

Evening Meeting.

Monday, March 3, 1879.

LIEUT.-GENERAL SIR HENRY LEFROY, K.C.M.G., R.A., F.R.S.,
in the Chair.

ON THE PRODUCTION OF STEEL, AND ITS APPLICATION TO MILITARY PURPOSES.

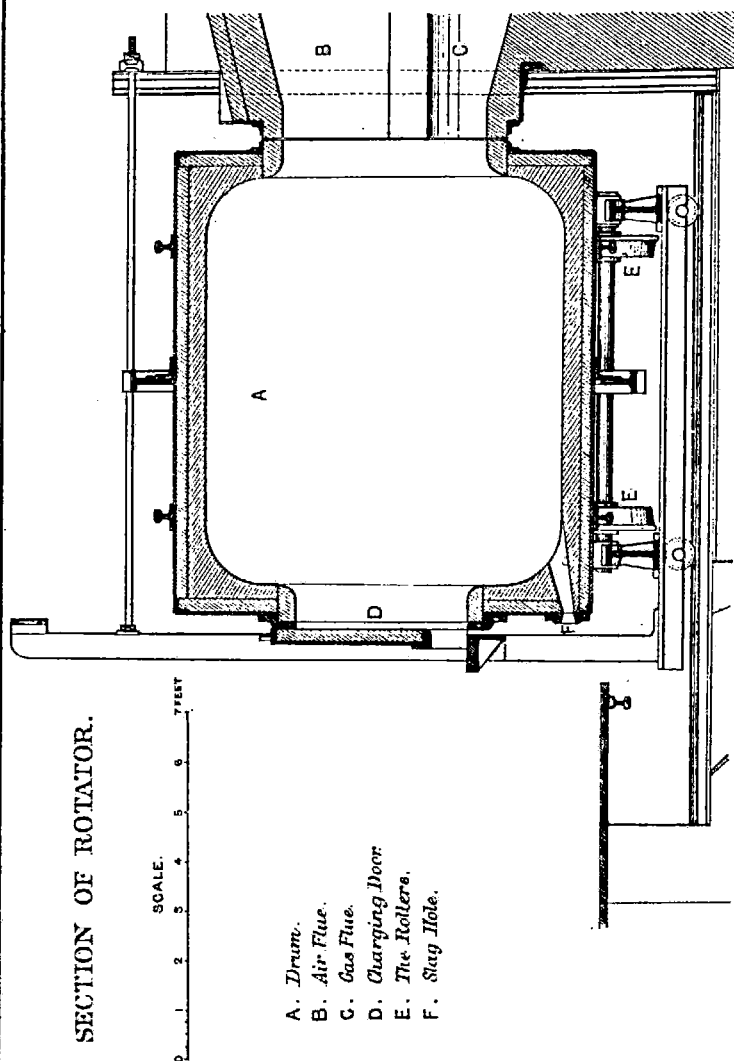
By C. W. SIEMENS, Esq., D.C.L., LL.D., F.R.S., &c.

The CHAIRMAN: It is scarcely necessary for me to remind you that you have before you one of the most distinguished physical philosophers of the present day. We have to do to-night, not with the distinguished electrician, with the constructor of the "Faraday," with the inventor of the bathometer, with the fertile inventor whose range has gone over subjects as various as the setting of type, and the measure of the depth of the ocean, but with one of the most scientific metallurgists of England, the inventor of many remarkable processes in that art, and particularly of one which I daresay he will allude to for the direct extraction of steel and iron from the ore, and of whom it may be very safely said that he has touched no subject which he has not adorned.

Dr. SIEMENS: The subject-matter regarding which I propose to engage your attention this evening is not new. Steel was known to the ancients, and is still produced by semi-barbarians in a similar manner to what we find described in ancient records. Rich ferruginous ores were placed upon ignited charcoal in a cavity formed in the side of a hill, and as the result of a day's hard labour in activating goat-skin bellows, a lump of metal mixed with charcoal and slag was produced, which after being subsequently forged, would prove sometimes of a comparatively soft nature, when it was called iron, and at other times harder when it was denominated steel. This shows that the two metals iron and steel are substantially the same, and that they are distinguishable only by difference of physical qualities which are the result of very small chemical admixtures.

The steel produced by the ancients was of very high quality, remarkable for its great hardness, and for its power to resist abrasion. Who has not heard of the blades of Damascus, and at a somewhat later period of those of Toledo, and of the remarkable swords that were made by the Norsemen? So much value indeed did the Norsemen place upon the production of cutting edges of great hardness

Fig. 3.



coupled with tenacity to resist chipping, that those who could produce a blade of unequalled edge were highly esteemed, and in one or two instances even rewarded with the purple of royalty in being elected sea kings.

Notwithstanding the antiquity of the metal called steel, its production and its application have taken a new and very remarkable stride within our recollection. It was, however, as early as the year 1722, that Reaumur, the distinguished French philosopher, proposed to produce steel on a large scale by fusing cast or pig metal with wrought metal or scrap. He put these ingredients into a crucible, and melting them together produced a metal partaking of the nature of steel. The difficulty he encountered, however, was insufficiency of heat. As far as we can make out, Reaumur's suggestion amounted to little more than a proposal, and it was not until 1820 that steel melting was introduced into commerce in a successful manner by Huntsman of Sheffield, using coke in a furnace actuated by intense draught, such as we know at present as an air furnace. Huntsman succeeded in melting steel in considerable quantity in pots, and from that date steel has become of great value in commerce for various applications.

Steel has variable properties depending upon very slight differences in chemical composition. Thus one steel when hardened will be next to diamond in its power to resist abrasion, and in its suitability to cut other metals, or when drawn out it will show a permanent elasticity not equalled by any other substance; it is susceptible of retaining magnetism, and will become what is called a permanent magnet, which property is shared with it to an inferior degree by only two other metals, nickel and cobalt. It is now produced in another condition known as mild steel, in which it manifests a quality of a totally different kind, a ductility not equal only but superior to that of copper and silver.

I hold in my hand a vase that has been wrought from a bar of this mild steel by an ordinary blacksmith, or I should rather say by an extraordinary blacksmith, because upon examination the workmanship displayed in the production of this vase is found to be really astonishing. The vase is hollow throughout, and not more than $\frac{1}{8}$ of an inch in thickness and perfectly sound, without weld or soldering. For this work of art I am indebted to my esteemed friend Mr. Henri Schneider, of the celebrated Crenсот works in France, who has forwarded it to me as a sample of what he had produced by the open hearth process of steel making, of which process I shall have occasion to speak further on.

It was not, however, until the year 1856, that a means was proposed of producing steel at a cheap rate. This was the year when Mr. Henry Bessemer read his famous paper at the meeting of the British Association at Cheltenham. His paper was entitled "The manufacture of malleable iron and steel without fuel," and it naturally created the greatest possible interest throughout the country. Mr. Bessemer, however, did not immediately succeed in producing by his process such steel as could be used. It was not until the year 1862, the time of the Universal Exhibition in London, that Bessemer steel

attained a decided position in commerce. But, in speaking of this very important process, I feel in justice bound to make reference to the name of Mushet, who, when he heard of the Bessemer process, thought that it would require an addition—analogue to what Heath made in the Sheffield pot-melting process—that of manganese. Mushet proposed and patented a mode of adding spiegeleisen (or pig metal containing a considerable percentage of manganese) to the Bessemer metal whilst it is still in the liquid state, thereby separating from it the oxygen held in suspension in the metal in consequence of the blowing, and as we now know, adding to it some manganese which is essential in order to make the metal thoroughly malleable. We have here then a process that has done more than any other invention in modern times to revolutionize, I may say, the most important industries of the land. At present not only railway machinery, but the very rails upon which we travel, are made not of iron, but of steel, and if I say that steel rails have shown a power of endurance five or six times greater than those of iron, I may add, with some regret (and I now speak not as a consumer, but as one connected with the production of steel as a manufacture) that they are unfortunately produced at a price almost cheaper than iron or any other metal that could be named. Perhaps, however, the manufacturer will learn to produce them at those prices and yet clear some profit.

Almost at the same time that Mr. Bessemer made his remarkable invention experiments were instituted, at a distance of not 100 yards from this place, which have led to another process of producing steel upon a large scale. I, in conjunction with my brother, Frederick Siemens (who had previously been my pupil), erected an experimental furnace at Scotland Yard, by which we proposed to attain very high degrees of heat, and it was almost from the first that I looked upon that furnace as capable of accomplishing what Reaumur, and after him, Heath, had proposed to do, namely, to produce steel in large quantities upon the open hearth.

At first our attention was confined to melting steel in crucibles, to melting glass, and to other applications of this mode of producing intense heat; the difficulties encountered were very great, and it was not until the year 1861 or 1862 that the prejudices in the way of the practical application of the furnace were sufficiently overcome, and that the furnace itself had assumed such a shape as to enable us to show that it could be applied with commercial advantage. And it is a curious coincidence that it took us just as long to mature this furnace as it took Mr. Bessemer to mature his process. In the year 1861, a large furnace was erected at the glass works of Messrs. Lloyd and Summerfield, near Birmingham, which has been at work up to the present time, and has realized those results that we, up to that time, had only hoped to attain. The success then achieved encouraged me to commence a series of experiments in the direction of producing steel on the open hearth, but, in order not to weary you, I will proceed to describe the regenerative gas furnace in the form in which it is now applied for the production of steel on the hearth, in quantities of from 5 to 10 tons at a time.

The regenerative gas furnace is so essential a part of the process of open hearth steel making that it is indispensable to describe its principle and construction to some extent. It consists of two distinct parts—the furnace proper, with its reversing valves, regenerators, and melting chamber, and the gas producer, in which the raw fuel (mostly small coal) is converted into gaseous fuel, which is thus separated from all the drossy and dirty constituents in the coal. It would appear, at first sight, a roundabout operation to convert fuel from the solid into the gaseous condition and then to take and burn this gas in a furnace elsewhere; the gas, as it passes from the producer, is in a heated state, and in its transit to the furnace a great deal of that heat must necessarily be lost; therefore, it might well be asked, why make this conversion of solid into gaseous fuel? Surely, in burning the gas less heat is obtained than if the fuel were burnt in the heating chamber of the furnace, and produced its effect there. That would be perfectly sound argument, if it was not for the regenerators of the furnace. These regenerators are by far the most important part of the whole arrangement, and, in order to understand the general principle of the furnace, I will first describe their action.

The drawings represent the furnace, the one being a longitudinal and the other a cross section; the gas coming from the gas producer passes in through what I call a reversing valve, by means of which it is directed into the bottom part of the regenerator chamber. The gas flowing up through the mass of brickwork the chamber contains, and which is placed so as to form a large aggregate surface, with intricate zigzag passages, will become heated, provided any heat has been accumulated therein. In the first place, there will be no heat, and the gas will pass unheated through this chamber and thence to the combustion chamber of the furnace. At the same time, a current of air is admitted through the air-reversing valve into the air regenerator chamber, which is larger than the gas chamber. The air passing up through the chequer work will reach the same point as the gas does at the entrance into the combustion chamber of the furnace. Now, since both the air and gas are cold, and as they meet for the first time at the entrance into the furnace, they will, if there ignited, produce a heat not certainly superior to what would be produced if solid fuel had been burned there instead; on the contrary, gas of the description we are dealing with is a poorer fuel than solid fuel, and the heat produced in the furnace will, therefore, be very moderate indeed. But the flame, after passing over the bed of the furnace, does not go to the chimney direct, but has to pass through two regenerative chambers, similar to those already described; the larger proportion of the heated products of combustion will pass through the air regenerator chamber, simply because it is the largest channel, and another portion will pass through the gas regenerator. The products of combustion pass from these chambers through the reversing valves, and are by them directed into the passage leading to the chimney.

The operation; therefore, is simply this, that the air and combustible gas pass up into the furnace through the one pair of chambers, and pass away, after combustion, towards the chimney through the other

pair. But in passing through the second pair, the heat of the products of combustion is given up to the brickwork. The upper portions of this brickwork take up the first, and, therefore, the highest degree of heat, and, as the burnt gases are passed downward through the regenerators, they are, by degrees, very completely deprived of their heat, and reach the bottom of the chambers and the chimney comparatively cold. After this action has been going on, say, for an hour, the reversing valves are turned over. They are simple flaps, acting like a four-way cock, and, by throwing over the levers which work them, the direction of the currents is reversed. The gas and air will enter now through the second pair of chambers, and the air passing up one regenerator and the gas passing up the other, will take up heat from the bricks previously heated by the descending current. The gases so heated, say, to $1,000^{\circ}$ F., will enter into combustion, and if the heat produced at the former operation was $1,000^{\circ}$, it ought this time to be $2,000^{\circ}$, because the initial point of temperature is $1,000^{\circ}$ higher. The products of combustion will also escape at $2,000^{\circ}$, and passing through the chequer work of the first pair of regenerators, its uppermost ranges will be heated to very nearly $2,000^{\circ}$. The temperature will diminish by degrees in descending till the gaseous currents have again reached the bottom nearly cold. Again reversing the process, after another hour or half hour as the case may be, the gas will take up heat to the extent of nearly $2,000^{\circ}$, and since another $1,000^{\circ}$ is again produced in combustion, the temperature of the furnace will this time attain $3,000^{\circ}$, and in this way it might be argued that, unless work is done in the furnace, the heat developed in combustion will, step by step, increase the temperature of the furnace $1,000^{\circ}$, or something less, each time a reversal of the valves takes place, till we arrive at the practical limit imposed by the melting point of the most refractory substance we can find (pure silica, in the form of Dinas brick), of which the melting chamber is usually formed. This high temperature is obtained by a gradual process of accumulation, and without any such current as would be likely to destroy, by oxidation, the metal in the bath, or cut away the sides and roof of the melting chamber.

There is, however, a theoretical as well as a practical limit to the degree of heat obtainable in combustion, which was first pointed out by M. H. St. Claire Deville, namely, the point of dissociation at which carbonic acid would be converted back into its constituents, carbon and oxygen. If carbonic oxide or any other combustible gas and air enter the furnace at a temperature very nearly equal to the point of dissociation, it is evident that association or combustion cannot take place, and thus nature fortunately steps in to restrict the increase of heat by accumulation, within comparatively safe limits. In a furnace fully heated up to the melting point of iron, this action of dissociation can be very clearly observed. At first, when the gas and air are comparatively cold, combustion takes place sluggishly, the gases will flow through the furnace and produce only a dark-red flame; the next time the valves are reversed a whitish flame is produced; the next time a short white flame; and after having reached

a full white heat, exceeding the welding point of iron, the flame will again become a long one, but this time not red, and of little apparent power, but bluish white, and flowing in clouds. This indicates the near attainment of the point of dissociation; combustion can no longer take place, except in the measure of the heat being dispersed to surrounding objects, or to the metal in the furnace, and that is about the degree of heat required for the process of making steel on the open hearth.

Before I leave the question of the furnace, I must refer back to the apparatus in which the solid is converted into gaseous fuel. This is a very simple apparatus consisting of a cubical brick chamber of about 8 feet side, one side of which is cut off in a slanting direction. Fuel descends on this inclined plane, to the grate at the bottom where combustion takes place. The result of this combustion is carbonic acid at a high degree of temperature, and if this product of combustion was allowed to pass up the gas-collecting channel, and through the overhead tube to the furnace, there would be nothing to burn; and the only result we should probably observe would be that the iron tube would very soon become red hot, and be melted down. But the carbonic acid, as it is formed near the grate, encounters a further layer of fuel descending from above, which is also incandescent, but which cannot be consumed on the same terms, because there is no longer any free oxygen present. The first result of combustion being carbonic acid, a compound of one atom of carbon and two of oxygen, this carbonic acid in passing through the subsequent layers of incandescent fuel is broken up, and a second molecule of carbon is added to the first, thereby producing carbonic oxide, which is a combustible gas. But coal is not simply carbon, it consists also of volatile matters, hydro-carbons, water, and the constituents of ammonia, and the hot carbonic oxide, in passing through a further thickness of the fuel which contains these gaseous constituents, acts upon them in the same manner as heat does upon the coal in a gas retort. This action absorbs a portion of the free heat in the carbonic oxide, and the result is a gas consisting of carbonic oxide, hydrogen, hydro-carbons, aqueous vapours, and nitrogen, which latter, being a constituent of atmospheric air, necessarily passes with it through the fuel, and dilutes the combustible gas produced to the extent of about 50 per cent. of the total volume. This combined gas leaves the producer not at 3,000°, the temperature of direct combustion, but at about 700° F. only. This remaining heat is thrown away and purposely so, and many criticisms have been made in consequence of this apparent waste of heat in the regenerative gas furnace, but I think I can prove that although there is loss of heat, no waste is incurred.

The gases passing from the gas producer could be forced to the furnace by mechanical means, but this would be very troublesome and costly, and the duty performed by the 700° of heat is to give them onward motion in the direction of the furnace. The hot gases rising in the uptake represent a column of heated gas at a temperature of 700°, at which its density will be about half the density at ordinary temperature. From the uptake they pass through a long tube of sheet

iron or steel, and on their journey through this horizontal tube they part with most of their heat, so that when they reach the downtake their temperature has probably fallen from 700° to 200° , having parted with 500° of heat by radiation from the tube. The consequence is that the descending column will be of about twice the specific weight of the ascending column, and therefore a continual flow of the gas will take place, ascending on the one side, and descending on the other in forcing its way towards the gas furnace; by this means the heat apparently lost in the gas is utilized to produce useful mechanical effect.

But suppose that the gas passed from the producer to the furnace without being allowed to cool, what would be the result? The gas would enter the regenerative chamber at a temperature not of 200° but of 700° ; it would, in ascending, take up more heat and enter the heating chamber at the temperature previously imparted to the upper ranges of the chequer work by the descending current or product of combustion. The same temperature would be attained by the gas if it entered at 200° , the only difference being that the regenerator in the case of the cooled gas would work through a greater range of temperature by 500° . But a regenerator will work with the same economy through a greater range as through a less range, therefore, this heat, if it could be saved, would be of no benefit whatever to the gas furnace. The only difference in result would be that the gases would get less cooled in descending on their way towards the chimney, and that we should have a hot chimney instead of a comparatively cool one. Therefore, no loss to the furnace is incurred in cooling the gas on its way to the regenerative chambers, and the temperature of the gas is utilized to produce the very essential mechanical effect of urging the gas from the producer to the furnace.

The economical action of the furnace depends upon the circumstance that the products of combustion reach the chimney, not at the temperature of the heating chamber, as is the case when ordinary furnaces are employed, but at a temperature not exceeding 300° or 400° F., thus rendering nearly all the heat produced in actual combustion available for accomplishing useful work. It will be readily perceived that the economy of this system must be greatest in melting steel or in accomplishing operations of melting or heating at very high temperatures, whereas for the attainment of low temperatures, such as the heating of boilers, the economy would be comparatively small. Its practical economical result for high temperatures is well illustrated by the fact that in melting steel in pots in the ordinary air furnace at Sheffield, 3 tons of Durham coke are required to melt a ton of steel, whereas a ton of small coal suffices to melt a ton of steel in the same pots when the regenerative gas furnace is employed. In melting steel in bulk upon the open hearth, the consumption of fuel is further reduced, and does not exceed 12 cwt. of coal for the production of a ton of steel. In re-heating iron, the practical economy effected in the regenerative gas furnace over the ordinary furnace amounts to from 40 to 50 per cent., owing to the inferior degree of temperature required. When applying the system

to inferior temperatures, there is advantage in suppressing the cooling tube and gas regenerator, and in approaching the gas producers to the furnace, to consume the gas at its initial temperature.

At large works such as are now erected for carrying out the open-hearth steel process, a cluster of producers are put up outside the works; and the fuel is delivered from the railway at an elevated point in order to be put into the producers in which it is gradually consumed, and flows as a gas through the large overhead tubes into the works where a number of furnaces are supplied for the production of steel. I think these observations may suffice to describe the furnace which plays a most important part in the process to which I shall presently refer.

I have already stated that one of the chief objects I had in view in maturing this furnace was the production of steel on the open hearth, but, as usual, in introducing a new process, great difficulty was encountered in first attempting to carry out that idea. The question arose whether steel could be melted and maintained as steel upon the open hearth of a furnace at a temperature exceeding the melting point of most fire-bricks. The general opinion of practical men was entirely opposed to the idea of accomplishing the object, and it is, therefore, perhaps natural that its realization was a question of time. The first attempt to make steel on the open hearth of a regenerative furnace was made by Mr. Charles Atwood, of Tow Law, who, in 1862, agreed to erect such a furnace—a small one, it is true—to my design; but although he was partially successful, he abandoned the attempt because he was afraid that the steel so produced would not be of the proper quality. In the following year, another attempt was made in France. A large furnace was erected at the Montluçon works, and my colleague in the experiment was a very celebrated French metallurgist, the late M. le Chatellier, Inspecteur-Général des Mines. The experimental results were on the whole satisfactory. We obtained some charges of metal that was decidedly steel, but, unfortunately, the roof of the furnace soon melted down, and the Company who had undertaken the erection of this furnace were so much disheartened that they, for the time at least, abandoned the idea of following up the trials. After two or three very similar disappointments, I decided to erect experimental works at Birmingham, where the processes of producing steel on the open hearth have been gradually matured, until they were sufficiently advanced to entrust them into the hands of others. But another French manufacturing firm, MM. Martin, of Serenil, undertook to erect a regenerative gas furnace that could be used for making steel on the open hearth, but which, in the first place, was to be used as a furnace for heating wrought iron. While I was engaged at Birmingham with experiments to produce steel of good quality by my process, MM. Martin also succeeded in obtaining results with the furnace I had designed for them. At the time of the French Exhibition, in 1867, MM. Martin brought forward their excellent exhibits, for which they soon got a considerable name. I also sent samples of steel produced by me at Birmingham, differing from those sent by MM. Martin as regards the material used in the process; they

had turned their attention to the production of steel by dissolving wrought iron in a bath of cast iron, whereas my efforts were directed, from the first, to the use of cast iron and ore for the production of open-hearth steel.

In the process as it is now carried on at the Landore and other works, both scrap metal and ore are employed, in conjunction with pig metal and such other ingredients as serve finally to adjust the quality of the steel. The process may be described as follows:—The furnace having been heated up to the steel-melting point, or, say, 3,500° F., the first duty of the steel melter is to see that the silica bottom and tapping hole are in the proper condition for work. If, in consequence of wear caused by previous charges, the surface-bed should be pitted, white sand, previously calcined, is introduced in such quantities as to fill up the inequalities, and heat is allowed to act for eight or ten minutes with the furnace doors closed, by the end of which time the silica or white sand introduced will be partially melted and consolidated with the older portion of the furnace-bed. The tapping hole is filled up with white sand mixed with powdered anthracite or coke, which serves to prevent its entire consolidation, and thus facilitates the tapping of the furnace at the end of the operation.

These preliminary operations completed, the furnace is charged with, say, six tons of pig metal, mixed with two tons of such iron or steel scrap, as gits, spillings of previous operations, old iron or steel rails, that may be available. The furnace doors are thereupon closed, and heat is allowed to act upon the charge for two hours and a half, when it will be found to have fused, and analysis would prove the metal to be in an intermediate condition between pig iron and steel, its percentage of both carbon and silicon being greatly reduced. The subsequent work of oxidation of these ingredients consists in the introduction, at intervals of about half-an-hour, of rich ores or oxides of iron, in charges of about 5 cwt. each; the immediate effect of the introduction of each charge is an active ebullition, through the reaction of the oxide of the ore upon the carbon of the metal producing carbonic oxide. This gas escapes to the surface, whereas the iron contained in the ore or oxide becomes metallic, and is added to the bath. When about 25 cwt. of ore has been thus added, a sample is taken from the bath, by means of a small iron ladle, and subjected to a simple mechanical test, whereby the percentage of carbon remaining in the metal is readily, though somewhat roughly, ascertained. If it appears from the test that the carburization is nearly completed, no more ore is added, but 3 or 4 cwt. of limestone is thrown into the furnace, which has the effect of combining with the silicon contained in the slag, and of liberating ferrous oxide from the same, which latter, being thus set free from its combination with silicon, continues the action of decarburization of the metallic bath. Samples are again taken, until the steel melter finds that, upon breaking the sample, the peculiar silky fibre is obtained which is indicative of a reduction of the carbon in the metal to 0.1 per cent. The metal is now ready for final adjustment, according to the strength or temper of the steel required.

If it is intended to produce ordinary rail metal, from 7 to 8 cwt. of spiegeleisen, containing 20 per cent. of manganese, previously heated to redness, is charged in, the bath is stirred by means of a rabble, and, after being allowed to rest for a few minutes, is tapped either into a ladle or directly into ingot moulds, arranged in groups, whilst the slag that followed the metal through the tap-hole is collected in a pit or mould prepared for its reception. The amount of slag produced depends chiefly upon the percentage of silicon in the pig metal used, and also upon the degree of purity of the ore employed in effecting the reduction, and amounts generally to 2 tons in an 8-ton charge. The yield of metal should be within 1 or 2 per cent. of the total amount of pig metal and scrap (if of a solid description) charged into the furnace, because, although the pig metal would contain some 7 or 8 per cent. of carbon and silicon, which have to be expelled, this loss of weight is made up by the metallic iron given up by the ore. The lime added near the end of the operation is useful in taking up some of the other impurities, such as sulphur and phosphorus, from the metal, although the amount so taken up is only small.

After tapping, the steel melter again inspects his furnace-bed, repairing any slight defects that may have arisen, fills up the tapping-hole, and introduces the next charge.

The time each charge occupies is from seven to nine hours, according to its character and to the heat of the furnace. When pig metal and scrap alone are used, a charge can be worked in from six to seven hours, and the proportion of pig metal employed can be reduced to from 10 to 15 per cent. of the total charge, whereas when no scrap at all is used, the amount of pig metal charged must be equal to the total amount of steel to be produced, and the reaction between the ore and pig metal extends the time of each operation by about three hours. In this respect, then, the scrap or Siemens-Martin process has an advantage over the ore process, which is compensated for, however, by the corresponding advantage in favour of the ore process, that it is not dependent upon the irregularities appertaining to scrap metal, and upon the purifying action produced upon the fluid metal first by the oxide and thereafter by the lime. It has been found generally that for small applications the scrap or Siemens-Martin process is the more advantageous, while for large applications the ore process has the advantage.

For the production of steel of special quality, such as is employed for boiler and ship plates and castings, the process is different only towards the end of the operation from that already described. The reduction is carried to a still lower degree than 0.1 per cent. of carbon, and in order to make sure that the right degree of carburization is attained, chemical analysis of a sample is resorted to. Instead of spiegeleisen, a rich ferro-manganese is employed, together with a small proportion of silica iron (a pig metal containing about 10 per cent. of silicon), which latter metal has the effect of taking up oxygen from the fluid iron, and thus preventing blow-holes in the casting. Another method of consolidating steel is that which has been introduced and so successfully carried out by Sir Joseph Whitworth. The steel upon which he

operates is made upon the open hearth of the furnace in the manner I have described; but steel when it is poured from the ladle into the moulds shrinks, and during shrinkage little air-spaces or hollows are formed, which break the continuity of the steel, although the cavity may afterwards be closed. Sir Joseph Whitworth, by applying great pressure through hydraulic agency to the steel while in the fused condition, closes up these cavities, and steel is thus produced perfectly continuous in its nature, and of such great hardness and tenacity combined, that when put, for instance, into the form of shells, some of these shells have gone three or four times through thick iron armour, and have been quite fit to go into the gun again.

The rich ferro-manganese now introduced into the market affords the steel maker great facility for producing sound metal, notwithstanding its admixture with a considerable amount of impurities, notably of sulphur and phosphorus. By its means such inferior irons as the Cleveland can be rendered suitable for the production of steel rails, and large contracts have been carried into effect by some of my licensees for converting old iron rails of mixed or doubtful parentage into steel rails.

The facility thus offered to steel manufacturers introduces, however, a danger upon which the steel user will have to fix his attention. A steel rail containing from 1 to $1\frac{1}{2}$ per cent. of manganese may look well and resist the tests for toughness and strength which are usually applied, and may yet contain more than $\frac{1}{4}$ per cent. of phosphorus or sulphur, or both these substances. It is only at temperatures below the freezing-point that the presence of phosphorus will make itself felt by symptoms of cold shortness, and it would therefore certainly not be advisable to put down rails of this description in cold climates.

For the construction of ordnance and other high class purposes, more than a trace of manganese in the metal is, in my opinion, decidedly objectionable. Manganese, though very efficacious in hiding impurities in the steel, is in itself an impurity inconsistent with high quality of the material produced. Its admixture with the metal is purely mechanical, and upon analysis of different portions of the same ingot it is found that its distribution is very irregular. Being more oxidizable than iron, a metal containing a considerable percentage of manganese cannot be re-heated without deterioration; is pitted by exposure to sea-water; and its strength and toughness are also found to be below those of really pure metal when subjected to crucial tests. It is important, therefore, that steel for war purposes, where high temper and great tensile strength is required, should be practically free from manganese, as well as from all other admixtures, with the sole exception of carbon. Extra mild steel, which is so remarkable for its extreme ductility, should contain in 100 parts 99.75 parts of metallic iron, and only 0.25 per cent. of all foreign substances put together.

It is for the production of these special qualities of steel that the open hearth process has come into extensive use, being employed, either wholly or partially, by many of the leading works both in this country and abroad. The total production of open-hearth steel (both the

Siemens-Martin and Siemens variety) amounted in 1877 to 275,000 tons, since which time its production has gone on increasing, notwithstanding the extreme depression which continues to prevail in the iron and steel trades.

The French Admiralty were the first to take up the subject of constructing ships of very mild steel, and the British Admiralty now use it largely in naval construction, with such results as I believe will shortly be placed before another Institution by their Chief Constructor, Mr. Barnaby.

Although I have described the open hearth process, as dealing with pig metal and ore—or, when it can be had, pig and scrap metal—my attention has been directed for many years to the accomplishment of a process, in which the ore used is put through a preparatory process of reduction and precipitation, and only a minimum quantity of pig metal is employed to impart fluidity to the mass in the melting-furnace. In my early experiments in this direction I followed the lead of Chenot and others in producing what is called spongy iron, or iron deprived of its oxygen by heating it to redness, in combination with carbonaceous material. I soon convinced myself, however, that no practical results could be obtained by this means, inasmuch as the spongy iron contains, bound up with it, the gangue of the ore, which can with difficulty be separated from the metal, and afterwards encumbers the melting-furnace with excessive slag. All the hurtful impurities contained in the ore, such as sulphur, phosphorus, arsenic, &c., remain, moreover, in the spongy iron; and, as regards sulphur, its quantity is much increased on account of a powerful absorbing action, exercised by the spongy iron upon the sulphurous acid contained in the flame of the furnace. It was necessary, therefore, to devise some plan by which the metallic iron could be simultaneously separated both from the ore and its impurities. This object I have succeeded in accomplishing by means of a rotating furnace, which has, however, hitherto received only a limited application. The furnace, which is represented in Fig. 3, consists of a gas producer, the air regenerator, a reversing valve, and the revolving drum. No gas regenerators are employed in this furnace, but the gas passes from the producers through an oblong channel continuously into the revolving chamber, where it is brought into contact with the heated current of air passing in from one or the other of the air regenerators. The flame thus produced rushes forward into the heating chamber, and after heating the material therein, passes back again towards the inlet side, whence the products of combustion pass through the second air regenerator and the reversing valve into the chimney stack. By this arrangement the front of the rotatory furnace is left free for access, and is provided with a charging and discharging door placed eccentrically, for the convenience of withdrawing masses or balls of iron from the furnace on a level with the lining when the furnace is stopped with the aperture in its lowest position. The lining of the furnace is made of highly aluminous or bauxite bricks covered on the inside with a certain thickness of iron oxide produced by melting hammer scale and rich ores in the furnace, which set while the

furnace is kept slowly rotating. The rotation of the furnace is effected by means of a small Brotherhood or other engine, and suitable gearing.

The *modus operandi* is as follows:—The furnace, being already lined and heated, a batch of ore mixed with fluxing and reducing materials, in a proportion depending upon the chemical constitution of the ore employed, is charged from an elevated platform in front, the rotator being stopped for this purpose with the charging orifice in its upper position. From 30 to 40 cwt. of batch is thus charged, upon which the door is closed, and the furnace chamber is made to rotate at the very slow rate of six or eight revolutions per hour. A high temperature is produced within the chamber by the combination of the gas with the highly heated air from the generator, causing the mass rapidly to become hot, whilst slowly rotating, so as to present continually new surfaces to the heat. No chemical action takes place under these circumstances until the temperature of the mass is raised to a full red heat, when reaction between the carbonaceous matter and the ore will take place, giving rise to the development of carbonic oxide, which, meeting the heated air proceeding from the regenerators, is burned, and thus adds to the heating action of the flame. When this reaction has fully set in, the supply of producer gas may be almost entirely stopped, and thus no sulphurous gas is admitted into the furnace during this critical interval. The heat now rises rapidly, and fusion of the earthy constituents of the ore occurs simultaneously with a continuance of the reducing action. In the course of an hour and a-half after starting, the charge consists of metallic iron in a more or less agglomerated condition, found on analysis to be almost chemically pure, and of a liquid mass of cinder containing the earthy constituents of the ore and other foreign matter. The rotation of the furnace is now stopped with the tapping-hole in its lowest position, and the bulk of the cinder is discharged; the tapping-hole is there-upon closed again, and the furnace made to rotate somewhat more rapidly with a view of facilitating the agglomeration of the metallic iron; by the timely introduction of a rabble, the agglomeration of the mass can be so regulated as to induce the formation of two or three balls of convenient size for handling. The balls being formed, the furnace is stopped with the large door in its lowest position, which, upon being removed, admits of the charge being withdrawn. This is effected by the introduction of tongs supported by pulleys running upon overhead rails for transferring the balls in rapid succession from the furnace to a squeezer (which has for its purpose to expel adhering cinder), and from the squeezer to the bath of such a steel melting-furnace as already described.

The great purity of the metal thus reduced from the ore, and the rapid and comparatively inexpensive nature of the reducing process, are conditions highly favourable to the production of steel of high quality by this method at reasonable cost; and it is my intention gradually to complete the open hearth process of producing steel by combining with it the mode of preparing the material to be melted just described.

Report on Tests of Mild and Hard Bars.

Mild Bars.

Strain per square inch.	Annealed.						Unannealed.					
	No. 1 Test.			No. 2 Test.			No. 3 Test.			No. 4 Test.		
	I.		II.	I.		II.	I.		II.	I.		II.
	Elonga- tion.	Set.	Elonga- tion.	Set.	Elonga- tion.	Set.	Elonga- tion.	Set.	Elonga- tion.	Set.	Elonga- tion.	Set.
Tons.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
3	0.015	..	0.015	..	0.015	..	0.015	..	0.015	..	0.015	..
6	0.03	..	0.03	..	0.03	..	0.03	..	0.03	..	0.03	..
9	0.046	..	0.046	..	0.046	..	0.046	..	0.046	..	0.046	..
12	0.062	..	0.062	..	0.062	..	0.062	..	0.062	..	0.062	..
15	0.078	..	0.078	..	0.078	..	0.078	..	0.078	..	0.078	..
18	0.090	..	0.090	..	0.090	..	0.090	..	0.090	..	0.090	..
18½	0.100	0.015	0.095	..	0.125	0.045	0.09	0.015	0.090	0.015	0.09	0.015
19	..	..	0.125	0.03	..	..	..	..	0.150	0.07	..	0.175
<i>Hard Bars.</i>												
3	0.015	..	0.015	..	0.015	..	0.015	..	0.015	..	0.015	..
6	0.03	..	0.03	..	0.03	..	0.03	..	0.03	..	0.03	..
9	0.046	..	0.046	..	0.046	..	0.046	..	0.046	..	0.046	..
12	0.062	..	0.062	..	0.062	..	0.062	..	0.062	..	0.062	..
15	0.078	..	0.078	..	0.078	..	0.078	..	0.078	..	0.078	..
18	0.092	..	0.092	..	0.092	..	0.092	..	0.092	..	0.092	..
21	0.108	..	0.108	..	0.108	..	0.110	..	0.108	..	0.110	..
24	0.3	0.15	0.125	..	0.125	..	0.4	0.25	0.108	0.427	0.28	0.108
25	..	..	0.182	0.06	0.2	0.07	..	0.25	0.57	0.425	0.28	0.525

NOTE.—In tests marked I the elongation was taken in a 5' 0" bar; in those marked II at a point 4' 11" from bottom of same bar.

What I also wish on this occasion to call attention to are certain properties of steel which are of importance in considering its applicability to engineering and military construction. We know that steel varies between very large limits in its hardness and in its ductility, but it is not so generally known that steel up to a certain point is of the same strength to resist strain when it is mild as when it is hard, and I have prepared a table of results which shows very clearly the nature of both mild steel and hard steel if compared under different strains.

Upon reference to the table it will be seen that loads from 6 to 15 tons per square inch affected all the bars equally, whether hard or soft, annealed or unannealed, and with the exception of one bar only this uniformity holds good up to 18 tons; up to this limit, the elastic elongation of all the samples was equal; but with the strain of $18\frac{1}{2}$ tons, the mild steel has become permanently elongated, whereas the harder steel shows a normal increase of elastic elongation. With the hard bars experiments were continued, and 21 tons to the square inch was applied, producing an elastic elongation $\cdot 108$, which is entirely normal, and no permanent set is produced, but when 24 tons were applied, then a permanent set occurred also in the hard bars; therefore the elastic limit of the hard steel was 24 tons, whereas that of the milder steel was only 18 tons.

But there is a very peculiar circumstance connected with these elongations. If a bar of mild steel is taken from the rolls and subjected at once to a test of, say, 18 tons, it will very likely be found to show a permanent elongation, but if the same bar is first subjected to a strain of, say, 17 tons, for several hours, it will then be capable of resisting perhaps 19 or 20 tons before showing any permanent elongation. One might almost say the bar of steel can be taught to resist a higher strain without yielding permanently. Sir William Thomson has lately made some elaborate researches on this point, and perhaps he will favour the meeting with some account of them.

The question of using steel for the purposes of engineering or military construction depends a great deal upon the particular application. Mild steel has the peculiar quality of yielding to an enormous extent to strain before giving signs of rupture. Bars are tested generally to 28 tons, at which mild steel, such as is used in naval construction, generally breaks after showing an elongation of 25 per cent. The steel used in the construction of boilers, which is made still milder, will stand only a total strain of 24 tons, but will show a still greater elongation before breaking. From this we can go upwards, and produce steel that will bear a breaking strain of 50 tons, with an elongation of perhaps 12 per cent. Still harder steel shows a strength of 60 tons, and an elongation of only 7 or 8 per cent. before breaking, whilst Sir Joseph Whitworth has shown that the absolute strength of steel in the form of bars, of the proper temper, may be brought up to 90 tons per square inch, by subjecting it to a process of oil hardening; such a tensile strength is hardly exceeded by carefully tempered steel wire. Therefore we have a range of strength which

we can apply under different circumstances with great advantage. It must be borne in mind that the harder steel is apt to become brittle when suddenly cooled, and therein consists the great safety of using the milder description of steel for engineering and military purposes. With regard to this last matter I would say something before concluding, with reference to the construction of ordnance.

Years ago a great advance was made in gun manufacture by Sir William Armstrong in producing his well-known mode of construction. At that time wrought iron was the strongest material practically available for the gunmaker's use, and this was put into the strongest possible form by the construction of coiled rings, which method places the fibre of the metal in the direction of the strain. The Woolwich or Fraser system of gun construction being a modification of the Armstrong system comprises the same mode of putting iron into the condition of greatest strength; but it is time I think to enquire whether, after the recent advances made in the production of mild steel, which is a material of superior strength, tenacity, and uniformity to iron, the mode of constructing ordnance should not be modified to suit these altered circumstances.

It is important, then, to appreciate wherein consists essentially the difference between iron and mild steel.

Mild steel is a metal consisting of 99·75 per cent. of the elementary substance, iron, and only a quarter per cent. of manganese, carbon, and such impurity as phosphorus and sulphur in the smallest possible quantity; whereas wrought-iron of commerce generally consists of 96 to 97 per cent. of metallic iron and between 3 and 4 per cent. of other material, for the most part slag. Now, it seems not a very great matter that in 100 lbs. of iron there should be 3 lbs. of slag, but if we represent this proportion to our eyes we see that it is not such a very inconsiderable quantity, considering that slag is both voluminous and entirely devoid of tensile strength. I hold here two cubes, one of $4\frac{1}{2}$ " side, and the other of 2" side, representing, as nearly as may be, the one the metallic iron, and the other the slag, which when mixed together form wrought iron. If the slag was mixed up amongst the mass of metallic iron in an irregular way, the strength of the iron would probably be very little more than is due to that of the glassy slag, because filaments of slag might go right across; but in drawing out the iron, again and again, the little original globules of metal become elongated into strings or fibres of iron, held together by filaments of slag, and thus we get in iron a great apparent increase of strength by drawing it. But even if we draw it out to the utmost, we lose strength to the extent of the sectional area taken up by the slag, and thus get less resisting power than if the pure metal is separated from the slag in subjecting it to the melting process, when we get the maximum strength of which the metal is capable in all directions, and we have, in fact, metal of the greatest strength for moderate strains that can be obtained, as we have seen that even the hardest steel elongates as much as the mildest metal when subjected to moderate strains.

At another Institution Mr. Longridge has severely criticised the coil

system of construction, which is still followed at Woolwich, upon the ground that the stresses are not properly distributed; but whilst not agreeing with him chiefly as regards the limits to which shrinkage can be advantageously resorted to, I cannot, on the other hand, but think it is wrong in principle to use the harder and more resisting material in the inside, and the weaker material outside the gun, as is still practised at Woolwich.

Mr. Longridge says that the inner tube of the gun should be under compression, and therefore one or several layers of rings should be shrunk on with such increasing force as to bring the metal into considerable tension, in order that when the powder gas acts expansively upon the inside of the gun, the compression of the inner ring may be such as to resist the first part of the impact of the powder, and then after having come to its condition of neutrality take up its proper portion of the tensile strain. But, practically, I believe the shrinkage is not carried to any such extent, and it appears to me reasonable that it should not be, notwithstanding Mr. Longridge's argument, because if the large mass of iron he suggests to use is put under compression to the extent indicated by theory, it would inevitably crush or permanently deform the inner tube. But if the inner tube is of steel, and the outer portion of iron, a metal of less elastic range than steel, it follows that, by repeated expansive actions, the external metal will be strained beyond the limit of elasticity before the metal of greater elastic range in the interior.

Again, in firing the gun the inner metal will be expanded by the heat, which will increase the pressure exerted by the inner ring against the outer rings. This action will result in excessive strain on the outer rings tending to enlarge and loosen them, or in compressive action upon the inner tube, tending to produce the same result through crushing.

It appears, therefore, to me to be evident that in constructing a gun steel only should be used, in which the strains should, if possible, be so distributed that when the powder pressure acts, each portion should offer the same resistance to the strain. This, I think, might be effected in a very thorough manner by a process analogous to that employed by Admiral Rodman in the construction of cast-iron guns, only that cast iron is perhaps the material least adapted for the purpose. If a steel gun or a ring forming part of the same was put into a furnace, heated up to a temperature of, say, 600° C., and the inside was subjected to cooling action, while the outside was maintained at the temperature of the furnace, a distribution of stress would result which would be highly advantageous to the strength of the gun. The chilling of the inside surface of the ring or gun would cool the metal towards the inside circumference. This metal could not shrink, nor would the inner diameter of the gun diminish, because the diameter would be determined by the mass of metal still in the heated condition. The vacancies produced in the cooled metal would be filled up by the inflow of metal from the heated mass outside, resulting in equilibrium of the metal at the diameter originally due to the heated mass, and the temperature will gradually vary from, say,

100° inside to 600° outside. If the gun was afterwards taken out and allowed gradually to cool, but without stopping the cooling action from within, the whole mass would cool down to the minimum temperature. If we imagine the ring to consist of a succession of concentric cylinders, each cylinder would acquire a tensile strain due to its previous temperature, which, being a minimum on the inside and a maximum on the periphery, there would result a distribution of tension throughout the mass, being negative or compressive in the interior and more and more tensile towards the exterior. Then, when the full pressure of powder gas was active, the strain upon each portion would be equal, and the resulting strain would be opposed by the whole elastic strength of the metal. The internal portion of the tube would, with such a mode of construction, have no other function to perform than to resist the abrasion that is necessarily going on in the gun. This question is just now very much before the scientific public, and therefore I thought it well to bring before you my own view of the matter.

Before quite concluding, I would call attention to a machine which has lately been sent me from America for testing pieces of steel or iron, and after the meeting is closed I will break a test bar of mild steel, that the members may see the amount of elongation of which such a bar is capable before breaking.

The CHAIRMAN: We have some gentlemen present who are eminently qualified to assist in the elucidation of this subject, and particularly one who has been named by Dr. Siemens—I mean Sir William Thomson. Some of us have heard of the fatigue of metal, and when Dr. Siemens announced that Sir William Thomson has learned that so far from being fatigued by being subjected to a long continued strain, metal seems to get the stronger, or better able to resist it, it appeared to me a striking result.

Sir WILLIAM THOMSON: I think the information I am able to give has been rather over-estimated. My attention was first called to the subject many years ago in testing some copper wires used in the first Atlantic cable. The wire weighed about 14 grains per foot, and it began to stretch with a weight of 8 lbs. or 9 lbs. It was so very tender that it soon began to show signs of distress and permanent elongation, but by very gradually adding weights, I found I could bring up the elastic tension of that wire to 45 lbs., so that wire which first began to run down into permanent elongation with 8 lbs. would ultimately bear 45 lbs. off and on again without showing signs of further permanent elongation. That pull of 45 lbs. corresponds to the weight of about $3\frac{1}{4}$ nautical miles of the wire; for 21,000 feet, or $3\frac{1}{4}$ nautical miles of wire, weighed 42 lbs. That showed certainly a greater strength than I expected to find in copper wire; but that strength was only attained by very carefully adding weight, and giving time for the molecular condition consequent upon the state of strain which gave it the permanent increase of strength to be, as it were, deliberately taken by the molecules of the material. Similar results are found with iron wire. Some very soft iron wires, prepared for me by Messrs. Johnson, of Manchester, gave results somewhat similar to those of the copper wire. I found that at first a very small weight would stretch the wire, but after about 25 per cent. elongation, it bore at least five or six times the weight which originally produced a permanent elongation. I think these facts, and the more substantial information which Dr. Siemens has given us, may take away the anxiety with which testing is often regarded, especially testing steam boilers. There is a very common belief, which I consider is quite erroneous, that iron is apt to be injured by testing, and indeed the Board of Trade rule actually orders that an old boiler which is to be re-tested after having been in use is to be tested up to the working stress, but it is not ordered that it is to be tested above the working

stress, and, on the contrary, the rule enjoins that the inspector must be careful not to injure the boiler by testing. So that if the inspector puts on one pound per square inch above the stress the boiler is to stand, he does so at his own risk, and is liable to be called to account. I must say it seems to me that this rule of the Board of Trade absolutely requires revision. That men and ships are to be sent to sea with boilers that cannot be tested to double the working load is a very great anomaly. The injury depends on the force applied being greater than the material can properly bear. Now, if the material in a boiler can properly bear double the working load it is a boiler that will work, but if it cannot, it ought to be thoroughly repaired and strengthened or else broken up. It seems to me that the Board of Trade rule absolutely requires alteration, and that a steam boiler ought not to be considered to be tested at all unless it is tested to at least double the regular working load. It is quite a different thing from a test in which there is rough usage, which might cause a much heavier stress than that shown by the indicator. For instance, in the case of testing chains, nobody can say what the chain may have to bear; what you want to do is to see that the chain is free from flaws, and then let it bear the most it can. If a ship is prevented going ashore by the cable being stressed to three or four times the guaranteed breaking stress, the chain must be allowed to do its work; and as we never know the extreme force to which a chain cable is to be tested, of course no one would think of testing it to the very utmost that it is capable of bearing, lest its links should be damaged in form, or its material rendered brittle. Mr. Thurston, of the Stevens Institute of Technology, in Boston, has made some important experiments on metals which have led him to put them in two different classes, some of which do that which iron is falsely suspected of doing in ordinary criticism of testing. The ordinary criticism of testing supposes that applying a heavy strain to iron would injure it. That is true of some metals, but not of iron. Mr. Thurston finds some metals, tin being one of them, which will bear a certain weight for hours, or days, and then actually break with a less weight than that which it bore for a long time; but emphatically that is not the case with iron. Mr. Thurston's experiments prove that iron is not a metal of that class which yields after a time. Experiments by Mr. Bottomley, in the Physical Laboratory of the University of Glasgow, have been extended over long periods. We have taken some very soft iron wire, and hung on day after day, ounce by ounce, weights up to breaking weight, and the strength of the iron wire has been in some cases increased 10 per cent. above the breaking weight tested in the first instance. One of the wires broke for instance at 49 lbs., when tested quickly. Some wire of the same hank was taken and was kept for a considerable time with 45 lbs. hanging on it, and then half-pound by half-pound was added till the wire broke; and the power to resist the stress actually improved, sometimes by as much as 10 per cent., and in no case has the application and re-application, or the application and keeping on for months, as far as nine months, of a force within 1 or 2 per cent. of the breaking force, injured the whole. It has never injured it, and in some cases has decidedly increased its strength.

Mr. BARNABY: I should have been better pleased, Sir, if some of those gentlemen who are connected with the principal question of manufacture which has been brought before us this evening, namely artillery, had been called upon to speak rather than myself. As you have already heard, I shall have the opportunity shortly of saying some things of interest to those who are concerned in shipbuilding at the Iron and Steel Institute, but I should like to make just one remark with regard to what Sir William Thomson has said, and that is, that I do not quite understand what that rule of the Board of Trade is to which he refers. He must be right in what he says, but in the Royal Navy the test for boilers is always twice the working pressure. In the American Navy it is $1\frac{1}{2}$ times, but in the English Navy always twice, and I am surprised to hear of this rule. I suppose it must refer to some question of old boilers. If any gentleman here belonging to the Board of Trade could set that matter clear before we leave perhaps it would be better that it should be so explained. I think we have received a very great favour to-night in receiving from Dr. Siemens himself an account of those wonderful things by which our generation has been adorned. In ages to come I believe that our generation will be spoken of as that which produced Dr. Siemens and Mr. Bessemer.

Sir WILLIAM THOMSON: May I add one word with regard to the last part of Dr. Siemens' paper, as to the stresses in the gun and the proportions of material to adopt for resisting the stresses it will meet with in firing. I think the principle here laid down would be most valuable—a different way of producing that state of stress initially in the gun, so that you may be quite sure you have got the state of stress you desire. I hope Dr. Siemens will be able to carry it out, and actually produce a gun in which this state of stress will be realized.

Major-General YOUNGHUSBAND, R.A.: I wish, Sir, to meet an objection by Dr. Siemens as to the principle of a steel barrel in the interior of a gun while, as he rightly observes, we use the stronger metal in the interior and the weaker metal in the exterior. Dr. Siemens may not be aware that the barrel of the gun is made of steel, not for the purpose of having a stronger metal in the inside to resist the transverse strain, but because we require strength to resist the longitudinal strain. A coiled iron tube has very little longitudinal strength in itself, and therefore it is necessary to have a tube, a steel barrel, for that purpose, and also to have a hard metal for the rifled grooves, so as to be able to resist the abrasion of the studs, or whatever means may be used for giving rotation to the shot. He will know if he sees the section of any gun that steel forms a very small portion of the whole weight of the gun. It is not at all impossible, I may say not improbable, that these coiled bars used at present may be given up, though the day has not arrived yet. When we adopted that system of coiled iron bars the properties of steel were not known as they are now; we were not able to make that very mild steel which is capable of being welded, and therefore had recourse to coiled iron; and as to the construction of the gun, whatever objection may be made, we have this practical experience, that from 6,000 to 7,000 of those guns have been made, and not a single accident has happened. I believe that our guns will resist a greater strain per ton of gun than any guns that have been made. I do not say they are the very best guns that can possibly be made; I only say it, as a fact, that per ton of guns there is more strain put upon our larger guns than upon any guns that are used.

THE CHAIRMAN: General Younghusband has stated, in better words than I could find, just what I was about to remark in reference to Dr. Siemens' criticism of the existing form of gun. There is another consideration which General Younghusband did not touch upon, which is, that we have the more expensive material in the smaller quantity, and that is an important consideration when we enter upon the expenditure of three millions or four millions. Steel, if applied to the making of the outside of the guns, as well as the inner tubes, would have augmented the cost of their introduction very largely, into something appalling. I do not wish to prolong the discussion further, but will express in your name to Dr. Siemens the gratification that we feel when gentlemen of his eminence will favour us with the benefit of their experience upon subjects coming home so nearly to our business and our bosoms as does the use of iron and steel.

Dr. SIEMENS: With regard to an observation made by General Younghusband, I should ask permission to say one word. I do not wish to suggest for a moment that a gun, such as is now turned out at Woolwich, is not a very excellent mechanical production; and at the time the materials that were to be used were decided upon, those were the very best materials that could be obtained. And with regard to iron, I admit the value of putting the strain in the direction of the fibre, but at the present time we have made a very considerable step forward, which I think should be taken advantage of in the construction of guns. If the coil is limited in its length, it gives, as General Younghusband says, no longitudinal strength, and the inner tube becomes a matter of much greater importance than it would necessarily be if the outside of the gun, instead of being multifarious, was solid. But there seems to be no reason why, if the outside of the gun was of steel, and the elasticity of that mass of steel was properly distributed, it should be divided, and not be of a single piece. If that was the case, the inner tube would have only one function to fulfil, that of taking the rifling; but it is most essential, I consider, that it should be as mild as is consistent with its power to resist abrasion, inasmuch as it cannot be true in principle, although it may be perfectly workable, to have the material of which the lining is composed of greater resisting power than the material surrounding this inner tube, upon which the strength of the gun

depends. The lining must necessarily be subjected to very considerable expansion through the firing itself. One fact I should like to mention, viz., that a shrinkage of 1 in 1,000 produces $11\frac{1}{2}$ to 12 tons of strain to the square inch, and an elongation of 1 in 1,000 is produced by heating the material to 130° Fahr.; therefore, if a gun is built up by shrinkage, and the inner tube afterwards heated up to 130° Fahr., the amount of fight between the inside metal and the outside must be just double. If the heating should exceed that limit, as it appears to me it would be likely to do, the strain between the inside and the outside must increase in the same ratio; and this action between the two principal portions composing the gun could only be obviated if the inner tube was of such a material as to yield absolutely to the outside strain. Therefore, it was not with a view of criticising, but rather with a view of suggesting, that I ventured to make the observations I did. I thank you very much for the kind attention you have given me this evening.