a buggy puller in Pittsburgh receiving six times as much pay, but it does not follow that she only does one-sixth as much. There is a chance for a large margin of profit for the manufacturer, particularly in the very great number of cases where some human intelligence and some human hand must be at a certain post, and where the grade of the intelligence and the strength of the hand are matters of little moment. There are multitudes of positions in a steel works where this condition obtains, and in Belgium women fill such positions, receiving a mere pittance. As before stated, they do a very large share of the work that we call "general labor." About ten years ago Belgium passed laws regulating the employment of women and children in mines, and there has been a very marked advance in this direction. In 1870 there were from 8000 to 9000 women and girls working underground in the coal mines. In 1889 there were 3700. In 1891 the women and girls constituted four per cent. of all the working force under ground, while in 1899 they formed only a fraction of one per cent. Of the over ground workers the women and girls constituted 25.1 per cent. in 1891, 24.3 per cent. in 1899, and 23.1 per cent. in 1900. Of the over ground workers at these mines in 1900, in a total of 34,075 people, there were 3787 girls between the ages of 16 and 20, or 11.1 per cent. of the whole. In addition to these there were 2589 girls between 14 and 16, a proportion of 7.6 per cent., so that 18.6 per cent. of the entire force was made up of girls between 14 and 20 years of age.

Considering the works above and below ground together for the year 1899, concerning which I have the full official statistics, there was a total of 125,258 people, of whom there were 6522 girls from 14 to 20 years of age, or 5.2 per cent. A little calculation from the mortality tables will show that this represents over half of all the girls of that age that would be found in a community containing that number of people, and after allowing for the infirm it will be seen that in the coal mining communities of Belgium almost all the girls between the ages of 14 and 21 work around the coal mines or coke ovens.*

It is difficult for an American to appreciate what this means until he sees the conditions on the spot and until he has known what it is to work day and night shift out doors in all weather and in all seasons. It seems inevitable that the same law of progress which has just led Germany to abolish woman labor in steel works, which emancipated woman in England a generation ago, and which never allowed her to consider drudgery in America, will extend its power over Belgium and Austria. When this happens the wages of the men must be increased, as there will be but one wage earner in the houshold.

The spread of general intelligence will also have its effect upon even the remote districts. At present the working classes in many places seem bound to their home and to the vocation that their fathers knew before them. This is a sort of mediæval and provincial idea not entirely absent in other parts of Europe, and it may even be detected in America, but in England and in the United States it cannot be reckoned with in the labor situation. These ideas must disappear and with them will disappear the cheap labor of Belgium, although all history shows that an increase in the wages of the day laborer need not necessarily raise the cost of manufactures.

In addition to her production of steel, Belgium turns out a large quantity of puddled iron. In the year 1900 her production of steel was 655,000 tons and of wrought-iron 358,000 tons, a great deal of the latter being exported in the form of structural shapes. Belgium covers an area of only 11,370 square miles and had a population in 1899 of 6,744,532, so that her output of steel and wrought-iron is greater per inhabitant than any other nation. As a result she must seek an outlet and her exports of iron and steel wares amount to nearly one-half her total production. The actual tonnage so shipped, however, is comparatively small, being only one-quarter of the exports of Great Britain.

The area of Belgium is only one-fourth that of Pennsylvania,

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* I have calculated these figures from the official report of the Directeur General des Mines for 1899.

but if we take the southwestern part of the latter State, comprising the great coke and iron districts in the counties of Allegheny, Westmoreland and Fayette and as far east as Indiana, Cambria and Blair, we find that this section of the State, though having the same number of square miles as Belgium, contains less than one-fourth of her population. Or if we take the most thickly settled three States in the Union—the New England States, Massachusetts, Rhode Island and Connecticut—we find that these three have an area thirty per cent. greater than Belgium and yet have only half the population. These figures may give some idea of the density of population in this ancient state.

CHAPTER XXIX.

SWEDEN.

For the information herein given concerning Sweden I am principally indebted to my friend, Hjalmar Braune, metallurgical engineer of the Mining School at Filipstad, who has carefully read, corrected and twice reread the manuscript, and I feel sure that there can be no errors in the text. I have also consulted the Swedish official publication, *Kommerscollegii berättelse, for 1900* for the statistical data in Table XXIX-A and Fig. XXIX-A. Much general information has been taken from *L'Industrie Miniere de la Suede, 1897,* by Nordenström, and the paper by Akerman in the Journal of the Iron and Steel Institute for 1898.

Compared with the greater nations, the quantity of steel turned out by Sweden is of little importance when measured by tons, but she cannot be omitted from special consideration on account of her increasing importance as a source of iron ore, on account of the ancient prestige of her products, and on account of the care and skill with which that prestige is maintained.

TABLE XXIX-A.

Production of Coal, Ore, Iron and Steel in Sweden in 1900 and 1901; metric tons.

Data for 1901 from private communication from Richard Akerman.

	South 1900.	Southeast 1900.	Centre 1900.	North 1900.	Total 1900.	Total 1901.
Coal	250,000	....	....	....	250,000	271,509
Ore	....	1,000	1,563,000	1,044,000	2,608,000	2,795,160
Pig	....	24,000	503,000	....	527,000	528,375
Wrought Iron	....	23,000	165,000	....	188,000*	165,000*
Bessemer Steel	....	....	91,000	....	91,000	77,231
Open Hearth Steel	....	19,000	188,000	....	207,000	190,877
Total Steel	....	19,000	279,000	....	298,000	269,897

* The classification of wrought iron products is very imperfect and the figures are not accurate.

The chief characteristic of Sweden in the iron industry is her lack of coal and her supply of forests for the manufacture of charcoal. It is quite a safe assertion that had coal existed in Sweden to any extent the manufacture of iron would be far greater, but her steel would never have achieved its present reputation or commanded its present price. There are two or three ore beds of exceptional purity as far as phosphorus is concerned, and the fame of Swedish iron rests on these deposits at Dannemora, Norberg and

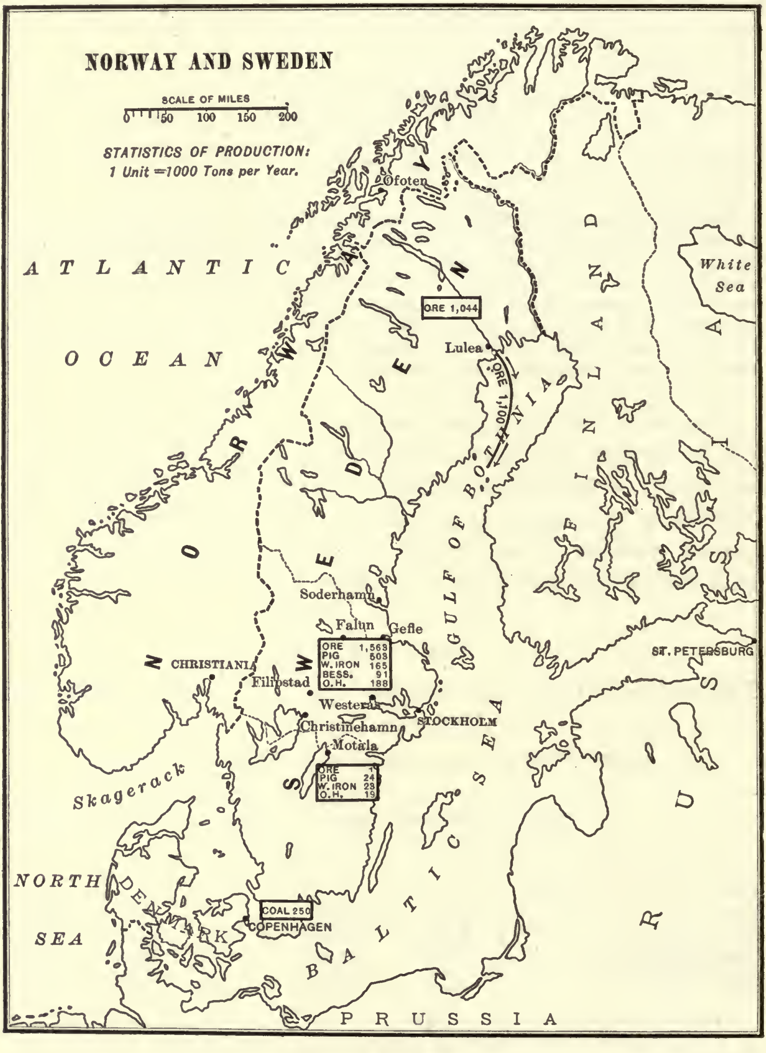

Fig. XXIX-A.

Persberg. It is well known that charcoal contains no sulphur, and if the ore after roasting contains none the pig-iron can contain none, even though the blast furnace be working cold. This is a proposition rather startling, but decidedly attractive to the average furnaceman.

Up to the year 1895 Sweden produced more wrought-iron than steel, but since then the output of iron has remained stationary, while the output of steel has increased. Ninety per cent. of this iron has always been made on the Swedish Lancashire hearth, an improved form of the ancient device, wherein a mass of pig-iron is caused to melt on the top of a charcoal fire and the melted mass again brought to the top and remelted, all the time being exposed to the blast, by which the silicon, manganese and carbon are eliminated under the influence of a slag of about the following composition: SiO_2=10 per cent.; FeO=78 per cent.; Fe_2O_3= 12 per cent. This gives the softest product that can be made by any steel or iron-making process, and when a charcoal pig-iron, low in phosphorus, sulphur, manganese and silicon, is used with charcoal, the latter being free from phosphorus and sulphur, the product must necessarily be pure.

In order to get the proper kind of pig-iron, it is necessary to have an ore free from phosphorus. The usual Swedish ore is a very hard magnetite; the blast furnaces are small, ranging from 40 to 60 feet in height and 7 to 10 feet bosh, with a diameter at the tuyeres of from 3.5 to 6.5 feet. When making pig for the Lancashire hearth the blast is kept at about 300° C. (570° F.) in order to keep the furnace cool, and for the same reason a diameter of over five feet at the tuyeres is not considered good practice, for a larger diameter even with cold blast will produce so high a temperature that manganese and silicon will be reduced. A drawing of a Swedish blast furnace for making pig-iron for the Lancashire hearth is shown in Fig. XXIX-B. The pig-iron used in the Lancashire hearth runs about as follows in per cent.:

Si	0.10 to 0.50, usually 0.25 to 0.30
Mn..	0.10 to 0.30
P.	0.01 to 0.03
S....	0.00 to 0.02

The composition of a very soft Lancashire wrought-iron, used for electrical purposes, is as follows in per cent.:

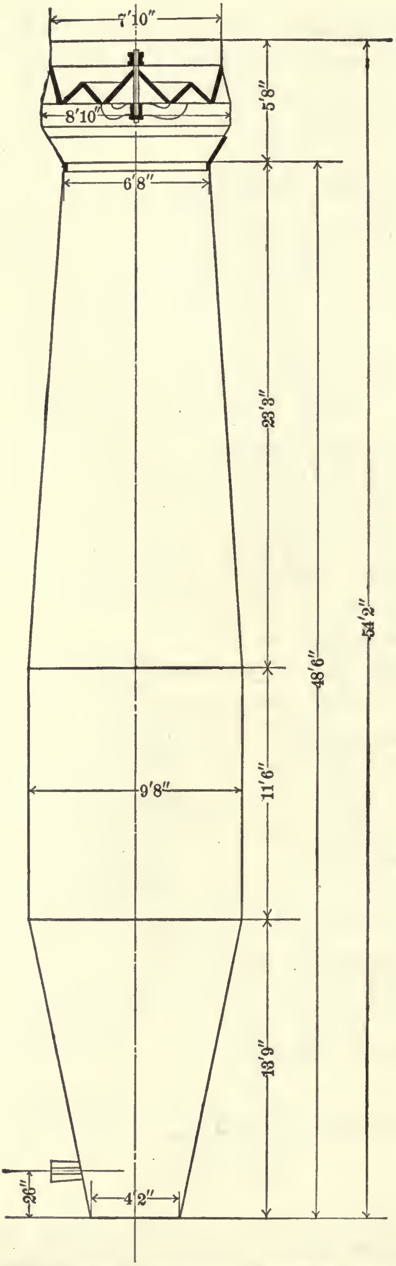

FIG. XXIX-B.—SWEDISH BLAST FURNACE.

C	0.05 — 0.06
Si	0.023
Mn	0.03
P	0.025
S	0.005

In making Bessemer iron a somewhat higher temperature is allowable and the diameter may be 6.5 feet, at the tuyeres, and the blast may be from 400° C. to 500° C. (750° F. to 930° F.), but even under this practice, and still more surely in the making of pig for the Lancashire process, the temperature of the zone of fusion in the blast furnace is so low that sulphur cannot be eliminated in the slag, and it is therefore necessary to always roast the ores even though they contain but a small quantity of pyrite. This roasting also changes the condition of the iron from Fe_3O_4 to Fe_2O_3, and thereby reduces the consumption of fuel in the blast furnace. In making Bessemer iron the aim is to get about 1.00 per cent. silicon and from 1.50 to 3.00 per cent. manganese. The charcoal contains about 85 per cent. of carbon, 3 per cent. of ash, 12 per cent. of moisture and 0.01 per cent. of phosphorus, and the consumption of fuel is such that from 600 to 1000 kg. of carbon are burned per 1000 kg. of pig-iron.

In 1897 an accurate calculation showed 144 active furnaces, and allowing for the actual time in blast there was an average production of 13.1 tons per day. There were 130 works making wrought-iron and steel, and they averaged 12 tons per working day, which may give some idea of the scale of operations in Sweden. It is, of course, true that the average is no measure of the best, but in 1897 the largest blast furnaces were reckoned at 40 tons per day. In 1901 there were 139 blast furnaces giving an average daily product of 13.96 tons for the time they were in operation. In 1893 the production of Bessemer steel was 84,400 tons, being a trifle more than the open-hearth, which was 81,890 tons. The Bessemer output increased to 114,120 tons in 1896, but it is decreasing and in 1901 was only 77,231 tons, while the open-hearth product meanwhile steadily increased, until in 1900 it was 207,450 tons, there being a falling off in 1901 to 190,877 tons. During the year 1900 about one-third of the Bessemer and one-fifth of the open-hearth steel was made by the basic process, the basic Bessemer being used in only one works. The production of crucible steel amounts to a little over 1000 tons per year.

Sweden exports large quantities of her iron and steel, the proportion sent to foreign countries varying very much according to general business conditions, but on the whole there has been a tendency for the proportion to be less as the growth of basic processes has enabled other nations to make the purer grades of metal. In 1840 she exported 86 per cent. of her wrought-iron and steel; in 1870, 62 per cent., and in 1897, 45 per cent. In 1890 the exports amounted to 225,000 tons and in 1897 to 210,000 tons. In 1900 she exported 356,080 tons of wrought-iron and steel, or about 73 per cent. of her output, showing the effect of the general revival in the iron industry.

Having regard to the coal and iron industry alone, we may arbitrarily divide the country into seven parts. In the extreme south there is the district of Malmohus, which produces about 250,000 tons of bituminous coal per year, but this has no bearing at all on the iron trade. On the southwest is the district of Elfsborgs, where two open-hearth furnaces make about 3000 tons of steel per year. In the immediate vicinity of Stockholm, in the districts of Stockholm, Upsala and Sodermanland, a small quantity of ore is mined, and there are eighteen works producing about 7 per cent. of the iron and steel output of the country. In the southern central portion, comprising the districts of Ostergötland, Jonkoping, Kronoberg, Kalmar and Blekinge, are 21 works making about 8 per cent. A little north of Stockholm is the district of Gefleborg making 15 per cent.

The western central portion, including the district of Vermland, Orebro, Vestmanland and Kopparberg, is the great center of manufacture. This district in 1900, notwithstanding the great development in the extreme north in the Gellivare mines, raised 55 per cent. of all the ore produced in Sweden, nearly one-half of this coming from the mines at Grangesberg. This last named ore runs about 55 per cent. in metallic iron and .08 per cent. in phosphorus, and most of it is exported. It is in this region that the old mines of Dannemora, Norberg and Persberg are located, some of which have been worked for six and seven hundred years, and which have made Sweden famous for the quality of her products.

There are 56 iron works in this western central section and in the year 1900 they made 74 per cent. of all the pig-iron and nearly 70 per cent. of all the iron and steel. There were 179 Lancashire hearths, 17 converters making a total of 58,392 tons in the year, and 34 open-hearth furnaces, making 156,110 tons of steel. The

Bessemer converters averaged a little over 3400 tons per year or less than 300 tons per month. The capacity of Swedish converters is from three to six tons. The iron is taken to them directly from the blast furnace and only three to five heats are blown per day.

To the outside world, one of the most important features of Sweden to-day is the exploitation of the great iron mines recently opened beneath the Arctic Circle. At present the Gellivare mines are the only ones that are well developed. The ore is carried by rail to Lulea on the Baltic Sea, but a railroad is now under construction in a westerly direction across Norway to Ofoten. This port, although so far north, is open all the year, while Lulea is inaccessible in winter. The railroad is now constructed as far as the great deposits of Kirunavaara and Luossavaara, where surveys indicate the existence of over 200,000,000 tons of ore above the water level, and it is expected to complete the line to Ofoten in the year 1903. The Swedish government has limited the amount for export to about 1,500,000 tons per year. The ore runs from 57 to 70 per cent. in iron, the A grade being guaranteed between 67 and 70 per cent. with phosphorus below .05 per cent., but unfortunately there is comparatively little of this kind. The next class runs from 66 to 69 per cent. with phosphorus from .05 to .10 per cent., and so on down to the poorest with 57 to 61 per cent. of iron and 1.50 to 3.00 per cent. of phosphorus.

The field has been only partially explored, but it is quite certain that the phosphorus is scattered haphazard throughout the whole deposit, so as to make careful selection necessary, and it also seems certain that the greater part will run from 0.7 to 1.0 per cent. in phosphorus and possibly from 1.0 to 2.0 per cent. The ore is very hard and must be blasted. The sulphur is almost always below 0.10 per cent., the manganese about 0.30 per cent., but titanic acid is present in varying quantities from 0.3 to 1.0 per cent. In the immediate neighborhood are the Routivare deposits, of great extent, but as they contain only 50 per cent. of iron and carry 11 to 13 per cent. of titanic acid, they can hardly be looked upon as of great value.

Some of the older iron mines in Sweden can offer ores of only moderate quality. The great deposit at Grängesberg has been already mentioned as being from 50 to 58 per cent. in iron, from .06 to .27 per cent. in phosphorus and from .03 to .25 per cent. in sulphur. These beds have only lately come into prominence being made valuable by the development of the basic process. The far-famed Dannemora mines produce about 47,000 tons per year. The phosphorus is extremely low, about .002 per cent., but the iron is about 50 per cent. and the silica from 9 to 15 per cent. The Norberg mines, producing 138,000 tons, give about 52 per cent. iron and from 2 to 32 per cent. of silica. Mention is sometimes made of the famous iron mountain of Taberg, but it is merely a rock carrying 30 per cent. of iron with 14 per cent. silica and 6 per cent. titanic acid.

The total exports of ore in 1900 were 1,619,900 tons, of which Northern Sweden, principally the Gellivare district, contributed two-thirds, the rest coming from the districts of Vestmanland, the Kopparberg and Gefleberg. Out of this total 1,390,000 tons went to Germany, 103,000 tons to Great Britain, 99,000 tons to Belgium, and 9000 tons to France, while about 19,000 tons were sent across the border into Finland. A large proportion of the ore shipped to Germany was really intended for trans-shipment to Austria, it being impossible to determine the exact amounts.

TABLE XXIX-B.

List of Largest Works in Sweden.

Districts.	Name of Works.	Nearest Large Town.	Steel Output in 1900; tons.
Gefleborg	Iggesund	Hudiksvall	6.000
	Forsbacka	Gefle	12,000
	Hofors	Gefle	20,000
	Sandviken	Gefle	25,000
Kopparberg	Avesta	Falun	20,000
	Domnarfvet	Falun	50,000
Vermland	Munkfors	Filipstad	6,000
	Hagfors	Filipstad	14,000
	Nykroppa	Filipstad	15,000
Örebro	Bofors*	Christinehamn	5,000
	Degenfors	Christinehamn	23,000
Vestmanland	Fagersta	Vesteras	15,000
Upsala	Soderfors	Gefle	5,000
Östergotland	Motola	Motala	6,000
	Finnspang	Norrköping	7,000

* Mainly steel castings, guns, armor, etc.

In Fig. XXIX-A I have combined the districts before described and have shown (1) the extreme north, a forest-covered, unsettled country, producing ore alone; (2) the extreme south, producing coal alone and the southern central portion, making a small amount of iron; (3) the central district west of Stockholm—in which the iron industry of Sweden is centered.

Some readers may inquire concerning the production of Norway, so that it may be well to say that there is no iron made in Norway, and the amount has always been small; but a great deal of Swedish Lancashire product has been taken to that country and worked into finished articles and exported under the very incorrect name of "Norway iron." This term may now be a fixture in the trade, but has no place in a metallurgical treatise.

In Table XXIX-B is a list of the principal steel works in Sweden, showing their location and production of steel in 1900.

CHAPTER XXX.

SPAIN.

The information concerning Spain is taken from a paper by Alzola, Jour. I. & S. I., Vol. 11, 1896, and from miscellaneous sources.

The only claim held by Spain to our consideration as an iron nation is her position as a source of supply for ore. It has been announced many times that the mines were exhausted, and it is a fact that the ore exported is growing leaner. At some mines considerable spathic ore is shipped, which was not considered of any value fifteen years ago, but in spite of the immense amounts of ore produced for so many years the total output has steadily increased, and the year 1899 saw by far the greatest record, the output of the mines being 9,400,000 tons, four-fifths of which was raised in the region around Bilbao. Quite a considerable quantity of this is smelted in the neighborhood of the mines, and there are a few steel works of considerable magnitude in the district, the fuel being drawn from coal mines in Asturias, about 200 miles west of Bilbao. The local steel works, however, use but a small proportion of the ore output, and in 1900 over 90 per cent. was exported, the port of Bilbao sending out two-thirds of the whole. England claimed nearly three-quarters of the shipments and Germany the greater part of the rest. Detailed figures are shown in Table XXX-A and are illustrated by Fig. XXX-A. The Bilbao ore proper comes from an area about 15 miles in length and 2½ miles in width. Four classes are distinguished:*

(1) *Vena,* a soft purple compact and often powdery hematite.

(2) *Campanil,* a compact and crystalline red hematite, often accompanied by rhombohedra of carbonate of lime.

(3) *Rubio,* a brown hematite usually mixed with silicious material.

(4) *Carbonato,* a grey granular and silicious or a creamy white laminated and crystalline spathic iron ore.

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* Brough, Cantor Lectures Soc. Arts, Man. and Commerce, Feb., 1900.

Vena is the purest of these and was the only one used in the ancient local Catalan forges. Campanil, on account of its low phosphorus, is the most valuable, but is now nearly exhausted.

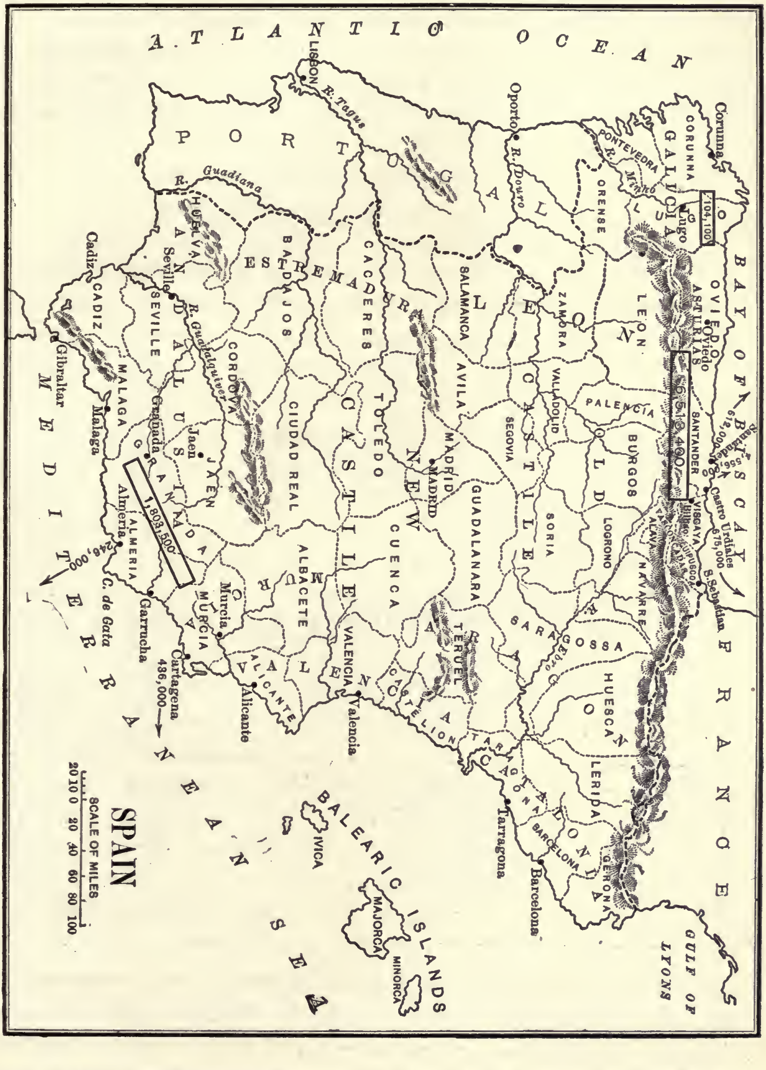

FIG. XXX-A.

Rubio is the most abundant, but is likely to be mixed with veins of iron pyrites. Carbonato is found usually below the other ores.

The district is divided into seven parts, of which the Sommorosto produces half the total from the beds of Triano and Matamoros. The other districts are Galdames, Sopuerta, Ollargan, Abondo, Alonsolegui and Guenes, each of which yields a supply for shipment. The Vena ore runs about 56 per cent. in iron; Campanil about 54 per cent., and the spathic ore from 40 to 45 per cent., giving 55 to 60 per cent. after roasting. The composition of Rubio ore, which is the great bulk of the hematite shipments, was the subject of discussion by William Whitwell, in his presidential address before the Iron and Steel Institute. He compared the analyses reported at his own works at Thornaby, near Middlesborough, during eleven years, and they showed a constant decrease in quality. Since the determinations are averages of a very large number of cargoes in each case, and are given under such authority, they must be accepted as representative.

Table XXX-A.

Spanish Ore Production and Exports.

			1899.	1900.
Production—				
	Northern part.	Province of Vizcaya	6,495,564	5,317,920
		" " Santander	1,158,169	1,117,017
		" " Oviedo	65,944	61,000
		" " Guipuzcoa	27,618	17,476
	Southern part.	Province of Murcia	668,947	806,609
		" " Almeria and Grenada	537,144	562,758
		" " Sevilla	309,688	365,434
		" " Malaga and Jaen	66,575	68,691
	Northwest	" " Lugo	14,000	104,110
	Others		54,085	99,131
	Total		9,397,734	8,520,146
Exports—				
	Northern ports.	From Bilbao in Vizcaya	5,512,067	4,556,317
		" Santander in Santander	673,807	612,109
		" Castro Urdiales in Santander.	662,715	674,690
	Southern ports	From Carthagena in Murcia	430,255	436,462
		" Porman in Murcia	120,120	128,180
		" Garrucha in Almeria	405,153	312,087
		" Almeria in Almeria	188,858	246,351
		" Sevilla	319,026	339,432
Destination—		Great Britain	6,224,229	5,484,323
		Germany via. Holland	1,416,198	1,268,623
		Germany direct	128,251	172,496
		France	443,818	450,749
		Belgium	254,860	247,351
		United States	32,422	195,961
		Other countries	13 359	3,758
		Total	8,613,137	7,823,270

	1890	1900
Fe in ore as received	50.50	47.99
SiO_2 in ore as received	7.10	10.09
Moisture	9.00	9.10
Fe in dry state	55.50	52.80

The spathic ore, which has been lately considered of much value, runs from 40 to 45 per cent. in iron, giving from 55 to 60 per cent. after roasting.

In addition to the well known deposits of Northern Spain, there are very extensive deposits on the Mediterranean, the principal ore centers being in the provinces of Murcia, Almeria and Malaga. It is from Murcia that the well known Porman ore comes, the mines being near to Carthagena. This is a brown hematite rather high in silica and containing a certain amount of lead, which is not a desirable thing around an iron furnace. There are other deposits farther inland, the deposits of Morata being ten miles from the coast and those of Calaspara about 85 miles, the latter ore being a red hematite running about 57 per cent. Some magnetite of poorer quality is also found. Almeria produces the Herrerias ore, containing on the average of about 52 per cent. of iron and 8 per cent. of manganese, which is used for the manufacture of spiegel, and it also furnishes the Sierra de Bedar ore from the mines of Jupiter, Porfiado and San Manuel. Some of the Bedar ore is fine and runs about 60 per cent. in iron when dry, while other mines give a purple lump ore running about 50 per cent. in the dry. The Sierra Alhamilla deposits at Los Banos, Alfaro and Lucainena are also in this province. They are remarkably low in phosphorus and are in the form of big hard lumps, and command an extra price for use in open-hearth furnaces.

In the provinces of Malaga are found the ores of Marbella, the mines lying about three miles from the coast and about thirty miles southwest of Malaga. This is a magnetite containing about 60 per cent. of iron. There are other deposits in the vicinity of Estepona and Robledal. The province of Sevilla also produces a considerable quantity from the mines of Pedroso and Guadalcanal, but the ore must be carried over fifty miles to Sevilla and this port cannot accommodate vessels of a large size. The province of Huelva furnishes the Rio Tinta ore, which is a hard and lumpy, but sulphurous deposit.

CHAPTER XXXI.

ITALY.

A certain amount of iron and steel is made in Italy, the whole country in 1899 having in operation 21 open-hearth furnaces, two Bessemer and two Robert converters. Most of the steel was made from imported pig-iron and scrap. The Terni works is the largest plant, and in 1899 it imported 90,000 tons of material, converting this principally into supplies for the railways and the navy. As the amount of pig-iron imported into the country is from six to eight times as much as is melted within its borders little need be said regarding this industry. It is necessary, however, to make mention of the mines of Elba, which have been famous for centuries and which have supplied America with large quantities of low phosphorus ores. These deposits are controlled by the Italian government, which has leased them for short periods to contractors, but now has followed the wiser plan of giving a long lease. The terms of the contract, made in 1898, are intended to encourage the manufacture of iron and steel at home. The government is to receive a royalty of ten cents per ton on all ore smelted in Italy, but it must receive $1.50 on all ore shipped to other countries. The company securing this lease is made up of home capital in the Island of Elba, and it is developing coal mines across the ocean in Venezuela for a supply of fuel. The lease runs twenty years, and not over 160,000 tons per year may be exported, while at least 40,000 tons must be offered to Italian furnaces.

An important point in the general problem is that in the past the ore has been taken away from Elba as return cargo in vessels carrying coal to Italy, and if such exports cease the cost of coal and coke will be higher. A still more important matter is the approaching exhaustion of the deposit. The government has carefully surveyed the remaining supply and has limited the output so that it will last twenty or thirty years at the rate of about 250,000 tons per year. Needless to say the working of the lessening and narrowing beds, scattered over a considerable area, will be done at a considerably increasing cost. It is safe to say therefore that the mines of Elba can hardly be viewed as an important factor in the international iron trade.

TABLE XXXI-A.

Exports of Ore from Elba in 1899.

	Tons.
Great Britain	102,700
Germany via Holland	53,300
United States	41,700
France	29,000
Total	226,700

CHAPTER XXXII.

CANADA.

Up to the year 1901 the iron and steel industry of Canada was of little importance, but it has now come to the front as the land of new enterprises of very considerable magnitude. The Cramp Steel Company is erecting a plant at Collingwood, Ontario, for making Bessemer and open-hearth steel, while a very extensive system of industries, of which a steel works is only a part, is developing on the Canadian side of the Sault, between Lake Superior and Lake Huron. The Bessemer plant connected with this latter enterprise consists of two six-ton converters and was started in February, 1902. It is for the future to say just how great all these works will become, but it is the intention now that they will follow the current American practice of smelting the rich ores of the Canadian Lake Superior region with coke brought from the coal fields of Pennsylvania or West Virginia.

Another plant is on different lines and presents points of interest to the metallurgist. The Dominion Iron and Steel Company has built a steel works at Sydney, Cape Breton, at which point the company owns very extensive fields of rich coal, giving a coke which has been successfully worked in blast furnaces. The high percentage of volatile matter leads to the hope that a large excess of gas will be available for use in open-hearth furnaces. The coal varies considerably and some beds are quite high in sulphur, so that for the production of coke it has been found necessary to wash the coal. Table XXXII-A shows the composition of the raw material as publicly stated by the management.

The ore, which goes by the name of Wabana, comes from Great Bell Island in Concepcion Bay, Newfoundland, about 35 miles from St. Johns, and about 400 miles from the steel plant at Sydney. It is easily mined, being in well defined thin layers and of a brittle nature, but it is not of the best quality, as shown in the table just given. It will give a pig-iron running about 1.5 per cent. in phosphorus, which is rather low for basic Bessemer practice and rather high for economical working in an open-hearth furnace.

TABLE XXXII-A,

Composition of Fuel and Ore at Cape Breton.

Raw Coal.	Reserve Mine.	Caledonia Mine.	Dominion Mine.
Moisture.........	1.45	1.54	1.21
Volatile Matter..	32 45	30.86	31.89
Fixed Carbon ...	60.45	62 91	61 49
Sulphur	1.64	1 50	1.56
Ash..............	5.65	4.69	5.41
Washed Coal—			
Moisture.........	1.01	1.08	0.84
Volatile Mattter.	32.99	33.92	37.86
Fixed Carbon....	62.21	61.69	62.60
Sulphur	1.11	1.07	1 17
Ash..............	3.79	3.31	4.50
Retort Coke—			
Sulphur	0.91	0.78	1.01
Ash..............	6.07	5.38	6.24

Bell Island Ore.	Best.	Worst.
Moisture.............	1.50	2.50
Fe.....................	54.43	51.84
SiO_2..................	9 34	13.00
P.......................	0.744	0 835
S.......................	0.05	0.03

There will be four blast furnaces 85 by 20 feet and ten 50-ton open-hearth furnaces of the Campbell type. The first steel was made on December 31, 1901, and the plant has been completed during the summer of 1902. There are to be 400 Otto Hoffman by-product ovens, which will be similar to those which have been in operation near Boston, Mass., for making gas for city use from Cape Breton coal. The steel plant of Sydney is in a good harbor, but this is closed by ice a part of the year, during which time traffic can be carried on by way of Louisburg, about forty miles by railroad on the south coast. The ore deposit at Bell Island is also on good water, but is likewise ice-bound for three or four months in the year.

One of the great arguments advanced in favor of new works in

Canada is the bounty offered by the government on pig-iron and steel manufactured within the Dominion. The bounty is to grow less in the future and expires completely in 1907. The schedule appears in Table XXXII-B, by which it appears that a company making steel from native ores receives a bounty of $2.70 per ton of pig-iron and $2.70 per ton of steel, or say about $6.00 per ton of finished product. From this it declines to nothing in July, 1907.

Table XXXII-B.

Canadian Bounty on Iron and Steel, per ton.

	Pig Iron.		Steel.
	From Native Ore.	From Foreign Ore.	
To April 21, 1902.............	$3.00	$2.00	$3 00
April 21, 1902, to July 1, 1903.	2.70	1.80	2.70
July 1, 1903, to July 1, 1904...	2.25	1.50	2.25
July 1, 1904, to July 1, 1905...	1.65	1.10	1.65
July 1, 1905, to July 1, 1906...	1.05	.70	1.05
July 1, 1906, to July 1, 1907...	.60	.40	.60

CHAPTER XXXIII.

STATISTICS OF THE IRON INDUSTRY.

In Tables XXXIII-D to M, inclusive, are given statistics of the production of coal, iron ore, iron and steel in the leading nations, and the imports and exports for the most recent year for which complete statistics are available, the official reports for different countries and for different branches of the same Government often appearing at different times. In the case of some countries certain information can hardly be obtained at all, as, for instance, in regard to the production of wrought iron or of lignite in the United States. In other cases there is much difference in the way the figures are usually given. In the United States the production of steel is always given in the ingot weight. We do have a figure of finished rolled material, but this includes all the wrought iron. In England the ingot is also used, but in some other countries the data are given for the finished bar, while in Belgium the records show the weight of the blooms or billets in the intermediate stage. Any one of these systems has its good points, but comparisons are difficult.

Judging from my own ignorance in the matter, it is doubtful if most people appreciate the difficulty of obtaining accurate statistics of production, and it may be well to illustrate by referring to an attempt to get data for Germany, which is supposed to have a complete system. In Table XXXIII-A are given the various figures encountered. The data from Wedding were collected exclusively for this book and as they disagreed with some other records, an investigation was made for me by Consul General Mason in Berlin, with the results accredited to him in the table, the divisions used being the customary items given in German statistics. The different figures were then sent to Mr. Schrödter and I asked for an explanation of what is meant by finished steel, and whether the same metal could appear twice in Mason's tabulation. Mr. Schrödter states that not until the year 1900 were any records kept of the output of ingots, but he does not cast any light on the question of duplication. He does state, however, that the amount of finished material in 1900 was 6,361,650 tons, which is the amount given by Mason as the total output. He also states that the total production of ingots and castings was 6,645,869. Now this is the same thing as saying that the weight of finished material was 95.72 per cent. of the weight of the ingots, a difference of only 4.28 per cent. to account for all scrap and oxidation, and while the losses from these causes may be much less in Germany than here, I can hardly believe that the figures are correct.

Table XXXIII-A.

Discordant Data on Steel Output in Germany.

Source of Information.	1898	1899	1900	1901
Swank; Am. I. & S. Ass., 1901		6,328,666	6 365 259	
Mineral Industry, 19 1	5 734 307	6 290,434	6 645,869	
Rentzoch.	5 065 896	5,667,050	6.645,869	
Gemeinfass, Darstel , 1901	4 352 831	4,791,022	4,799,000	
Wedding*		4 967,770		
Mason;* ingots	441 601	467 721	352 935	
Blooms, billets, etc.	986 572	1 040,670	1,183,128	
Finished steel	4,352,831	4.820,275	4,825,587	
Total	5,781,004	6,328,666	6,361,650	
Schrödter;* steel castings				107,210
Bess. and O. H. ingots				6,287,012
Total			6,645,869	6,394,222

* Private Communication.

A great deal of confusion is caused by differences in nomenclature and classification in different countries by different statisticians. The term "iron and steel productions" may include pig-iron and it may not. The term "bar-iron" may mean wrought-iron, or it may include steel, as soft steel is called ingot-iron on the Continent. Sometimes steam engines are included in "iron and steel exports," and sometimes they are classed under machinery. It is difficult to find the truth without a detailed analysis of the original records, and if professional statisticians are guilty of grievous errors, I trust I may be pardoned for any that may creep into the data herewith given. In almost every case I have indicated the authority by putting a small distinguishing numeral. The key to these numbers is given in Table XXXIII-B.

TABLE XXXIII-B.

Key to Numbers Denoting Source of Statistical Information.

[1] Swedish Offic. Stat., 1900.
[2] Swank: Am. I. and S. Assoc., 1900, 1901 and 1902.
[3] Gemeinfass. Darstell. des Eisenhütten, 1901.
[4] U. S. Geol. Survey.
[5] Min. Ind., 1900.
[6] British Iron Trade Assoc., 1900.
[7] British Home Office Reports, 1900.
[8] Russian Journ. Financial Stat., 1899.
[9] Struthers: Sci. Pub. Co.; private communication.
[10] Nimot: Belgium; private communication.
[11] Wedding: Berlin; private communication.
[12] Iron and Coal Trades Rev., Jan. 5, 1900.
[13] Min. Ind., 1893.
[14] Oesterreich. Zeitschrift, XLIX, 1901.
[15] A. von Kerpeley, Vienna; private communication.
[16] Bertrand, Kladno; private communication.
[17] Verein Deutscher, E. and S., Ind., 1882.
[18] Iron, Vol. XXXIII, p. 376.
[19] Stahl und Eisen, Vol. IX, p. 445.
[20] Stahl und Eisen, Vol. X, p. 164.
[21] Kintzle; Journ. I. and S. I., Vol. II, 1890.
[22] Stahl und Eisen, Vol. XI, p. 428.
[23] Swedish Offic. Stat., 1890.
[24] British I. T. Assn. Bulletin, No. 20.
[25] Swedish Offic. Stat., 1892.
[26] Stahl und Eisen, Vol. XII, p. 1007.
[27] Swedish Offic. Stat., 1893.
[28] Verein Deutscher, E. and S., Ind., 1893, No. 17.
[29] Verein Deutscher, E. and S., Ind., 1894, No. 21.
[30] Journ. I. and S. I., Vol. II, 1894.
[31] Verein Deutscher, E. and S., Ind., 1895, No. 20.
[32] Stahl und Eisen, Vol. XVI, p. 395.
[33] Journ. I. and S. I., Vol. II, 1896.
[34] Swedish Offic. Stat., 1897.
[35] Stahl und Eisen, Vol. XVIII, p. 38.
[36] Swedish Offic. Stat., 1898.
[37] Stahl und Eisen, Vol. XIX, p. 32.
[38] Comité des Forges Bulletin, 1458.
[39] Stahl und Eisen, Vol. XX, p. 39.
[40] Akerman; private communication.
[41] Comité des Forges.
[42] Mining Industries of Russia, 1901.
[43] Schrödter; private communication.
[44] British Iron Trade Ass'n, 1901.
[45] British Consular Report, No. 555.

A complete statistical digest cannot be attempted in such a limited space, but it is desirable to find the main conditions in order to know the internal economy of each nation and its relation to the world at large at the beginning of the new century. The tables show that the iron producers may be divided into three classes according to the quantity of pig-iron and steel they produce. First, and almost in a class by itself, is the United States; next come Germany and Great Britain, the latter producing slightly more pig-iron than Germany, but very much less steel. These three nations produce eighty per cent. of all the coal, pig-iron and steel made in the world, and nearly seventy per cent. of the iron ore.

In the next class are France, Russia, Austria and Belgium. These four nations produce about eighteen per cent. of all the pig-iron and steel made in the world, and about fifteen per cent. of all the coal and iron ore.

The third class includes Sweden and Spain, which are important as sources of the iron ore supply for the greater nations, but which have no coal for smelting. In the same list, but of less importance, are Greece, Algeria, Cuba and Italy, which are widely known for their ore mines, but produce very little or no iron.

Another way of comparing the nations is according to the amount of pig-iron produced per inhabitant. This is done in Table XXXIII-C.

Table XXXIII-C.

Production of Pig-Iron per Capita in 1899, Pounds.

Great Britain	505
United States	405
Germany	330
Belgium	322
Sweden	244
France	145
Austria-Hungary	67
Russia	46
Italy	1

The United States may be looked upon as self-contained, possessing within its borders all the material necessary for the iron industry. A certain amount of ore is imported for use in plants near the seaboard, and some small lots of foreign pig-iron find their way into distant portions of the country; but the proportion of imports to the total consumption is very small for either fuel, ore, iron or steel. This condition arises in great measure from the geographical isolation of America and the almost prohibitory distances from sources of supply. To understand the totally different conditions in Europe it is only necessary to consider that the boundary of France touches the coal fields of Belgium, and the boundary of Belgium touches the ore fields of Luxemburg.

The close geographical relations of the countries in Northwestern Europe naturally give rise to inter-traffic in raw materials, when unhampered by foolish tariff restrictions on such articles. The iron industry of Belgium is founded on imported ore, while France, Germany and England bring from one-fifth to one-third of their ore supply from beyond the boundary. With coal also it is necessary to disregard the political limits, and in some cases the figures seem contradictory, as when a nation both imports and exports large quantities. This may be explained by local conditions, as for instance on the eastern boundary of Germany we may find coke going into Austria and brown coal returning into Germany, this brown coal being cheap and perfectly suitable for heating, but not fit for smelting.

There is room for difference of opinion as to just how percentages should be calculated, but I have compared the quantity of imports with the quantity actually used. Thus the amount of iron ore used in a country is the tonnage raised plus the imports minus the exports, and I have found the proportion of imports to this tonnage so smelted. In calculating the exports, however, I have taken into account only the quantity raised and the quantity exported, so as to find the proportion of the home production which was sent away from the country. Any other basis of calculation will be found to give curious results in the case of countries that both import and export large quantities.

Taking up the question of fuel supply it will be found that France imports one-third of all she uses. Austria imports one-third of all her bituminous coal, but produces large quantities of brown coal and is a heavy exporter of this inferior fuel. Russia and Belgium import about fifteen per cent. of their consumption, while Sweden is almost wholly dependent upon other countries for her coal.

The figures for iron ore show that Belgium imports almost all her supply and that Great Britain and France import about one-third of all that is used. On the other hand, Germany exports almost as much as she imports, while Sweden sends most of her ore abroad. Spain is also a factor in the ore question, but is not included in the table as she has no bearing on international commerce in any other line of iron products.

The statistics for pig-iron show that Belgium and Germany are the only nations that import any considerable portion of their supply, while Great Britain is the only one that exports any important amount. In 1899 and 1900 the latter nation exported 15 per cent. of her pig-iron. In these two years the United States exported only two per cent. and Germany about the same, while in 1901 the United States sent abroad only one-half of one per cent. of her pig-iron.

In wrought-iron and steel, Great Britain, Russia and Belgium import quite a considerable proportion of their total production, while the United States imports a very small percentage. Singularly enough, the nations that import the greatest proportion also export the greatest. for England exports one-third of her finished iron and steel, and Belgium nearly one-half of her output. The United States up to the present time has shipped away only a small proportion of her output, but in 1900 it reached 12 per cent. of the total. In 1901 there was quite a falling off in exports owing to the extraordinary home demand.

This comparison gives some idea of the character of the business of these nations, but it does not convey any definite information about the extent to which these nations influence the commerce of the world. Thus, although the United States sent abroad only a small proportion of her products, the actual tonnage so exported in 1900 was nearly three times the over-sea shipments of Belgium, although the latter nation, as above stated, sent nearly half of her products to other countries. The overshadowing factors in over-sea commerce are Great Britain, Germany and the United States in the order named, and in this calculation the commerce of England with her own colonies is not included. Other nations play a very small part in the general international iron trade.

There are some people who may look for a table giving the rate of wages in each country, and possibly it would please some of my political friends to have some figures duly tabulated to prove some tariff theories. It would be quite easy to give statistics on either side. From personal knowledge I could quote the earnings of boiler-makers in free-trade England at over $7.00 per day and the wages of skilled rolling mill men at $1.50 in protectionist Germany and Austria. It is thoroughly well known to manufacturers and practical employers of labor that the information collected by our Government at so much cost and trouble is hardly worth the trouble of printing, but statisticians are constantly quoting the records for want of better information. The weak points are recognized by the Department itself, but there are great difficulties in the way of obtaining really valuable data. Thus, for instance, it is of little use to record that the wages of bricklayers are $5.00 per day in a certain city and only $2.50 in a certain town, for it is quite probable that in the city the work is intermittent, made up of short jobs interrupted by weather, so that from inclement days and intervals between jobs, the annual earnings will be no more than in the town where perhaps a steel works offers perfectly steady work under shelter in rough weather throughout the whole year, and where the rent and cost of living is much less than in the greater community. It is also of little value to give the average amount of money drawn by an employee, for it is necessary to know whether every man worked full time. The information so gathered is, however, of more value than the usual statements of the number of men employed in good times and bad times. As a matter of fact, a rolling mill always employs the same number of men whether it runs six days per week or one day a month. The men are on the pay roll and never replace other men in other departments, but work when the mill works and are idle when it is idle. Their earnings are a measure of the industrial situation, but their number is constant. A decrease in the actual working force in a steel works generally signifies a stoppage of certain portions of the plant, as, for instance, a certain number of blast furnaces, or it indicates a cessation of new work on improvements, which in America we regard as an inherent part of the general plan of operation.

It is not in the province of this book to discuss the future, since prophecies are only guesses; but it may be well to call attention to the serious inroads now being made upon the supply of iron ore. I make no mention of the exhaustion of coal beds, because this is a hackneyed subject and a long supply is assured. The ore question is seldom considered, but it would seem to merit consideration. In 1865 the world mined about 18,000,000 tons of ore, and in 1900 about 87,000,000 tons. If this rate of increase continues during the coming years it will be found that in 1935 the consumption will be so rapid that in a period of five years, say from 1935 to 1939 inclusive, as much ore will be smelted as was used from 1880 to 1900. This is true of the United States in particular as well as of the world in general, and I believe that few American iron masters can view with equanimity such a prospect.

We are to-day eating up the hoardings of untold geologic ages at a rate which will exhaust the known rich deposits during the present century. When these are gone it may be that others will be discovered, and it may be that the eastern part of the United States will depend upon the concentration of the lean beds of New York, New Jersey, Pennsylvania and Alabama, while Europe will work the mammoth beds of Luxemburg and Lothringen. It is to be expected that the Rocky Mountains will furnish new fields, while Africa and the unknown corners of the earth may be relied on to prevent a catastrophe.

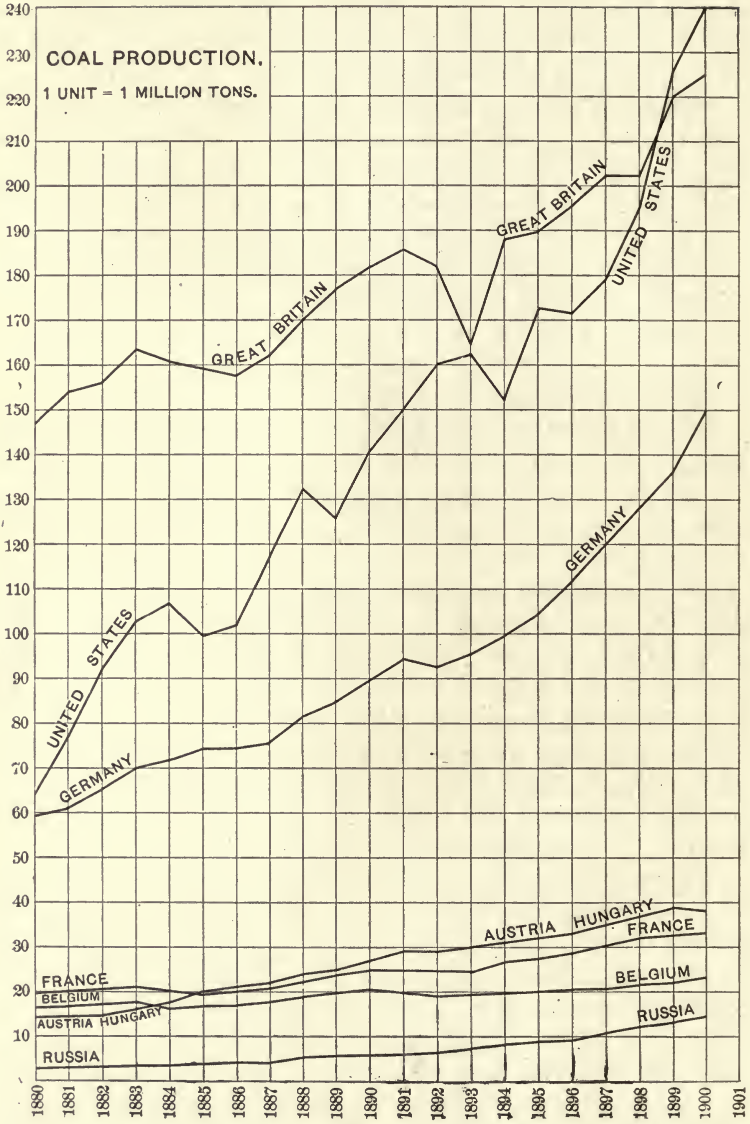
COAL PRODUCTION.
1 UNIT = 1 MILLION TONS.
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
GREAT BRITAIN
UNITED STATES
GERMANY
AUSTRIA HUNGARY
FRANCE
BELGIUM
RUSSIA
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901

FIG. XXXIII-A.

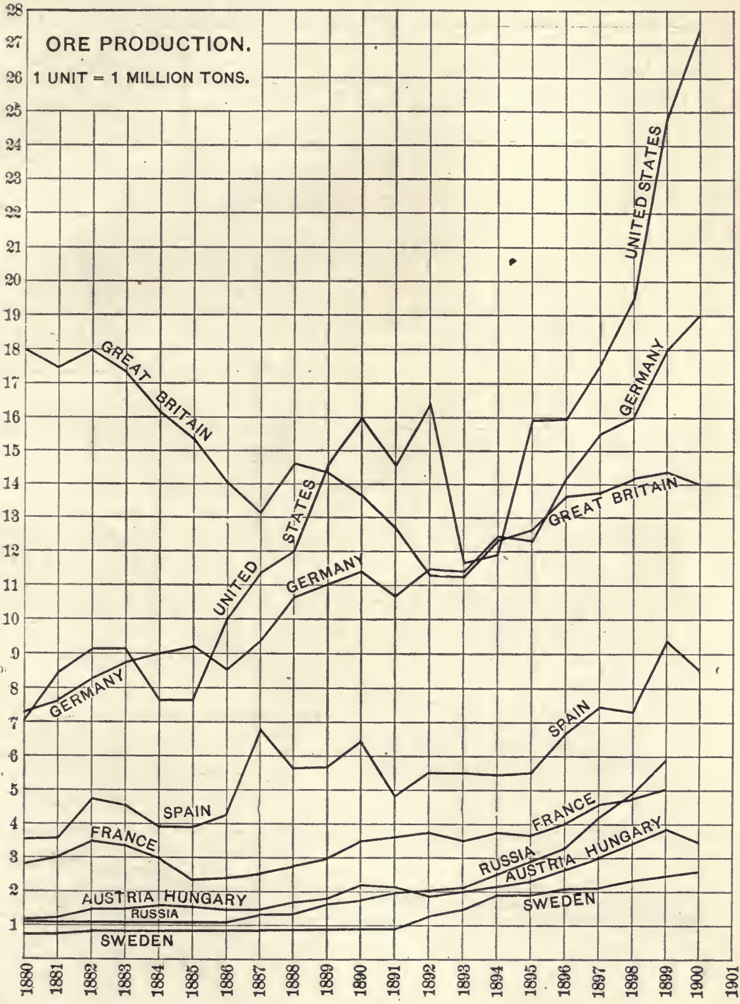
ORE PRODUCTION.
1 UNIT = 1 MILLION TONS.
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
GREAT BRITAIN
UNITED STATES
GERMANY
SPAIN
FRANCE
AUSTRIA HUNGARY
RUSSIA
SWEDEN
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901

FIG. XXXIII-B.

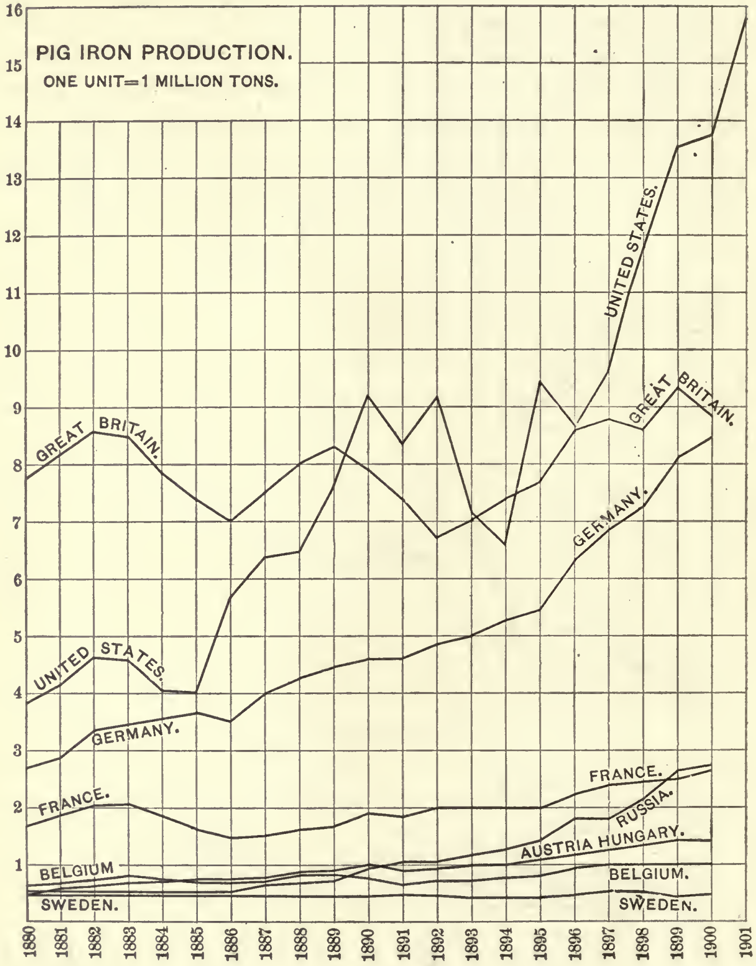
PIG IRON PRODUCTION.
ONE UNIT=1 MILLION TONS.
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
GREAT BRITAIN.
UNITED STATES.
GERMANY.
FRANCE.
BELGIUM
SWEDEN.
UNITED STATES.
GREAT BRITAIN.
GERMANY.
FRANCE.
RUSSIA.
AUSTRIA HUNGARY.
BELGIUM.
SWEDEN.
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901

FIG. XXXIII-C.

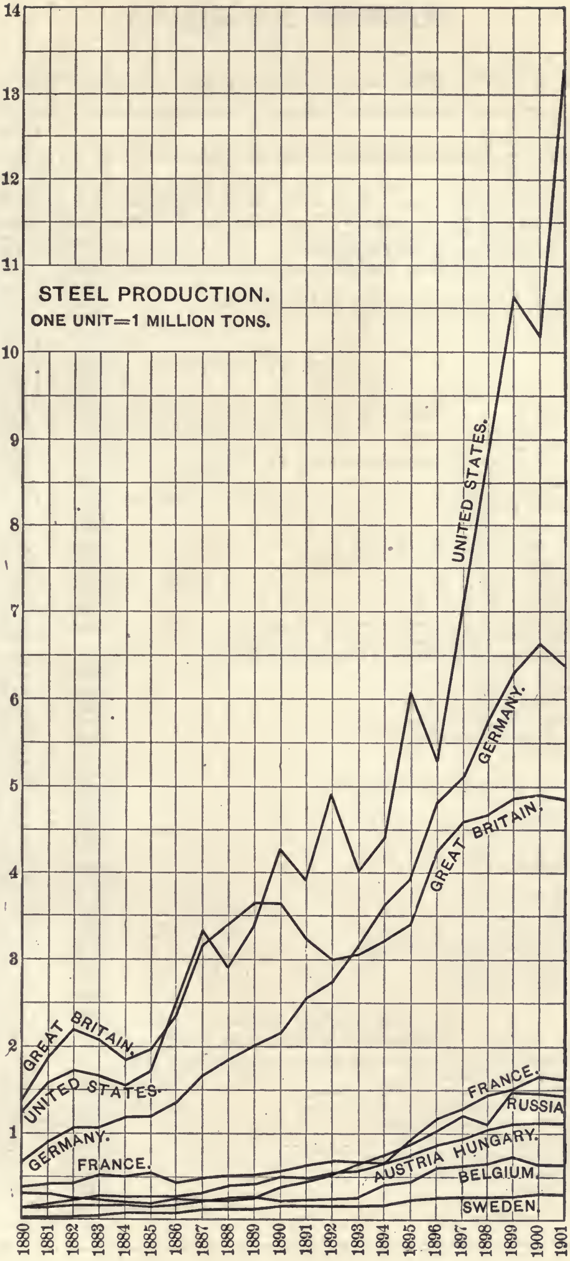
STEEL PRODUCTION.
ONE UNIT=1 MILLION TONS.
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
UNITED STATES.
GERMANY.
GREAT BRITAIN.
GREAT BRITAIN.
UNITED STATES.
GERMANY.
FRANCE.
FRANCE.
RUSSIA
AUSTRIA HUNGARY.
BELGIUM.
SWEDEN.

Fig. XXXIII-D.

TABLE XXXIII–D

Pig Iron Producing Districts of the World.

Rank	District; see foregoing chapters for further information.	Year.	Output, Tons. Estimates in parentheses.	Per Cent of total.
1	Pittsburg; parts of Pa., Ohio and W. Va., U. S. A.	1902	(7,852,000)	17.89
2	The Ruhr, western Westphalia, Germany	1899	3,187,000	7.26
3	Cleveland, northeast coast of England	1900	3,110,000	7.09
4	Lothringen and Luxemburg, the Minette district of Germany	1899	2,273,000	5.18
5	Illinois, U. S. A.	1902	1,730,000	3.94
6	West coast of England; Lancashire and Cumberland	1900	1,586,000	3.61
7	Eastern France, the Minette district	1899	1,576,000	3.59
8	Southern Russia	1900	1,474,000	3.36
9	Alabama, U. S. A.	1902	1,472,000	3.35
10	Scotland	1900	1,156,000	2.63
11	Belgium	1900	1,019,000	2.32
12	Cleveland, Ohio, U. S. A.	1902	860,000	1.96
13	South Wales	1900	818,000	1.86
14	The Urals, Russia	1900	791,000	1.80
15	Silesia, Germany	1899	743,000	1.69
16	Steelton; Dauphin and Lebanon counties, Pa., U. S. A.	1901	695,000	1.58
17	The Siegen, Germany	1899	657,000	1.50
18	Eastern Central England, Lincoln, Leicester and Northampton	1900	637,000	1.45
19	Staffordshire, England	1900	597,000	1.36
20	The Saar, Germany	1899	597,000	1.36
21	New York and New Jersey, U. S. A.	1902	593,000	1.35
22	Central England, Derby and Nottingham	1900	562,000	1.28
23	Virginia, U. S. A.	1902	537,000	1.22
24	Lehigh Valley, Pa., U. S. A.	1902	518,000	1.18
25	Johnstown, Pa., U. S. A.	1902	512,000	1.17
26	Central Sweden (95 per cent. of total for Sweden)	1900	503,000	1.15
27	Southeastern Pennsylvania, U. S. A. (the Schuylkill Valley, Philadelphia, Delaware and Chester counties)	1901	478,000	1.09
28	Hungary	1900	452,000	1.03
29	Tennessee, U. S. A.	1902	393,000	.90
30	Hanging Rock, Ohio, U. S. A.	1902	327,000	.75
31	Moravia and Silesia, Austria	1900	313,000	.71
32	Sparrow's Point, Maryland, U. S. A.	1902	303,000	.69
33	Northern France	1899	297,000	.68
34	Spain	1900	294,000	.67
35	South Yorkshire (Sheffield) England	1900	291,000	.66
36	Bohemia, Austria	1900	282,000	.64
37	Styria, Austria	1900	276,000	.63
38	Wisconsin and Minnesota	1902	274,000	.62
39	Poland, Russia	1900	263,000	.60
40	Central France	1899	247,000	.56
41	Canada	1901	245,000	.56
42	Moscow, Russia	1900	239,000	.55
43	Colorado, U. S. A.	1902	223,000	.51
44	Michigan, U. S. A.	1902	155,000	.35
45	Aachen (Aix la Chapelle) Germany	1899	153,000	.35
46	Southern France	1899	136,000	.31
47	Ilsede (Peine) Germany	1899	124,000	.28
48	Japan	1897	58,000	.13
49	Italy	1900	24,000	.06
50	India	1899	20,000	.05
	Kentucky, Missouri, Washington, North Carolina, Georgia, Texas, Massachusetts, Connecticut and parts of Pennsylvania and Ohio not included above	1902	899,000	2.05
	Great Britain, parts not included above	1900	203,000	.46
	Germany, parts not included above	1899	396,000	.90
	France, parts not included above	1899	181,000	.41
	Russia, parts not included above	1900	35,000	.08
	Austria, parts not included above	1900	130,000	.30
	Sweden, parts not included above	1900	24,000	.06
	Other countries	1900	(100,000)	.23
	TOTAL		43,890,000	100.00

TABLE XXXIII–E

Steel Producing Districts of the World.

Rank	District; see foregoing chapters for further information.	Year.	Output tons; estimates in parentheses	Per Cent of total
1	Pittsburg; parts of Pa., Ohio, and W. Va., U. S. A.	1901	(7,317 000)	22.33
2	The Ruhr, western Westphalia, Germany	1902	4,329,000	13.21
3	Illinois, U. S. A.	1901	1,750,000	5.34
4	Lothringen and Luxemburg, the Minette district of Germany	1902	1,406,000	4.29
5	Cleveland, northeast coast of England	1900	1,333,000	4.07
6	The Saar, Germany	1902	1,037,000	3.17
7	South Russia	1899	982,000	3.00
8	Scotland	1900	963,000	2.94
9	South Wales	1900	960,000	2.93
10	Cleveland, Ohio, U. S. A.	1901	(870,000)	2.65
11	West coast of England; Lancashire and Cumberland	1900	659,000	2.01
12	Johnstown, Pa., U. S. A.	1901	656,000	2.00
13	Belgium	1900	655,000	2.00
14	Southeastern Pennsylvania, U. S. A. (the Schuylkill Valley, Philadelphia, Delaware and Chester counties.)	1901	629,000	1.92
15	Eastern France, the Minette district	1900	626,000	1.91
16	Silesia, Germany	1902	589,000	1.80
17	South Yorkshire (Sheffield) England	1900	588,000	1.79
18	Steelton, Pa., U. S. A.	1901	427,000	1.30
19	Northern France	1900	371,000	1.13
20	Staffordshire, England	1900	367,000	1.12
21	Hungary	1900	353,000	1.08
22	Sparrow's Point, Maryland, U. S. A.	1901	352,000	1.07
23	Scranton, Pa., U. S. A.	1901	352,000	1.07
24	Aachen (Aix la Chapelle), Germany	1902	333,000	1.02
25	Central France	1900	314,000	.96
26	The Urals, Russia	1899	291,000	.89
27	Poland, Russia	1899	282,000	.86
28	Central Sweden (94 per cent. of total for Sweden)	1900	279,000	.85
29	Ilsede (Peine), Germany	1902	240,000	.73
30	Colorado, U. S. A.	1902	238,000	.73
31	Moravia and Silesia, Austria	1900	235,000	.72
32	Bohemia, Austria	1900	214,000	.65
33	Styria, Austria	1900	205,000	.62
34	Moscow, Russia	1899	190,000	.58
35	Northern Russia	1899	178,000	.54
36	New England, U. S. A.	1901	173,000	.53
37	The Siegen, Germany	1902	154,000	.47
38	Alabama, U. S. A.	1901	(150,000)	.46
39	Spain	1900	150,000	.46
40	Saxony, Germany	1902	143,000	.44
41	Bavaria, Germany	1902	130,000	.40
42	New York and New Jersey, U. S. A.	1901	107,000	.33
43	Southern France	1900	93,000	.28
44	Northwestern France (Loire Inferieure)	1900	88,000	.27
45	Lehigh Valley, Pa., U. S. A.	1901	69,000	.21
46	Southwest France (Landes)	1900	61,000	.19
47	Osnabruck, Germany	1902	59,000	.18
48	Italy	1900	58,000	.18
49	Canada	1901	26,000	.08
	Missouri, Delaware, Kentucky, Tennessee, Indiana, Michigan, Wisconsin, Minnesota, California and parts of Pennsylvania and Ohio not included above	1901	472,000	1.44
	Great Britain, parts not included above	1900	30,000	.09
	France, parts not included above	1900	69,000	.21
	Austria, parts not included above	1900	127,000	.39
	Sweden, parts not included above	1900	19,000	.06
	Other countries	1900	16,000	.05
	TOTAL		32,764,000	100.00

TABLE XXXIII-F.

Production of Coal, Ore, Pig-Iron and Steel in 1900.

United States and Great Britain, 1 unit = 1000 gross tons; other countries = 1000 metric tons.
Index of Authorities (see Table XXXIII B).

Country.	Coal.		Iron ore.		Pig iron.		Steel.	
	Tons.	Per cent. of total.	Tons.	Per cent. of total.	Tons.	Per cent. of total.	Tons.	Per cent. of total.
United States	239,567[5]	31.5	27,553[4]	30.8	13,789[2]	34.2	10,188[2]	37.5
Great Britain	225 181[2]	29.6	14,028[2]	15.7	8,909[2]	22 1	4,901[6]	18.0
Germany and Luxemb'g	149,551[2]	19 7	18,964[2]	21 2	8,520[2]	21.1	6,646[5]	24.4
France	33.270[2]	4 4	4 986[1]*	5.6	2,699[2]	6 7	1,660[2]	6.1
Russia	14,913[8]	1 9	5,880[1]*	6.6	2,821[2]	7.0	1,463[2]	5.4
Austria-Hungary	38,064[9]	5 0	3,462[9]	3.9	1.452[9]	3 6	1,145[2]	4 2
Belgium	23,463[2]	3.1	248[10]	0 3	1,019[2]	2 5	655[2]	2.4
Sweden	252[4]	......	2.610[2]	2 9	527[2]	1 3	301[2]	1 1
Spain	2,773[2]	0 4	8.480[2]	9 5	294[2]	0 7	150[5]	0.6
Italy	480[2]	0 1	247[2]	0.3	24[2]	0 1	58[5]	0 2
Canada	5,598[2]	0.7	122[2]	0.1	86[2]	0 2	24[2]	0.1
India	6,095[2]	0.8	63[2]	0 1	20[2]*	0 1	....	......
Cuba	....	......	439[2]	0.5	....	......	....	......
Greece	17†		485[2]†	0 5	....	......	....	......
Algeria	....	......	551[2]	0 7	....	..	....	......
Japan	6.722[2]	0.9	27[2]§	......	58[2]‡	0 1	....	......
N. S. Wales	5,507[2]	0 7	....	..	....	......	....	......
Other Australasia	1,830*	0 2	....	......	....	......	....	......
Natal	388†	0.1	....	......	....	......	....	......
S. African Republic	1,938†	0.2	....	......	....	......	....	......
Others	5,000[2]	0 7	1 200[2]	1.3	100[2]	0.3	16[2]	......
Total	760,609	100 0	89,345	100.0	40,318	100.0	27,207	100.0

* 1899. † 1898. ‡ 1897. § 1896.

TABLE XXXIII-G.

Production of Coal (all kinds) by the Leading Nations.

United States and Great Britain, 1 unit = 1000 gross tons; other countries = 1000 metric tons.
Index of authorities; see Table XXXIII-B.

Year.	United States.	Great Britain.	Germany and Luxemburg	France	Russia	Austria-Hunga'y	Belgium.	Sweden.	Italy.	Spain.
1880	63,823[4]	146,969[4]	59,118[4]	19 362[4]	3 238[4]	14,800[4]	16.867[4]	98[4]	139[4]	847[4]
1881	76,865[4]	154,184[4]	61,540[4]	19.766[4]	3,440[4]	15,305[4]	16.874[4]	115[4]	135[4]	1,210[4]
1882	92.219[4]	156 500[4]	65,378[4]	20,604[4]	3.673[4]	15,555[4]	17 591[4]	140[4]	165[4]	1,196[4]
1883	102,868[4]	163,737[4]	70.443[4]	21 334[4]	3.916[4]	17.048[4]	18.178[4]	149[4]	214[4]	1,071[4]
1884	106,906[4]	160,758[4]	72,114[4]	20 024[4]	3,870[4]	18,000[4]	18 051[4]	161[4]	223[4]	979[4]
1885	99,069[4]	159 351[4]	73.676[4]	19,511[4]	4 208[4]	20,435[4]	17 438[4]	170[4]	190[4]	946[4]
1886	101 500[4]	157.518[4]	73,683[4]	19,910[4]	4,506[4]	20,779[4]	17,286[4]	166[4]	243[4]	1,001[4]
1887	116,652[4]	162,120[4]	76,233[4]	21,288[4]	4 464[4]	21 879[4]	18 379[4]	165[4]	328[4]	1,028[4]
1888	132.733[4]	169,935[4]	81 960[4]	22,603[4]	5.187[4]	23,860[4]	19 218[4]	169[4]	367[4]	1,037[4]
1889	126.098[4]	176 917[4]	84,789[4]	24,304[4]	6,216[4]	25.328[4]	19,870[4]	187[4]	390[4]	1,154[4]
1890	140.867[4]	181.614[4]	89,057[4]	26.083[4]	6,017[4]	27.504[4]	20 366[4]	188[4]	376[4]	1.212[4]
1891	150,506[4]	185,479[4]	94 252[43]	26,025[4]	6,233[4]	28,823[4]	19 676[4]	198[4]	289[4]	1.288[4]
1892	160,115[4]	181,787[4]	92 544[43]	26 179[4]	6.816[4]	29,038[4]	19.583[4]	199[4]	296[4]	1,461[4]
1893	162,815[4]	164,326[4]	95.426[43]	25 651[4]	7.535[4]	30,449[4]	19.411[4]	200[4]	317[4]	1,485[4]
1894	152,448[4]	188 278[4]	98.806[43]	27,459[4]	8.629[4]	31.492[4]	20.459[4]	214[4]	271[4]	1,657[4]
1895	172,426[4]	189.661[4]	103 958[43]	28,020[4]	9.079[4]	32.655[4]	20 415[4]	224[4]	250[4]	1,784[4]
1896	171.416[4]	195,361[4]	112 471[43]	29.190[5]	9 229[4]	33.676[5]	21.252[5]	226[4]	276[4]	1,878[4]
1897	178,769[4]	202.119[5]	120.474[43]	30,798[5]	11 207[4]	35,939[5]	21 492[5]	224[4]	314[4]	1,939[4]
1898	191.941[5]	202,042[5]	127.959[43]	32,356[5]	12.242[5]	37.786[5]	22 088[5]	236[4]	341[4]	2.467[5]
1899	225.103[5]	220.085[5]	135,844[43]	32.863[5]	13,558[2]	38,738[5]	22 072[5]	239[4]	389[4]	2.600[5]
1900	239,567[5]	225,181[2]	149.788[43]	33,270[2]	14 913[45]	38.064[9]	23,463[2]	252[4]	480[2]	2.773[2]
1901	261,874[2]	219,047[2]	152,629[2]	32,325[2]	16.270[2]	41,203[2]	22,213[2]	272[40]	426[2]	2,748[2]
....	....	....	....	....	....	....	....	....	....	....

TABLE XXXIII-H.

Production of Iron Ore by the Leading Nations.

United States and Great Britain, 1 unit = 1000 gross tons; other nations = 1000 metric tons.
Index of authorities; See Table XXXIII-B.

Year.	United States.	Great Britain.	Germany and Luxemburg.	France.	Russia and Finland.	Austria.	Hungary.	Belgium.	Sweden.	Italy.	Spain	Algeria.
1880...	7,120[1]	18,026[7]	7,239[1]	2,874[1]	1,024[1]	697[1]	446[1]	253[1]	775[1]	289[1]	3,565[1]	614[1]
1881...	8,400[1]	17.446[7]	7,600[1]	3,032[1]	1,017[1]	619[1]	465[1]	223[1]	826[1]	421[1]	3.503[1]	657[1]
1882...	9,154[1]	18,032[7]	8,263[1]	3,467[1]	1.077[1]	903[1]	546[1]	209[1]	893[1]	242[1]	4,726[1]	567[1]
1883...	9,114[1]	17,383[7]	8.757[1]	3,298[1]	997[1]	882[1]	598[1]	216[1]	885[1]	204[1]	4,526[1]	557[1]
1884...	7,640[1]	16,138[7]	9,006[1]	2.977	1,015[1]	974[1]	651[1]	176[1]	910[1]	225[1]	3,907[1]	493[1]
1885...	7.600[1]	15,418[7]	9.158[1]	2,318[1]	1,094[1]	931[1]	651[1]	187[1]	873[1]	201[1]	3,933[1]	419[1]
1886.	10,000[1]	14.110[7]	8,486[1]	2,286[1]	1,089[1]	796[1]	635[1]	153[1]	872[1]	209[1]	4,167[1]	433[1]
1887...	11.300[4]	13,098[7]	9,351[1]	2,579[1]	1,356[1]	847[1]	566[1]	172[1]	903[1]	231[1]	6.796[1]	438[1]
1888...	12,060[4]	14,591[7]	10,664[1]	2,842[1]	1.401[1]	1,009[1]	634[1]	186[1]	960[1]	177[1]	5,610[1]	384[1]
1889...	14,518[4]	14,546[7]	11,002[1]	3,070[1]	1,640[1]	1,115[1]	666[1]	182[1]	986[1]	173[1]	5,711[1]	352[1]
1890...	16,036[4]	13,781[7]	11,410[1]	3,472[1]	1,796[1]	1,362[1]	792[1]	172[1]	941[1]	221[1]	6,546[1]	475[1]
1891...	14,591[4]	12,778[7]	10,658[1]	3,579[1]	1.999[1]	1,231[1]	876[1]	202[1]	987[1]	216[1]	4,882[1]	405[1]
1892...	16,297[4]	11,313[7]	11,539[1]	3,707[1]	2,044[1]	993[1]	921[1]	210[1]	1,294[1]	214[1]	5.436[1]	453[1]
1893...	11,588[4]	11,203[7]	11,458[1]	3,517[1]	2,095[1]	1,109[1]	977[1]	239[1]	1,484[1]	191[1]	5,498[1]	394[1]
1894...	11.880[4]	12,367[7]	12,392[1]	3.772[1]	2,488[1]	1,215[1]	900[1]	311[1]	1,927[1]	188[1]	5,397[1]	344[1]
1895...	15,958[4]	12,615[7]	12,350[1]	3,680[1]	2,927[1]	1,385[1]	955[1]	313[1]	1,905[1]	183[1]	5,514[1]	318[1]
1896...	16,005[4]	13,701[7]	14.162[1]	4.062[1]	3,205[1]	1,449[1]	1,270[1]	307[1]	2,039[1]	204[1]	6,763[1]	374[1]
1897 ..	17,518[4]	13,788[7]	15,466[1]	4,582	4,112[1]	1,614[1]	1,421[1]	241[1]	2,087[1]	201[1]	7.420[1]	441[1]
1898...	19.434[4]	14,177[7]	15.893[1]	4,731[1]	4,871[1]	1,734[1]	1,667[1]	217[1]	2,303[1]	190[1]	7,197[1]	474[1]
1899...	24,683[4]	14,461[7]	17,990[1]	4,986[1]	5,880[1]	1,900[1]	1,953[1]	201[1]	2,435[1]	237[1]	9.398[1]	551[1]
1900...	27.553[4]	14,028[2]	18,964[2]	5.448[2]	5,989[42]	1,894[9]	1,568[9]	248[10]	2.610[2]	247[2]	8,480[2]	602[2]
1901...	28,887[4]	12,275[2]	16,570[2]	4,791[2]	5,663[2]	......	......	219[2]	2,795[40]	232[2]	7,907[2]	514[2]

TABLE XXXIII-I.

Production of Pig-Iron by the Leading Nations.

United States and Great Britain, 1 unit = 1,000 gross tons; other countries = 1,000 metric tons.
Index of authorities; see Table XXXIII-B.

Year.	United States.	Great Britain	Germany and Luxemburg.	France.	Russia and Finland.	Austria.	Hungary.	Belgium.	Sweden.	Italy.	Spain
1880....	3,835[2]	7,749[7]	2,729[1]	1,725[1]	471[1]	320[1]	144[1]	608[1]	406[1]	17[1]	86[1]
1881....	4,144[2]	8,144[7]	2,914[1]	1,886[1]	492[1]	380[1]	164[1]	625[1]	430[1]	28[1]	114[1]
1882....	4,623[2]	8.587[7]	3,381[1]	2,039[1]	501[1]	435[1]	176[1]	727[1]	399[1]	25[1]	120[1]
1883....	4.596[2]	8,529[7]	3,470[1]	2,069[1]	500[1]	522[1]	176[1]	783[1]	423[1]	24[1]	140[1]
1884....	4,098[2]	7,812[7]	3.601[1]	1,872[1]	532[1]	540[1]	195[1]	751[1]	431[1]	18[1]	124[1]
1885....	4,045[2]	7.415[7]	3,687[1]	1,631[1]	552[1]	499[1]	2[illegible]6[1]	713[1]	465[1]	16[1]	159[1]
1886....	5,683[2]	7,010[7]	3,529[1]	1.517[1]	549[1]	485[1]	235[1]	702[1]	442[1]	12[1]	118[1]
1887....	6,417[2]	7.560[7]	4,024[1]	1,568[1]	633[1]	512[1]	193[1]	756[1]	457[1]	12[1]	165[1]
1888....	6,490[2]	7,999[7]	4,337[1]	1,683[1]	687[1]	586[1]	204[1]	827[1]	457[1]	13[1]	165[1]
1889....	7,604[2]	8,323[7]	4,525[1]	1,734[1]	755[1]	617[1]	239[1]	832[1]	421[1]	13[1]	198[1]
1890....	9,203[2]	7.904[7]	4.658[1]	1,962[1]	950[1]	666[1]	299[1]	788[1]	456[1]	14[1]	171[1]
1891....	8,280[2]	7.406[7]	4.641[43]	1,897[1]	1,028[1]	617[1]	305[1]	684[1]	491[1]	12[1]	149[1]
1892....	9,157[2]	6,709[7]	4.937[43]	2,057[1]	1,038[1]	631[1]	310[1]	753[1]	486[1]	13[1]	134[1]
1893....	7,125[2]	6,977[7]	4,953[43]	2,003[1]	1,181[1]	663[1]	319[1]	745[1]	453[1]	8[1]	135[1]
1894....	6,657[2]	7,427[7]	5,559[43]	2.070[1]	1,333[1]	690[16]	33[illegible][1]	819[1]	463[1]	10[1]	124[1]
1895....	9.446[2]	7,703[7]	5,789[43]	2,004[1]	1,454[1]	759[16]	349[1]	829[1]	463[1]	9[1]	18[illegible][1]
1896....	8.623[2]	8,660[7]	6,361[43]	2,340[1]	1,867[1]	817[16]	401[1]	959[1]	494[1]	11[1]	246[1]
1897....	9,653[2]	8.796[7]	6,889[43]	2,484[1]	1,869[1]	900[16]	420[1]	1,055[1]	538[1]	8[1]	282[5]
1898....	11,774[2]	8,610[7]	7,313[43]	2,534[1]	2,222[1]	958[16]	469[1]	983[1]	532[1]	13[1]	262[5]
1899....	13,621[2]	9,421[7]	8.143[43]	2,567[1]	2,726[1]	996[16]	471[1]	1,036[1]	498[1]	13[1]	300[5]
1900....	13.789[2]	8,960[7]	8.423[43]	2.714[41]	2.667[42]	1,000[9]	452[9]	1019[2]	527[2]	24[2]	294[5]
1901....	15,878[2]	7,761[44]	7,786[43]	2,400[41]	....	......	......	765	528[40]	16[2]	297[2]
1902....	17,821	....	....	2,427	2,831	......	......	1,103	524	......	......

TABLE XXXIII-J.

Production of Steel by the Leading Nations.

United States and Great Britain, 1 unit = 1000 gross tons; other countries = 1000 metric tons.
Index of authorities; see Table XXXIII-B.

Year.	United States.	Great Britain.	Germany and Luxemburg.	France.	Russia and Finland.	Austria.	Hungary.	Belgium.	Sweden.	Italy.	Spain
1880....	1,247[2]	1,375[2]	661[13]	389[3]	296[3]	113[14]	21[14]	132[3]	29[3]	......	......
1881....	1,588[2]	1,860[2]	897[13]	422[3]	293[3]	150[14]	38[14]	142[3]	38[3]	4[3]	.....
1882....	1,737[2]	2,190[2]	1,075[13]	458[3]	248[3]	199[14]	41[14]	183[3]	41[3]	3	......
1883....	1,674[2]	2,089[2]	1,061[13]	522[3]	222[8]	233[14]	56[14]	179[3]	45[3]	?	......
1884....	1,551[2]	1,855[2]	1,200[13]	503[3]	207[8]	198[14]	61[14]	187[3]	74[3]	5[3]	......
1885....	1,712[2]	1,968[2]	1.203[13]	554[3]	193[3]	206[14]	73[14]	155[3]	81[3]	6[3]	......
1886....	2.563[2]	2,345[2]	1 361[13]	428[3]	242[8]	203[14]	57[14]	164[3]	77[3]	24[3]	20[3]
1887....	3,339[2]	3,151[2]	1,685[13]	493[3]	225[8]	234[14]	65[14]	229[3]	110[3]	73[3]	?
1888....	2,899[2]	3.406[2]	1.862[13]	517[3]	222[8]	292[14]	101[14]	244[3]	115[3]	118[3]	?
1889....	3,386[2]	3,670[2]	2,022[13]	529[3]	259[8]	309[14]	108[14]	261[3]	135[3]	158[3]	49[3]
1890....	4,277[2]	3,679[2]	2,162[13]	582[3]	378[8]	343[14]	157[14]	221[3]	169[3]	108[3]	75[3]
1891....	3,904[2]	3,257[2]	2,563[43]	639[3]	433[8]	334[14]	152[14]	244[3]	173[3]	76[3]	70[3]
1892....	4,928[2]	3 020[2]	2,756[43]	682[3]	515[8]	352[14]	159[14]	260[3]	159[3]	57[3]	56[3]
1893....	4,020[2]	3,050[2]	3,163[43]	664[3]	631[8]	380[14]	189[14]	273[3]	166[3]	71[3]	71[3]
1894 ...	4,412[2]	3,211[2]	3,642[43]	663[3]	726[3]	453[14]	207[14]	406[3]	168[3]	55[3]	70[3]
1895....	6,115[2]	3,390[2]	3,963[43]	900[3]	879[3]	498[14]	247[14]	455[3]	232[3]	50[3]	65[3]
1896....	5,282[2]	4,233[2]	4,821[43]	1,160[3]	1,023[3]	583[14]	295[14]	599[3]	251[3]	60[3]	105[3]
1897....	7,157[2]	4,586[2]	5.137[43]	1,282[3]	1,205[8]	626[14]	303[14]	617[3]	268[3]	57[3]	121[3]
1898....	8,933[2]	4,666[2]	5.781[43]	1,442[3]	1,596[42]	723[14]	332[14]	653[3]	264[3]	59[3]	113[3]
1899....	10,640[2]	4.855[6]	6 329[43]	1.499[9]	1,939[42]	784[14]	333[14]	731[3]	272[3]	62[3]	123[3]
1900....	10,188[2]	4,901[6]	6,646[43]	1,565[41]	1,463[2]	781[14]	353[14]	655[2]	300[9]	58[5]	150[5]
1901....	13,474[2]	4,904[44]	6,394[43]	1,465[41]	2,050	....	....	....	270[40]	123	....
1902....	14,947[2]	......	8.419	1,660	.....	....	....	....	284	....	....

TABLE XXXIII-K.

Production of Wrought-Iron in the Leading Nations.

United States and Great Britain, 1 unit = 1000 gross tons; other countries = 1000 metric tons.
Index of authorities; see Table XXXIII-B.

Year.	United States.	Great Britain.	Germany and Luxemburg.	France.	Belgium.	Sweden.	Russia.	Austria-Hungary.
1881	....	2,681[6]	1,294[17]	1,026[13]	480[13]	250[13]	....	....
1888	....	2,031[6]	1.547[18]	817[13]	548[13]	253[13]	366[8]	349
1889	....	2,254[6]	1.650[19]	794	577[13]	275[13]	428[8]	....
1890	....	1,923[6]	1.454[20]	825[13]	514[13]	282[13]	433[6]	....
1891	.. ..	1,734[6]	1 484[43]	833[13]	497[13]	280[13]	448[8]	....
1892	....	1.561[6]	1,367[43]	829[13]	479[13]	274[13]	498[8]	....
1893	....	1,364[6]	1.178[43]	830[13]	485[9]	277[29]	499[8]	....
1894	......	1 339[6]	1.143[43]	786[9]	453[9]	282[30]	502[8]	....
1895	....	1,148[6]	1.080[43]	757[9]	446[9]	189[31]	440[6]	....
1896	... .	1,214[6]	1 200[43]	829[9]	464[9]	188[32]	498[8]	....
1897	....	1 288[6].	1,112[43]	784[9]	479[13]	190[33]	512[9]	....
1898	....	1.116[6]	1,160[43]	802[9]	510[9]	199[6]	474[42]	....
1899	....	1 202[6]	1,204[43]	833[6]	475[6]	195[6]	511[42]	....
1900	....	1.163[6]	1,016[43]	708[41]	362[6]	188[9]	....	....
1901	....	974[44]	....	554[41]	....	165[40]	420	....

TABLE XXXIII-L.

Production, Imports and Exports of Certain Staples by the Leading Nations.

1 unit = 1000tons.
The amount "used" is the output, plus imports, minus exports.
Index of authorities; see Table XXXIII-B.

	United States.	Great Britain.	Germ'y and Luxemburg.	France.	Russia.	Austria H'gary.	Belgium.	Sweden.
	1900	1899	1900	1899	1897	1899	1899	1899
Bituminous coal raised	239 567[5]	220,085[5]	109,272[5]	32.863[9]	11.207[4]	12 694[5]	22,072[5]	239[4]
Imported..........	1,909[5]	2[5]	6,220[9]	13,370[9]	2,122[5]	5,291[5]	2,844[5]	3.048[5]
Exported..........	6,255[5]	41,839[5]	15 276[2]	1,026[9]	33[5]	879[5]	4.569[5]	1[5]
Used.	235,221	181 779	100,216	45,207	13,293	17,106	20 347	3 286
Imports; % of use....	1	....	6	30	16	31	14	93
Exports; % of output.	3	19	14	2	....	7	21	....
	1900		1900	1899		1899		
Lignite raised	little	nil	40,279[5]	607[5]	?	26,045[5]	nil	nil
Imported	....	....	7,960[9]	....	....	21[5]	....	....
Exported..........	....	....	53[9]	....	....	8 663[5]	....	....
Used..............	....	....	48,292	607	....	17,403	....	....
Imports; % of use	....	....	17	.... ..	.. ..	......	....	....
Exports; % of output.	....	....	....	....	....	33	....	....
	1900	1899	1899	1898	1897	1900	1899	
Coke made	17,149[5]	Est. (12,500)	11,500[11]	1,952[9]	?	1 241[16]	2,434[10]	nil
Imported..........	103[5]	....	463[5]	....	400[5]	564[5]	297[5]	little
Exported..........	....	881[5]	2,138[5]	... ..	.. ....	253[5]	1,009[5]	....
Used..............	17,252	....	9,825	....	?	1,652	1,722	....
Imports; % of use....	....	....	5	....	?	34	17	....
Exports; % of output.	....	7	19	....	?	20	42	....
	1900	1900	1900	1899	1897	1899	1899	1899
Iron ore raised.........	27,553[4]	14,028[2]	18,964[2]	4.986[1]	5,880[1]	3,853[1]	201[1]	2,435[1]
Imported..........	898[5]	6,399[5]	4.108[6]	1,951[5]	....	212[2]	2,621[5]	....
Exported.......	51[5]		3.248[6]	.... ..	....	327[2]	318[5]	1,628[5]
Used..............	28,400	20,427	19,824	6 937	5,880	3,738	2,512	807
Imports; % of use.....	3	31	21	28	....	6	100	....
Exports; % of output.	..... .	....	17	....	....	9	100	67
	1900	1900	1900	1900	1898	(?-1899) 1900	1899	1901
Pig iron made.........	13,789[2]	8,909[2]	8,520[2]	2 699[2]	2,821[2]	1,452[9]	1,036[1]	513[40]
Imported..........	53[5]	181[6]	727[6]	150[6]	109[6]	97[6]	362[5]	(50 Est.)
Exported..........	287[5]	1 427[6]	129[6]	114[5]	.... ..	16[6]	43[5]	85[40]
Used.......	13,555	7,663	9,118	2,735	2,930	1,533	1,355	478
Imports; % of use	....	2	8	5	4	6	27	10
Exports; % of output.	2	16	2	4	....	1	4	17
	1900	1900	1900	1900	1898	(1899 ?) 1900	1900	1899
Finished iron and steel Made..............	9,487[2]	6,057[6]	7.576[5+6]	2,405[6+2]	Est. (1,645)	....	1,017[6+2]	467[3+6]
Imported..........	210[2]	578[6]	150[6]	64[6]	448[6]	162[6]	....	47[6]
Exported..........	1,154[2]	2 013[6]	1.314[6]	197[6]	... .	108[6]	416[6]	197[6]
Used..............	8,543	4,622	6,412	2,272	2,027	....	....	317
Imports; % of use. ...	2	12	2	3	19	....	....	15
Exports; % of output.	12	33	17	8	....	....	41	42

TABLE XXXIII-M.

Import Duties on Iron Staples in Dollars per Long Ton.

Round numbers are given and ad valorem duties are calculated for average values.
Arranged from the Mineral Industry for 1900.

	England	United States.	Germany.	France.	Russia	Austria.	Sweden.	Spain.
	$	$	$	$	$	$	$	$
Coal	Free.	Free.	Free.	....	....	Free.	....	6.00
Coke	Free.	0.40	Free.	0.23	....	Free.	....	6 00
Pig iron	Free.	4 00	2 40	3 90	14.00	3 25	Free.	4.20
Bars	Free.	13.40	6 00	9 70	....	11.20	6.70	22.00
Sheets and plates	Free.	....	7.20	14.50	....	16 20	10 70	....
Ingots.	Free.	6.70 to 10.50	6 00	9.70	25.00	11.20	5.50	12.00
Rails	Free.	7.80	6.00	13.50	28 00	11.20	Free.	14.00
Tin plates	Free.	33 60	12 00	29.00	79.00	16.20	Free.	46.00

APPENDIX.

Value of Certain Factors Used in Iron Metallurgy.

ATOMIC WEIGHTS.

Fe,	56	Si,	28	C,	12
Mn,	55	Ca,	40	O.	16
S,	32	Mg,	24	N,	14
P,	31	Al,	27	Ti,	48
Ni	59	Cr	52	W	184

CONTENT OF METALLIC IRON IN PURE COMPOUNDS OF IRON.

$FeCO_3$	$\frac{14}{29}$ or 48 28	per cent.
FeO	$\frac{7}{9}$ or 77.78	"
Fe_2O_3	$\frac{7}{10}$ or 70.00	"
Fe_3O_4	$\frac{21}{29}$ or 72.41	"

REACTIONS IN OPEN-HEARTH FURNACES.

100	pounds	$CaCO_3$	produce	56	pounds	CaO.
100	"	$MgCO_3$	"	48	"	MgO.
100	"	Si	"	214	"	SiO_2.
100	"	Mn	"	129	"	MnO.
100	"	Fe	"	128	"	FeO.
100	"	P	"	229	"	P_2O_5.
100	"	C	"	233	"	CO.
100	"	C	"	367	"	CO_2.

Properties of Air.

Composition by volume $\begin{cases} \text{O=20.9 per cent. N=79.1 per cent.} \\ \text{O : N=1 : 3¾=4 : 15.} \end{cases}$

Composition by weight $\begin{cases} \text{O=23.2 per cent. N=76.8 per cent.} \\ \text{O : N=3 : 10} \end{cases}$

Weight of 1 cubic metre=1.293 kilogrammes.

Weight of 1 cubic foot=0.0807 pounds.

Coefficient of expansion $\begin{cases} \text{Constant volume=0.003665} \\ \text{Constant pressure=0.003670} \end{cases}$

Comparison of English and Metric Systems.

1 metre=39.37 inches.
1 cubic metre=35.316 cubic feet.
1 kilogramme=2.2046 pounds.
1 kilogramme per square millimetre=1422.32 pounds per square inch.
1 kilogramme per cubic metre=0.0624 pounds per cubic foot.
1 gross ton=2240 pounds.
1 metric ton=2205 pounds.

Gravimetric and Calorific Values.

1 calorie raises 1 kilogramme of water 1° Centigrade.
1 British thermal unit raises 1 pound of water 1° Fahrenheit.
1 calorie=3.9683 British thermal units.

Factor.	Weight per cubic metre in kilogrammes.	Calorific Value in Calories.		
		Products of combustion.	Per kilo.	Per cubic metre.
CO_2	1 97	....	......	......
N	1 26	....	......	......
CO	1.25	CO_2	2438	3072
H	0 09	H_2O	29040	2614
CH_4	0.72	CO_2 and H_2O	11970	8620
C_2H_4	1.25	CO_2 and H_2O	10300	12980
C	....	CO	2450	......
C	....	CO_2	8133	......
Si	....	SiO_2	6414	......
P	....	P_2O_5	5740	......
Fe	....	FeO	1173	......
Fe	....	Fe_2O_3	1746	......
Mn	....	MnO	1635	......

FORMULÆ FOR SPECIFIC HEAT OF GASES BETWEEN 0°C and t°C.

$CO_2 = 0.374 + 0.00027\,t$
CO, O, H, N and $O = 0,30; + 0.000027\,t$
$H_2O = 0\ 342 + 0.00015\,t$
$CH_4 = 0.418 + 0.00024\,t$
$C_2H_4 = 0.424 + 0.00052\,t$

Mariotte's Law.—The volume of a gas is directly proportional to the absolute temperature and inversely proportional to the pressure upon it.

Note: Absolute zero = – 273·5°C.

Law of Dulong and Petit.—The product of the atomic weight of an elementary substance by its specific heat is always a constant quantity.

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