NOTES ON THE BLAST FURNACE.

BY JOHN HARTMAN.

[*A lecture delivered before the Franklin Institute, February 19, 1892.*]

MR. HARTMAN spoke as follows:

Pig Iron.—History tells that about 1,500 to 1,600 years before Christ the Phœnicians taught the Greeks the manufacture and use of iron. After that time Greek history gives some detailed account of it. The Phœnicians, before leaving their original home on the Indian Ocean, practised the art of iron-making, and on migrating to the Land of Canaan, whose hills were well covered with wood and contained iron ore, they made iron and sold it to the neighboring nations.

Tracing its early history back, it is lost in the twilight of fable. The hurling of Hephæstus from Olympia and the working of iron established by that act, when divested of its fiction, will be found to be the falling of an iron meteorite and the use made of it.

The Cretans' claim to the discovery of iron-making is more rational. Mount Ida in Crete was well wooded and had a fine vein of iron ore on its side. Timber left to grow, decay and fall will accumulate to quite a depth. This timber being accidentally fired at the bottom of the mountain by the inhabitants, in burning upwards burns slower, as the smoke and carbonic acid from below prevents the air from getting freely at the fire above to support combustion. This slow combustion favors turning the wood into charcoal, which, covering any pieces of iron ore, they are reduced or deoxidized by contact with solid carbon. As the wood below is burned off, the pure air sweeping up the hot mountain side, is heated by the ground and rocks, and the charcoal over the ore is burned off at a high heat, causing the slag to flow from the reduced iron, leaving the iron remain as a sponge, which is easily hammered into wrought iron. We have here in nature's work the hot blast and the principle of regenerative furnaces.

The Phœnicians, however, being the older nation, must have the honor of first discovery, and to them more than any other nation the world is indebted for metallurgical science and massive structures. How these people could transport and erect the blocks of stone forming their structures is a puzzle to modern engineers, who with their best appliances, can only lift one-fourth of their weight. They used steel tools, as is shown by the grooves in their quarries, and grappling irons were used to handle the blocks, to which the holes in them attest. All ancient iron was made by reducing pure oxides in a shallow charcoal fire, forming a sponge, and then hammering out the slag, a process carried on to this day.

The oldest and finest of all ruins are at Baalbec, Syria. Their columns, seven feet diameter, in three sections of twenty-four feet each were held together by wrought-iron dowels, but these have been dug out by the Turks and Arabs during the Dark Ages to get material for implements of war and agriculture. They replaced a people of superior intelligence by their rugged nature and strength of muscle, but could not make a pound of iron. In all the Egyptian ruins the same destruction is noted. The massive coping stones of the temples were held together with iron clamps, but they have all been dug out and much of the work of these grand old masters has been destroyed by the lazy, arrogant vandals of the Dark Ages.

To make steel, the ancients submitted wrought iron to the cementation process, which is heating the iron in a closed vessel in contact with carbon at a red heat. In this state it absorbs sufficient carbon to harden it and give it steely qualities. This process is carried on in India to-day.

Aristotle gives us a few notes on iron, but Pliny speaks more freely, thus: "Nature, in conformity with her usual benevolence, has limited the power of iron by inflicting upon it the punishment of rust, and thus displays her usual foresight in rendering nothing in existence more perishable than the substance which brings the greatest danger upon perishable mortality."

He states that the method of making iron is the same as

that employed in making copper, and while some ores produce a metal that is soft and nearly akin to lead, others produce a brittle, coppery iron. Also that "it is a remarkable fact that when the ore is fused the metal becomes liquefied like water, and afterwards acquires a spongy, brittle texture." This can be seen to-day in any Catalan forge, where the slag accumulates, and on tapping off runs like water, leaving behind a brittle, spongy mass, which being consolidated by the hammer, becomes soft and tough. The brittleness is overcome by patting the bloom at first with light blows until it is compacted, then striking heavy blows and drawing it into billets. Also that "iron which has been burned in the fire is spoiled, and is useless until it is forged with the hammer;" this refers to the burned part being worked off in scale and sparks, and that "some iron cannot be worked at a red heat, but must be a bright yellow." This is the modern red-short iron. The iron, he says, "that is used for hob nails is soft like lead," which corresponds to our pure neutral iron, made in the Catalan forge.

The earliest record of furnaces for making molten iron (not sponge) show a hole some 15 inches diameter and 3 feet high in a clay bank. This was filled with charcoal and blown with air caught by deflectors and conveyed to the interior through pipes or reeds. After the furnace was warmed up with the burning coal, charges of ore and coal were put in, and after a few hours a lump of molten iron was taken out of the crucible by tearing the crucible open. This iron contained a little combined carbon, and if it had the right quantity, it could be worked into steel at once, or it could be decarbonized and made into wrought iron. The slag formed in these furnaces was silicate of protoxide of iron from the fusion of part of the ore with the gangue. It was tapped off from the furnace when it accumulated too high.

Carbon exists in iron as combined carbon or as graphitic carbon. Combined carbon makes iron steely or hard; graphitic carbon denotes soft iron. After bellows, made of pig or goat skins and operated by the foot or hand were

invented, higher heats could be obtained. This necessitated the use of more refractory material for the furnace, and caused separate structures to be built. The higher heats gave more combined carbon to the iron, which was worked off in another fire. After the Germans began making iron, they built their furnaces or stuckofens higher to economize heat and save charcoal, as they found wood getting scarce. In these higher furnaces the ore and coal collected the ascending heat and returned it to the crucible, increasing its heat and giving them an iron of different character. Part of the carbon was chemically combined and part was mechanically mixed with the grains, giving the iron a dark color and fluidity so that it would run like molten lead. As this iron was difficult to decarbonize, they called it bad or sow iron.

Prior to the thirteenth century, the art of iron founding was unknown, but with the use of higher furnaces a metal was made that was fluid and could be cast, which soon came into use and formed a new branch of the iron business. As the old German furnaces were small, they ran the combined carbon iron out in a long groove made in the sand, as the iron was mushy and flowed with difficulty from the furnace. When they used higher furnaces and made iron with graphitic carbon which ran fluid, they ran short grooves at right angles to the long groove, and filling them with metal, they called them pigs, a practice in use to-day.

By some it is thought the head of the battering-ram used by the ancients was cast iron, but it is too brittle for that purpose; it was forged to the shape shown on ancient monuments. Only rich, pure ores could be used by the ancients. They could not get the intensity of heat in their furnaces to give them graphitic carbon in the iron; hence, they could only make wrought iron.

Among the earliest appliances of cast iron in founding was to make cannon, but they frequently burst in the third or fourth round and killed as many friends as enemies, like some of the canonical laws made at times in the world's progress.

After the iron business had been conducted in England

for many years, the wood becoming scarce, they turned their attention to mineral fuel or coal with more or less success. About 1630 Dud Dudley experimented with coke.

In 1735, Abraham Darbey, of England, made the first successful blast with coke, and from that day to this it has been continued in making pig iron.

In 1837, anthracite came into use for pig iron making in Wales, and is continued in Pennsylvania to the present time.

In 1828, Neilson first applied heated air to the furnace, which raised the temperature of the crucible and allowed a more basic or limy flux to be used. This melts at a high temperature, but picks up the sulphur in the ore and fuel and gives a better iron. With the introduction of hot air, cheaper ores, but containing a higher percentage of sulphur and silica, could be used, which lowered the cost.

The heat of the crucible has been further increased by the use of regenerative stoves giving lower fuel consumption, more output and better iron, as the less fuel used, the less impurity goes from the fuel to the iron.

While metals as a rule increase in value with their purity, pure iron has no commercial existence and is never known outside of the chemical laboratory. Its value is only established when it is combined with carbon, but some of the following elements always accompany it in greater or less quantities and modify its character: silicon, manganese, magnesium, sulphur, phosphorus and aluminum. In chemical combination with iron there is no exact line of demarcation with these elements. Carbon exists in pig iron in the combined or the graphitic state, or in both states. Combined carbon closes the grain of iron, making it smaller and harder. Graphitic carbon is the combined carbon changed by high heat to the graphitic state which softens the iron. Silicon destroys the grain of the iron, making it weaker, softer, and cold-short. Manganese destroys the grain, weakens it and makes it red-short. Magnesium is claimed to soften and strengthen iron. Phosphorus is an unwelcome ingredient which cannot be eliminated and has to be tolerated; it weakens iron and makes it cold-short. Sulphur is

a vigilant enemy, closing the grain, making it harder, and causing red-shortness, but it can be eliminated. Aluminum strengthens and softens iron. Copper makes iron red-short. Cold-short iron will work in the smith's fire at a low heat, but is weak when cold. Red-short iron will work only at a high heat, but is strong when cold. If the iron is not worked at the heat to suit its nature it will crumble or break.

Pig iron is sold in the market in five grades, Nos. 1, 2, 3, 4 and 5. Besides these there are special grades established recently but used extensively, namely: Low phosphorous and sulphur iron used in the open hearth and Bessemer processes, and low silicon with high phosphorous iron, used in the basic process. Silicized iron containing four per cent. to seven per cent. of silicon is also made to soften other irons and make them run liquid.

ANALYSIS OF A STANDARD NO. 1 PIG IRON.

	Per Cent.	
Iron, ...	92'37	} Gray. — A large, dark, open-grain iron, softest of all the numbers and used exclusively in the foundry. Tensile strength, low. Elastic limit, low. Fracture, rough. Turns soft and tough.
Graphitic carbon, ...	3'52	
Combined carbon, ...	'13	
Silicon, ...	2'44	
Phosphorus, ...	1'25	
Sulphur, ...	'02	
Manganese, ...	'28	

NO. 2 PIG IRON.

	Per Cent.	
Iron, ...	92'31	} Gray. — A mixed large and small dark grain, harder than No. 1 iron, and used exclusively in the foundry. Tensile strength and elastic limit higher than No. 1. Fracture, less rough than No. 1. Turns harder, less tough and more brittle than No. 1.
Graphitic carbon, ...	2'99	
Combined carbon, ...	'37	
Silicon, ...	2'52	
Phosphorus, ...	1'08	
Sulphur, ...	'02	
Manganese, ...	'72	

NO. 3 PIG IRON.

	Per Cent.	
Iron, ...	94'66	} Gray. — Small, gray, close grain, harder than No. 2 iron, used either in the rolling mill or foundry. Tensile strength and elastic limit higher than No. 2. Turns harder, less tough and more brittle than No. 2.
Graphitic carbon, ...	2'50	
Combined carbon, ...	1'52	
Silicon, ...	'72	
Phosphorus, ...	'26	
Sulphur, ...	trace	
Manganese, ...	'34	

NO. 4 PIG IRON.

	Per Cent.		
	A.	B.	
Iron, ...	94.48	94.08	} <i>Mottled</i> .—White background, dotted closely with small black spots of graphitic carbon, little or no grain. Used exclusively in the rolling mill. Tensile strength and elastic limit lower than No. 3. Turns with difficulty, less tough and more brittle than No. 3.
Graphitic carbon, ...	2.02	2.02	
Combined carbon, ...	1.98	1.43	
Silicon, ...	.56	.92	
Phosphorus, ...	.19	.04	
Sulphur, ...	.08	.04	
Manganese, ...	.67	2.02	

[The manganese in this (B) pig iron replaces part of the combined carbon, making the iron harder, and closing the grain, notwithstanding the lower combined carbon.]

NO. 5 PIG IRON.

	Per Cent.		
	A.	B.	
Iron, ...	94.68		} <i>White</i> .—Smooth, white fracture, no grain, used exclusively in the rolling mill. Tensile strength and elastic limit much lower than No. 4. Too hard to turn and more brittle than No. 4.
Combined carbon, ...	3.83		
Silicon, ...	.41		
Phosphorus, ...	.04		
Sulphur, ...	.02		
Manganese, ...	.98		

Fig. 1, of the plate, shows the fracture of a No. 1 pig of the Thomas Iron Company (as are all the others). The large patches show the grain of the iron, which is rough and projects up in sharp points. On examining it with a powerful glass the grains of iron are found embedded in the graphitic carbon similar to a wall of rubble masonry laid solid in mortar. The grains are connected but the interstices are filled with the graphite. Graphitic carbon high, combined carbon low.

Fig. 2, of the plate, shows the fracture of a No. 2 pig. The patches are smaller, showing a smaller grain. Graphitic carbon lower, and combined carbon higher than No. 1.

Fig. 3, of the plate, shows fracture of No. 3 pig. The patches are smaller than No. 2 and show smaller grain. Graphitic carbon lower, and combined carbon higher than No. 2.

Fig. 4, of the plate, shows fracture of No. 4 pig. The patches are smaller and more of them than in No. 3 and

show little or no grain. Graphitic carbon lower and combined carbon higher than No. 3.

Fig. 5, of the plate, shows fracture of No. 5 pig. The patches are small and closer but no grain. No graphitic carbon, all combined carbon.

The strength for tension culminates in No. 3 pig iron, but falls off more rapidly from No. 3 to No. 5 than from No. 3 to No. 1.

	<i>Per Cent. Combined Carbon.</i>
Malleable iron contains	'25
Steely iron contains	'35
Steel contains	'50
Hard steel contains	1 to 1'50

Taking the sum of the graphitic and combined carbon in each quality of pig iron they are practically the same. The softness of pig iron is dependent on the amount of graphitic carbon in it. Separating the iron in the No. 1 pig from the graphitic carbon, it is a nearly pure wrought iron embedded in the graphitic carbon, and it is the absence of combined carbon which gives it the softness and flexibility that make it desirable for machinery and other purposes.

The grains of iron are crude crystals. When the iron is nearly pure and allowed to cool very slowly, regular octahedral crystals of iron are formed. Fine crystals were found twelve years ago in the hearth of Crown Point Furnace. They used an ore low in phosphorus, sulphur and manganese. These crystals are now in the Academy of Natural Sciences.

No. 1 pig iron may be defined as being composed of grains of wrought iron connected together but embedded in graphite. No. 2 pig iron has more combined carbon, which converts the wrought iron into a soft steel harder to the tool working it. No. 3 pig iron has more combined carbon, and the iron portion is a crude steel harder to the tool working it. Nos. 4 and 5 are virtually crude, high combined-carbon, steels.

The numbers here given, 1, 2, 3, 4, 5, for qualities of pig iron are the old standard. Some founders grade in

given. If the impurities in pig iron were uniform, which would be the case if there were only one kind of ore and fuel, the proper plan would be to buy iron by chemical analyses on a basis of graphitic and combined carbon, but the impurities so change the character that the eye is found to be the best guide so far in fixing the grade. In running the ends of the fingers over the fracture of a pig of iron, if the ends of the grain tear the fingers, the iron is strong. The analysis (B) of No. 4 pig iron, shows low in combined carbon, but the manganese hardens the iron and changes it from gray to mottled iron.

Fig. 6, of the plate, is a hot-blast No. 1 charcoal iron from Grand Rivers, Ky. The pigs bend before breaking. The ends of the grain are sharp and tear the fingers. The analysis is as follows:

	<i>Per Cent.</i>
Silicon, ...	1.955
Sulphur, ...	.029
Phosphorus, ...	.488
Manganese, ...	.213
Graphitic carbon, ...	3.310
Combined carbon, ...	.460
Iron, ...	93.545

On breaking this iron, the pig when it strikes the breaking blocks, emits a dull thud like lead. It is an iron of high tensile strength and well adapted for making car wheels. There are times in furnace practice when the first iron at a cast runs sluggish and mushy, but the iron on cooling is found to be excellent No. 1. This iron is the first formed directly after casting and lying near the tapping hole has slowly lowered its temperature and formed coarse grained iron. On opening the tapping hole the more fluid iron in the hearth pushes this cooler iron out first and it is then followed by the fluid iron.

The bending of pigs is not confined to charcoal iron. Cake and anthracite iron do the same when using good stock and running the furnace at the proper temperature.

Referring to the pig iron furnace section, *Fig. 7*, the air blown through the tuyere is quickly converted to carbonic oxide gas and the heat from it keeps the fuel in the bosh at

a white heat. The bosh and hearth are always filled with fuel when the furnace is working well. If the heat in the bosh becomes too high from a light burden, the silicon in the fuel is reduced, part of it going to the pig iron, giving a weak, light iron. When silicon is reduced, the cinder will

FIG. 1.

not take it up, what escapes the iron is burned to silica in the stoves and boilers; hence the heavy white fumes at the chimney top. Silicized iron was unknown to the ancients for want of heat to produce it. With a good burden of ore the heat of the bosh can be kept at the temperature

six divisions, and in some cases ten to eleven grades are required for a given iron. As the ore reduces in the upper part of the furnace a finely divided carbon penetrates the ore and combines with the iron; when the iron melts out of the ore it leaves it with the carbon in the combined state. As it trickles down through the glowing fuel it may form some graphitic carbon, but as a rule, it reaches the crucible with combined carbon only. With a clean, hot hearth, the carbon in the iron is gradually transformed to graphitic carbon. As the fluid iron running from the furnace cools, more or less of the carbon separates as graphitic carbon which is squeezed into the interstices between the grains as they form. If this pig iron is run against a cold plate the graphitic carbon is changed to combined carbon, and the lower the silicon in the pig iron the harder and greater is the depth of the change. If the thickness of the running iron is too great to change the whole thickness of the pig iron, then part of the pig will be close and hard, while the other part is open and soft. As more burden of ore is applied to the furnace the heat of the bosh and crucible is decreased, and Nos. 2, 3, 4 or 5 is produced as the bosh and hearth get cooler.

In making No. 1 iron, the founder must be careful to keep a large, clean, hot crucible, as the finishing touches to the iron for grade are made in it. In the crucible alone and not above it, must the intensity of the heat be applied to the iron to form graphite.

After the founder has made good No. 1 pig, it is sent to market and bought for the cupola. The cupola is charged with fuel and iron, the No. 1 iron being placed in the lower part of the cupola on a good bed of fuel, above it is more fuel, and on this is laid the harder iron. Suppose it is to make a roll; then No. 3 would be used. Blast is applied to the cupola, it burns up one side more than the other, and the hard iron above melts, comes down and mixes with the good No. 1 meant for pulleys; the result is, both irons are spoiled, and the founder making the No. 1 gets soundly berated for making an iron that changes in remelting.

Again, suppose all No. 1 is charged, and the iron is

melted at a lower temperature than that at which it was made; the carbon will partly change from graphitic to combined carbon, and make the iron harder. Again, suppose the fuel is high in sulphur, the iron, in the absence of the strong basic cinder of the blast furnace will take it up, closing the grain and making the iron harder; or, if the cupola scaffolds on one side, the air rushing up through the contracted opening decarbonizes the shots of falling iron and makes it harder. Iron melted with an excess of fuel will take up the kish or graphite formed by the intense heat, and on pouring the casting the cooling effect of the pouring squeezes out the graphite, which floats to the top of the mould and makes spongy castings. It is important to melt with the proper heat and no excess. Certain sands also exert a bad mechanical influence on pig iron by forming an asbestiform material that floats to the top of the mould, making defective castings.

Iron, to retain its quality as sold, should be melted by gas containing no free air. The gas should be burned to carbonic acid with an excess of air while heating up the iron. As soon as melting begins, the gas should be burned to carbonic acid with a slight amount of carbonic oxide in excess to take care of any truant air entering the furnace door. This can be accomplished by a regenerative furnace, using gas for heating. This furnace is the same as the open hearth furnaces now in use in all our large steel works, and consists of a square building of iron plates, lined with refractory brick and having a basin-shaped hearth on bottom. At each end of the square building are two round iron stoves, filled with fire brick having numerous passages from top to bottom of the bricks, called regenerators. The hearth and regenerators having been warmed up by wood, gas is turned through one of the regenerators and air through the other alongside of it. The gas and air meet at the end of the hearth and burn across it, heating it up and melting the iron placed on the bottom of hearth. After the burned gas passes the hearth, it enters the two opposite regenerators, heating them up. When the two first regenerators begin to cool off, the valves are reversed and the gas

and air sent back over the iron and through the other two regenerators. The burned gas in passing through the two first regenerators heats them up, when another reverse is made, and so on until night. By this arrangement all the waste heat of the furnace is utilized except the heat escaping in the carbonic acid at the chimney, which is about 350° . Comparing this with the $2,000^{\circ}$ escaping at the chimney of the cupola, a saving is effected in fuel. It will be safe to take the saving at 100 pounds fuel per ton of iron melted, which will pay the interest on difference of cost between the cupola and open-hearth regenerative plant.

With this furnace, slow or quick melting, and hot or cold melting, can be had at once; no sulphur will be taken up by the iron, and it can be kept at any desired heat, which avoids a change in the original quality. A perfect mixture can be made, as different irons charged when melted can be well stirred through the doors and made homogeneous. No precision of this kind can be obtained with the cupola, as it is guess-work when certain qualities of iron get down to the melting-point, and they cannot be stirred except in the ladle, which may not get equal quantities of each iron. No graphite can be formed in this furnace to make poor castings. An objection to this furnace will be the loss of heat keeping it hot over night with a small volume of gas, but it has the advantage of being ready in the morning for work as soon as the men arrive. As the high heat used in open hearth steel plants is not required for melting pig iron, the loss in heat to keep furnace warm over night would be slight. With the improved cranes and appliances for handling the metal, there is no longer need of suspending all moulding while pouring. When this system is taken up and worked out carefully in all its details, it will prove a decided success, as moulding and pouring can go on side by side.

From the data now being collected by the different iron works, some active brain in the future will give the world a table, showing how each element affects the pig iron, and by it a founder will be enabled to make his mixture to

produce the required results without having recourse to trial for each brand of pig iron.

The blast furnace is still in its infancy, yet in this country it has made rapid strides, and gone far beyond Europe in output and low fuel consumption.

THE PRESENT STATUS OF THE STORAGE BATTERY SYSTEM OF STREET RAILWAY PROPULSION.

BY PEDRO G. SALOM.

[*Read at the stated meeting of the Franklin Institute, held June 15, 1892.*]

JOS. M. WILSON, President, in the chair.

MR. SALOM: A distinguished scientist once told me that many years ago he was invited to give his first public lecture. He chose a subject that he thought he was very familiar with, as it was one in which he had been making long and careful investigations, but much to his amazement, after talking for ten or fifteen minutes, he found that he had exhausted the subject, and had told his audience all that he knew about it. Then he said he began to repeat himself, and he had continued to repeat himself ever since. Personally I am in very much the same position. I feel that I have already told all that I know about storage batteries, except what has been already better told by others. Still an old truth presented in a new light sometimes carries conviction for the first time.

This, then, is my reason for being here this evening. In discussing "The Present Status of the Storage Battery System of Electric Street Railway Propulsion," there are three questions to be considered:

(1) Why is it that so promising a field in electrical engineering has as yet produced no adequate commercial results?