manganese, for the reason that under the majority of conditions the blast-furnace manager regulates the manganese and phosphorus-content of his cast iron by regulating the quantity of these two elements which the ore itself contains, rather than through the variations of the management of the furnace. I do not here refer to the making of spiegeleisen or ferro-manganese, or other special kinds of cast iron, but to that of the common classes of cast iron which contain no very large quantity of manganese.

But when we come to the sulphur and silicon-content of the cast iron, this is something which the manager regulates to a very great extent by the manner in which he conducts the smelting operation. Of the silicon present in the ore as silica only a very small proportion in any event passes into the pig iron; but the variations in this proportion have the most profound effect upon the properties of the cast iron, and these variations are under the control of the manager so that from one and the same ore mixture he can make cast iron almost wholly free from silicon, or on the other hand cast iron containing much silicon.

So, too, by no means the whole of the sulphur present in the ore or fuel enters the cast iron, and of course the less the better. And by varying the management of the blast-furnace the manager is able to control to a very great extent the percentage of sulphur which does enter the cast iron.

The way in which the silicon-content of the pig iron is controlled is through controlling the deoxidation of the silica of the gangue and ash. This deoxidation takes place readily by reactions such as

$$(15) \quad SiO_2 + 2C = Si + 2CO;$$
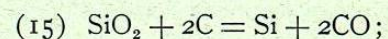
and any silicon which is reduced is immediately absorbed by the molten iron present. Indeed, this reaction does not readily take place in the absence of iron; but if iron is present to absorb the resultant silicon the reaction is readily effected.

Thus, by controlling the strength of the deoxidizing conditions the manager can control the extent to which reaction (15) takes place, and thus the quantity of silicon which is formed, and thus finally the percentage of silicon which enters the pig iron.

We have already seen (§ 184, p. 208) that the presence of silicon favors the separation of carbon in the condition of graphite, and thus leads to the formation of gray cast iron. In short, for foundry purposes the presence of a certain amount of silicon, but

only a certain amount, is desirable. In the processes for converting cast iron into steel the quantity of silicon which that iron contains is in general a matter of first importance. On both these accounts then it is important to regulate the quantity of silicon which the cast iron is to contain, or in short to regulate the strength of the deoxidizing action, since it is this action that determines how much silicon shall be deoxidized and enter the iron.

While the sulphur-content, too, of the pig iron is regulated by the same general steps, yet the principle through which these steps work is strikingly different. There is no general agreement as to the theory of this operation, yet we may adopt as a working hypothesis that it is through influencing the degree of deoxidation that these steps regulate the sulphur-content, and that the way in which they influence it is through controlling the degree to which the following reaction takes place:

$$(30) \quad FeS + CaO + C = Fe + CaS + CO.$$
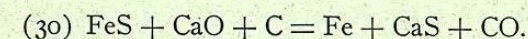
This reaction is clearly one of deoxidation; it is not, however, deoxidation of sulphur but of calcium, with the substitution of calcium sulphide for iron sulphide. How this substitution lessens the sulphur-content of the pig iron will now be explained.

The sulphur is initially present in the ore in the condition of sulphide of iron, and in most cases as pyrites, FeS_2. One of the equivalents of sulphur of the pyrites is nearly or quite completely expelled by heat; but the second remains combined with the iron as FeS. It appears to be a general principle of wide application that metals are capable of dissolving small quantities and even in certain cases large quantities of their own oxides and sulphides, but that they have much less solvent power for the oxides and sulphides of other metals. Accordingly if the sulphur remained in the condition of iron sulphide it would dissolve in the cast iron, which would thereby be injured. We can prevent this by reaction (30), i. e., by causing the sulphur to combine with calcium as calcium sulphide, which does not dissolve in the iron, but passes into the slag; and the thoroughness of desulphurization depends upon the degree to which this reaction takes place, i. e., upon the extent to which calcium is deoxidized, and this depends in turn on the strength of deoxidation.

I am quite aware that this theory does not explain all the facts; but, in default of a better I give it as one which explains

a great many of them, and is consistent and intelligible. It appears to me probable that the further facts which this theory does not explain are due to some additional agency, and that the principle underlying this theory is probably a true one, but simply not the only principle which is at work.

We here notice this contrast. The amount of silicon, manganese and phosphorus which the cast iron will contain increases with the strength of the deoxidation; whereas the quantity of sulphur decreases with it. Deoxidation causes silicon, manganese and phosphorus to pass from the slag to the metal, but deoxidation of calcium causes sulphur to go into the slag instead of into the metal.

The effect of sulphur on the separation of graphite, and through this on the fracture or " grain " of the iron, is the opposite of that of silicon, opposing the formation of graphite and tending to make the iron white instead of gray. As respects both silicon and sulphur, then, the effect of the increase of the deoxidizing action on the formation of graphite is alike. In other words, strengthening the deoxidizing action favors the formation of graphite and makes the iron grayer, both through increasing the silicon-content and also through lessening the sulphur-content of the iron.

304. MEANS OF REGULATING THE STRENGTH OF THE DE-OXIDIZING ACTION. — Those which we will consider are the following:

(1) Controlling the temperature in the hearth of the furnace.

(2) Varying the proportion of fuel to " burden," *i. e.,* to ore plus limestone.

(3) Varying the composition of the slag.

TABLE 19. — In order to keep before the reader in accessible form the results which we shall reach from time to time during the discussion which now follows, Table 19 has been prepared, presenting these results in an extremely condensed form. We are going to consider the effect of variations in the ratio of fuel to burden, in the blast temperature, and in the composition of the slag, on the silicon and sulphur-content of the pig iron. The influence of certain of these variations may be regarded as twofold, a thermal influence and a direct chemical influence. For instance, the coke is both the heating and the deoxidizing agent. If we increase the proportion of coke, then, we both raise the tem-

perature, which in itself favors deoxidation, and we further favor deoxidation by providing more of the deoxidizing agent. Of these two we may call the former the thermal influence, the latter the direct chemical influence. The effect of the former is recorded in columns 2, 3 and 4, that of the latter in columns 5 and 6.

Column 2 gives the effect of each of the variables of column 1 on the hearth temperature, and columns 3 and 4, give the influence of this change of hearth temperature on the quantity of silicon and of sulphur which the pig iron will contain. As the discussion proceeds we will record the results we reach by means of plus (+) and minus (—) signs in the proper places in this table. For instance the fact that increasing the proportion of coke

TABLE 19

LINE	VARIABLE	INFLUENCE ON THE CAST IRON MADE									
		Effect on the Silicon and Sulphur-content							Effect on Graphite and Grayness		
		Thermal Influence			Direct Chemical Influence		Resultant of 3, 4, 5 and 6				
		on Hearth Temperature	on Silicon-content	on Sulphur-content	on Silicon-content	on Sulphur-content	on Silicon-content	on Sulphur-content	By Silicon	By Sulphur	Net
	Column 1	2	3	4	5	6	7	8	9	10	11
A	Increase in the ratio of fuel to burden	+	+	−	+	−	+	−	+	+	+
B	Increase in the Blast Temperature	+	+	−			+	−	+	+	+
C	Increase in the Lime-Magnesia-content of the slag = raising its melting-point	+	+	−	−	−	±	−	±	+	±

raises the hearth temperature we indicate by the plus sign (+) in column 2 line *A*. The fact that this elevation of hearth temperature will tend to increase the silicon-content of the pig iron we indicate by the plus sign (+) in column 3 line *A, etc.*

Column 9 gives the influence of the change in silicon-content in column 7 on the proportion of graphite and the grayness of the pig iron; column 10 gives the corresponding effect of the change in sulphur-content in column 8; and column 11 gives the resultant of the effects recorded in columns 9 and 10.

305. The Hearth Temperature. — The temperature of the hearth, *i. e.,* of the lowest part of the furnace, has a most important influence on the strength of the deoxidizing action; it is here that the deoxidation is to be finished, or in other words, it is here that its thoroughness is determined. The higher the temperature the more powerful the deoxidizing action of carbon on iron, silicon, calcium, manganese and phosphorus, and very likely on most other elements. Therefore the hotter the hearth is, the more powerful the deoxidizing action of the fuel there present, and the more silicon should be deoxidized and enter the iron, and the more calcium should be deoxidized and carry sulphur from iron to slag.

In short whatever tends to raise the hearth temperature tends thereby to raise the silicon-content and to lower the sulphur-content of the pig iron, a principle to which we shall have occasion to refer several times in the beginning of the following discussion.

The manager can raise the temperature of his hearth in three chief ways:

(1) By increasing the proportion of fuel to ore and flux (*i. e.,* by lightening the burden).

(2) By raising the temperature of the blast.

(3) By making the slag more infusible.

That the first two should have this effect needs no explanation. We may, therefore, in Table 19, accept the plus mark (+) in lines *A* and *B*, column 2. Further, because raising the temperature here in and by itself favors deoxidation, and thereby tends to increase the silicon-content and decrease the sulphur-content of the pig iron, we may accept the plus signs in column 3 and the minus signs in column 4 of lines *A* and *B*. That increasing the proportion of coke charged should increase by direct chemical influence the strength of the reducing tendencies is perfectly clear for the reason that the fuel itself is the deoxidizing agent. And

as any increase in the strength of the deoxidizing tendencies should tend to increase the silicon-content and to decrease the sulphur-content of the pig iron, for reasons with which we are now so familiar, we accept the plus mark and the minus mark in columns 5 and 6 respectively of line *A*.

From the marks which we have now recorded in columns 3, 4, 5 and 6 of line *A* the marks in the remaining columns 7 to 11 of that line follow directly.

Thus the effect of an increase in the proportion of coke is to make the iron more graphitic and grayer in all the ways which we have considered.

We may for our present discussion assume that an increase in the temperature of the blast will have no direct chemical influence, apart from its thermal influence, or, at least we may ignore for simplicity in our present discussion any direct influence; hence, we leave blank columns 5 and 6 of line *B*. This done, the marks in the remaining columns 7 to 11 of line *B* follow directly from those of columns 2 to 4 of that line.

306. Influence of the Slag Melting-point on the Hearth Temperature. — Why raising the melting-point of the slag should in and by itself directly raise the hearth temperature requires a word of explanation.

Let us suppose that on the right-hand side of a given blast-furnace as shown in Fig. 89, p. 334, we are charging a mixture, the slag-making materials of which are extremely infusible, whereas on the left-hand side we are charging a mixture, the slag-making components of which are relatively fusible. Let us further suppose, to illustrate our point, that these two charges descend separately without mixing up. Such a state of affairs of course could not exist, and it is imagined here simply for the purpose of explaining what does occur.

A given lot of ore, flux and fuel charged on the left-hand side gradually descends, becomes hotter and hotter, and finally, at the level *A*, Fig. 89, reaches such a temperature that the gangue, the ash of the fuel, and the lime of the limestone react on each other, unite, that is to say form a slag or *scorify*, melt, and run to the bottom of the furnace, where they collect as a layer of slag.

A parallel lot of charge on the right-hand side of the furnace gradually descends and grows hot in the same way. But when it has reached the point *A* at which the charge on the left-hand

side melted, that on the right-hand side still remains unmelted because the slag-making substances present as a whole are so much more infusible. At the temperature at which their fellows on the left-hand side of the furnace had reacted on each other, united, melted and formed slag, those on the right fail to react on each other and remain separate; and not until they have been heated to the distinctly higher temperature at which their interaction becomes possible, *i. e.,* not until they have descended much lower in the furnace, say to level *C,* will they in turn react, unite, scorify, melt, and run to the bottom of the furnace.

Now, so long as solid materials descend through the furnace unmelted, their descent is slow, and they have abundance of time to acquire heat from the rising gases and from the fuel with which they are surrounded; in short, to acquire the temperature of the furnace level at which they are. But the moment they pass from the solid to the liquid state, instead of descending slowly they now run rapidly from the point at which they melt to the bottom of the furnace (see Fig. 114, p. 386); and during this rapid further descent, because of its rapidity, they have little further opportunity of acquiring heat. Hence the more fusible of the two lots will reach the bottom of the furnace at a temperature not greatly above its own melting-point; while the more infusible lot will reach a temperature also not far above its own higher melting-point. No doubt each, in running down after it has melted, will be to a certain extent superheated above its melting-point, *i. e.,* in its passage, rapid as that passage is, it will receive some heat; but this will not be enough to compensate for the difference in their melting-points.

An extreme case may help to make this clear. Suppose that in one of two furnaces, otherwise alike, we were to charge along with our fuel, masses of frozen mercury, and in the other masses of iron at the same low temperature. Let us neglect for the moment the volatility of mercury. When our mercury has descended a few feet at most it will melt, and will immediately run to the bottom of the furnace with great velocity. Our iron on the other hand will descend slowly through the furnace and will not melt until it had reached a level at which the temperature is 1600° C., its own high melting-point. Both the molten mercury and the molten iron in descending will certainly undergo a slight superheating, and the molten mercury, having a greater distance to

travel than the molten iron, would undergo a greater superheating. Nevertheless, this would not compensate for the fact that the mercury started to run down through the furnace as soon as it had been heated to a temperature of — 40° C., while the iron remained solid until it reached a temperature of 1600° C., when it in turn melted and ran. I dwell upon this principle because it underlies all reducing smeltings in shaft furnaces.

A second and less important reason why the more infusible slag leads to higher hearth temperature is that it gums over the walls of the lower parts of the furnace to a greater thickness, and so in effect thickens those walls and lessens the conduction of heat outward through them.

For the above two reasons, increasing the infusibility of the slag leads to higher temperature and thus to more thorough deoxidation.

Still a third reason why infusibility of slag favors deoxidation is that, in the way already sketched, it prolongs the exposure of the metallic oxides and of the silica, phosphoric acid, *etc.,* to the deoxidizing conditions in the furnace; and this added exposure is especially effective because of the very high temperature which accompanies it, and also for another reason, which is as follows. When silica, lime, iron oxide, *etc.,* are free, *i. e.,* when they are not in chemical combination with each other or with other substances, they are more readily deoxidized than when they are in such state of combination, because the bond which holds them together in any combination has to be broken before deoxidation can occur. In other words the bond between two combined substances is an impediment to their deoxidation. Now if the silica, iron oxide, lime, *etc.,* exist in the ore initially uncombined with each other, they may remain so up to the time when fusion sets in, or at least very nearly till then; but after fusion has set in these different substances are necessarily combined, and silica with the lime and any iron oxide which had escaped deoxidation. Hence deoxidation is in general easier, other conditions being equal, before than after fusion.

Manifestly the leaner the ore, *i. e.,* the greater the proportion of gangue, the more important will this consideration be; and in smelting copper ores it may be of the very greatest importance, because copper ores are very lean, *i. e.,* contain a very large quantity of gangue.

307. Regulation of Melting-point of Blast-furnace Slag by Means of its Composition. — Let us next ask what the ways are in which the manufacturer may vary the composition of his slag, in order thereby to vary its melting-point, and thereby the hearth temperature, and finally the sulphur and silicon-content of the pig iron.

Blast-furnace slags are essentially silicates of lime, magnesia and alumina, and almost necessarily so. In many cases it is well to consider very carefully the most desirable alumina-content; but such a search would take us too far for the purposes of the present outline. That which the manager actually varies from week to week for the purpose of controlling the working of his furnace is usually the lime-content, and this he does by varying the proportion of limestone to ore charged. For our purposes we may consider lime and magnesia as substantially equivalent, in order to simplify our problem; so that the question before us is substantially, how do the variations in the lime-content of the slag affect the fusibility of that slag.

On referring to Fig. 115, it is to be seen that the great majority of blast-furnace slags are, so to speak, on the lime side of the greatest fusibility; that is to say they contain more lime and magnesia than the most fusible lime-magnesia-alumina silicate contains.

The reason why they habitually are on the lime side of the most fusible ratio is that by means of a slag rich in lime, sulphur is more readily removed from the iron. If we take two extreme cases, one a slag consisting of $CaOSiO_2$ and the other consisting of $2CaO, SiO_2$, it is evident that calcium would be more easily deoxidized from the latter than from the former by the reaction:

$$(30) \quad FeS + CaO + C = CaS + CO + Fe.$$
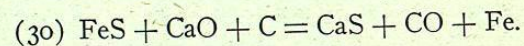
This is of course in harmony with the general principle that a given element or oxide, in this case the lime, is less tenaciously held in a chemical compound in which it is in excess, than in one in which it is in a sense deficient. From very high oxides in general, for instance from peroxide of hydrogen, H_2O_2, oxygen is readily removed. Ferric oxide, Fe_2O_3, and cupric oxide, CuO, are readily deoxidized to magnetic and cuprous oxides respectively, Fe_3O_4 and Cu_2O, by simple exposure to heat. So, too, carbonic acid, CO_2, is readily decomposed into carbonic oxide, CO, and oxy-
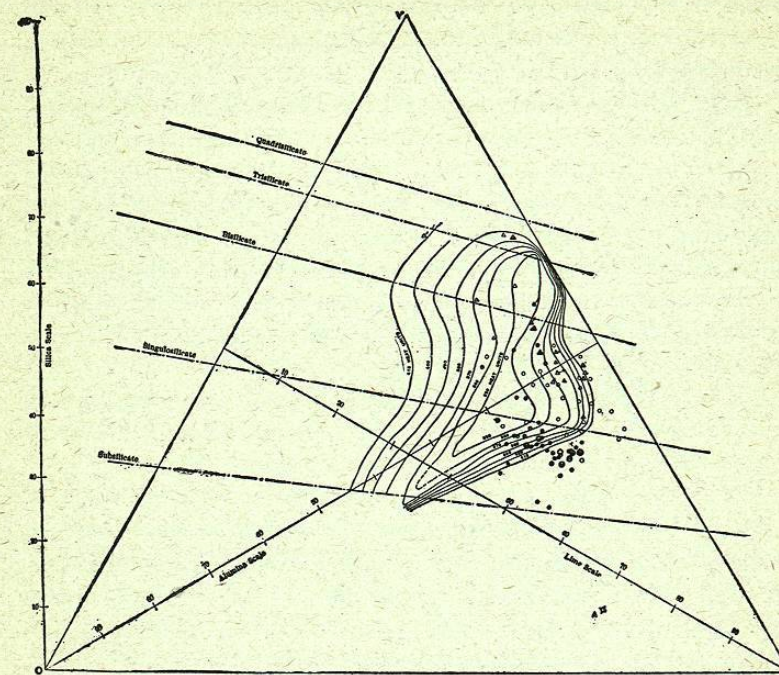
Fig. 115. Lines of Equal Total Heat of Solidification of the Lime-alumina Silicates, and the Composition of Certain Iron Blast-furnace Slags.

Legend:

▲ = Charcoal blast furnace slags.

Coke blast-furnace slags are indicated by circles, according to the grade of the accompanying cast iron, as indicated by the authority from which the example is taken as follows:

⊖ = When the iron is British Bessemer, or "Foundry," or No. 1, or No. 2, or contains 1.75 per cent or more of silicon.

● = When it is American Bessemer, or "Forge," or No. 3, or contains between 1 and 1.75 per cent of silicon.

◑ = When it is white iron or contains less than 1 per cent of silicon.

Percentage of manganese as

    10 per cent
    20 " "
    30 " "
    40 " "