Discussion.

Dr. Siemens. Dr. C. W. SIEMENS said, it perhaps would have been better if the discussion had been commenced by persons more interested in the use of iron and steel, than by those who, like himself, were intimately connected with their production; but in another respect it might possibly save the time of the Institution, if he took that early opportunity of referring to some conclusions in the Paper with which he could not agree. The Author had given the results of elaborate experiments on a subject which was of the utmost importance to engineers; and if his conclusions were to be relied upon, engineers were daily committing a grave error in using a material which gave so slight a guarantee of endurance. But while he accepted every one of the experimental facts adduced by the Author, he thought he was in a position to prove, from the Author's figures alone, that his conclusions were entirely erroneous. He had referred, in the first place, to a long series of experiments made by the Admiralty, under the direction of Admiral Aynsley, and as far as the collection of facts was concerned, nothing could be more conscientious or thorough than that series of experiments; but as regards proof, they went no further than to show what every experimenter ought to avoid, and how he ought not to conduct his experiments in the future. The Author had placed before the Institution the apparatus then used. It consisted of thirty-eight tubes of iron and steel riveted in metallic contact with the shell of a boiler, and exposed partly to air and partly to hot water and solutions. Although the Author had a very poor opinion of electricity and its effects, Dr. Siemens had a strong belief in electricity wherever it had a chance of acting for good or for evil, and he was convinced that the results obtained in those experiments were rendered entirely unreliable owing to galvanic agency. The results were most variable. Whereas one iron (common iron seemed to be the best) gave a corrosion of only 7 grains, on an average, per square foot, Bessemer steel gave 21 grains, or three times the amount during the time of exposure. The Author was really most merciful when he stated that the result was only 69·3 per cent. in favour of iron, because it was really 300 per cent. in that instance. Notwithstanding these experiments, the Admiralty had adopted a mode of action which seemed strangely at variance with the conclusions to which the experiments would point. They now used steel almost to the exclusion of iron, and he hoped that some one connected

Dr. Siemens.

with the Admiralty would state the result of more recent experiments undertaken with a better knowledge of the conditions under which they should be made. He believed the conclusions since arrived at were very different from those deduced by Admiral Aynsley some years ago. At Table VII. the Author had compared Landore metal and iron, the one giving an average loss per square foot of 506·24 grains, and the other of 483·17 grains, showing a difference of only 4·8 per cent. against the steel, and that was, at any rate, a great deal better than 69 per cent. On the same page, the Author stated, "The only peculiarity worth noticing in this experiment is that, while the two plates in the feed-water heater lost 381·8 and 394·2 grains, the two in the boiler fed from the heater lost only 8·0 and 3·4 grains respectively." Therefore in the boiler the iron lost by corrosion about one forty-eighth, and the steel about one hundred and twentieth of what they respectively lost in the feed-water heater, the loss of iron in this case being about two and a half times that of the steel. In Table IX., set 98, the Y steel produced by the Siemens process gave a corrosion of 1,220 grains, and the DD. Yorkshire iron 1,221 grains, in each case per square foot of surface; the corrosion in those instances being practically the same. In the next set, 99, the Y steel gave a corrosion of 259 grains; Staffordshire iron 269 grains, and DD. Yorkshire iron 260 grains; showing that the steel came out best in that series. In set 102, the Y steel gave 109·5 grains (in rain water), and the DD. Yorkshire iron 144 grains. And yet the Author followed up these facts with the conclusion that steel corroded on an average 64·8 per cent. more rapidly than iron. He entirely objected to the mode of reasoning adopted; he contended that averages were only applicable to errors of observation. If an observer was not certain of his weighings, and he made a hundred weighings of the same piece of iron, he would be perfectly justified in taking the average. But nothing could be more unscientific or erroneous than averaging several materials, one group of which he chose to call iron, and another which he called steel. It was as if a moral philosopher wanted to find out whether fair complexioned people were more virtuous than dark complexioned people, and were to take six fair people and six dark people promiscuously; then finding that they were all very well behaved, except one of the fair people, who happened to have just escaped from gaol, and had committed six murders, he were to draw his average and say, "I find that fair people have committed, on an average, one murder each, and should therefore not be trusted." That was the kind of argu-

Dr. Siemens.

ment which the Author appeared to have adopted. There were substances, compounds of iron, manganese, and silicon, sold for steel, which no doubt corroded very rapidly; but it was for the consumer not only to select the proper material, but also to see that it was properly used. He believed it was in regard to the proper selection and use of the materials that the enormous discrepancies with which they had to deal would be found. The Author stated that there was more cinder in iron than in steel, and therefore that there was *primâ facie* ground for supposing that iron would corrode more than steel. There was, however, an essential difference between cinder in iron and the scale of steel. The cinder in iron was a glassy substance, which was a dielectric, and therefore had no effect upon the corrosion of the metal, whereas the scale on steel, which was produced in rolling, had a very deteriorating influence; it was a magnetic oxide, which was negative to the steel, and wherever the metal was exposed in the presence of such magnetic oxide, corrosion took place rapidly. Again, if the scale should be rolled into steel plates, as was sometimes the case, rapid corrosion ensued, for the same reason. But he need hardly say that with proper care those causes of undue corrosion could be and were prevented, and the extensive use to which steel was now put proved sufficiently that there was, at any rate in ordinary practice, no such destructive effect going on. The Author stated that those interested in steel had been singularly negligent in not following up the question of corrosion. Being himself much interested in steel, Dr. Siemens had for some years caused a running set of experiments to be carried out by Mr. Willis, the chemist at Landore, which told a very different story from the Author's. In one series, extending over six months, made partly in a boiler supplied with salt water, and partly by exposure in a tidal river—the plates being exposed to the air for six hours, and then immersed for six hours in salt water—the result was in some instances of open exposure slightly in favour of iron, but, in the cases of boilers, always very much in favour of steel. He had just received a report from Mr. Willis, in which reference was made to a point of importance, the perfect cleaning of the surfaces. It had been found that if the surfaces were carefully cleaned of oxide by dipping the plates in the first instance in an acid solution, the corrosion was always much diminished. The evil effects of scale on steel were pointed out at the Institution of Naval Architects,[1] by Mr.

[1] *Vide* Transactions of the Institution of Naval Architects, vol. xx., p. 225.

Barnaby, on the 5th of April, 1879, when he clearly showed that the magnetic oxide scale was very deleterious in its effects. He believed that it was now the practice of the Admiralty to clean the scale off before using the plates for shipbuilding. During the past week he had received a number of letters, quite unsolicited, from gentlemen interested in the use of steel, all speaking in the most definite manner in favour of steel as a metal not liable to corrode under ordinary circumstances. One of them was from the Clyde Bank Foundry, in which it was stated by Mr. Thompson that forty steel boilers had been at work for more than two years, and that their examinations had led to the conclusion that no active corrosion was going on. He believed it would be found, from general experience, that steel under proper conditions lasted at least as well as iron. He hoped that the discussion would bring out such further facts as would put the question practically at rest. That there was, under certain conditions, a very active corrosion going on both upon steel and iron was clearly proved by the Paper, and by other experiments; but the conclusions drawn by the Author in favour of iron were, he thought, unjustified by the results of his own experiments as well as of others. Dr. Siemens.

Mr. THOMAS W. TRAILL considered that the Paper showed evident signs of great labour having been bestowed upon it; but, without wishing in any way to detract from its merits, he thought that had the facts been derived from the actual employment of steel in the construction of marine boilers they would have been more useful and perhaps as interesting. Steel was used in the construction of ships and boilers about a quarter of a century ago, but it did not then, in his opinion, receive a fair trial. That also was the opinion of many others; and owing to a few failures the users of steel became frightened, and did not take the trouble to find out the cause of the failures, and it had not a fair chance given to it to run a successful race with iron. It often got spoiled in the manipulation, and after it was placed in the structure it did not receive the kindly treatment due to a new material, if it was to have a chance of existence. The result was that it had been neglected for years. Twenty-two years ago, to his knowledge, a pair of boilers made of steel were placed in a vessel, and they did not suffer corrosion more than if they had been made of iron; in fact, they corroded less than any boilers he had ever seen, though they were used under the most trying circumstances. They did not for about five years receive any repairs except from the engine-room staff. Many Mr. Traill.

Mr. Traill. ships had been constructed of steel, and from all he could learn from trustworthy sources, and also from personal observation, those ships, after many years' working, had shown nothing to distress or alarm any one as far as corrosion was concerned. Mild steel, as it was called, had been much used in marine boilers during the last few years, and he had certainly not seen or heard anything that would justify him in expressing an adverse opinion respecting its use in regard to corrosion. Only on the preceding day he had received a letter from a friend who had made many steel boilers and placed them in ships, and he stated: "We are carefully watching the steel boilers made by us in ships running to this port, and so far everything is satisfactory; there is no corrosion, and they keep very tight." He believed that those boilers were about two years old. He hoped that, if any note of alarm was raised on the subject, it would be founded on established facts derived from the actual use of steel in marine boilers. He had certainly heard nothing to justify the opinion that steel was not fit to run a successful race with iron, so far as its corrosive properties were concerned.

Mr. Martell. Mr. B. MARTELL thought engineers were much indebted to the Author for bringing his valuable experiments before them. When it was remembered that at the present time 82,000 tons of steel ships were being built, the great importance of the subject would be at once recognised. The question of the mechanical properties of mild steel was no doubt well understood. It was known that it could be produced possessing all the qualities required for ship purposes (he referred especially to the hulls of ships), with all the ductility and strength, as compared with iron, that could be hoped for in a material of that kind. The question of corrosion, however, was one that required to be solved, and for that purpose more information was needed than had been hitherto obtained. Many shipowners were anxious to build ships of steel, but an opinion was abroad that it deteriorated more quickly than iron; hence the importance of having reliable facts upon which to form a correct opinion on that branch of the subject. About eighteen months ago a steel ship, not a year old, was hauled up on a slip-way in the North of England; he went there for the purpose of examining her, and his examination appeared to bear out in a striking manner one of the results mentioned by the Author, who had shown the rapid deterioration that took place where steel was exposed alternately to salt water and to air. The vessel was riveted with iron rivets, and he found that between the

Mr. Martell.

light water mark and the load water mark, which was alternately wet with sea-water and then dry and exposed to the air, a rapid deterioration had taken place as compared with the other parts of the vessel, and with iron vessels; in fact the steel round the rivets had wasted to a considerable extent, so that the rivet points were protruding some distance beyond the steel. He thought it might probably be due to galvanic action. Dr. Siemens had referred to magnetic oxide, but that could not have been the explanation, because by hammering the rivets the whole of that would have been certainly beaten off. He attributed it more to the galvanic action taking place to some extent between the iron rivets and the steel plates. The result seemed to show that under such conditions as those to which he had referred a more rapid deterioration ensued than under other circumstances. Two months ago, however, that same vessel, which had been continuously running since, was hauled up again and thoroughly examined, and owing to the greater care taken in protecting that part, no deterioration of any moment had taken place more than in any other part of the vessel. A striking and important fact was at the same time brought out. The vessel was constructed with a double bottom, or water ballast tank, extending fore and aft, and inside that no deterioration had taken place beyond what would have occurred in iron, and possibly less. That seemed to show, that where steel was entirely immersed in water no more rapid deterioration followed than in iron. He was of opinion that the results stated by the Author might be correct, but they would not prevent his adopting steel for ships in preference to iron. Mild steel was superior to iron for every purpose for which it was used mechanically, and by continually coating the surfaces it could be protected as much as iron. With regard to chemical action, he had known an iron vessel carrying sugar, in which some of the bottom plates had been eaten through in a few months, and nothing could be worse than that with the use of steel. But there, again, there existed an excellent preservative in Portland cement, which would protect the bottom from any action of that kind. The inside was open to observation, and it could always be coated. By the use of steel the ship was stronger, and most of the parts could be protected from deterioration, with the exception of that between the light and the load line, and that only required a little closer attention in keeping it coated so as to prevent rapid corrosion. He hoped the result of the Paper and of the discussion would not be to scare shipowners from the use of steel. He trusted it would

Mr. Martell. not be considered, as the result of experience, that steel had deteriorated 120 per cent. more than iron, as would appear to be the case from some of these experiments; but that the facts derived from the actual wear and tear of ships would be considered before any decisive conclusion was arrived at.

Mr. Barnaby. Mr. N. BARNABY, C.B., drew attention to the statement in the Paper that (p. 87): "In spite of these reasonings, it is undoubtedly a fact, that under almost all circumstances iron, and particularly the harder classes, is far superior to the finer steels in its resistance to corrosion, and this the experiments described by the Author incontestably prove." When he saw that paragraph he remarked to the engineer-in-chief of the Admiralty, Mr. Wright, who was a member of the first Boiler Committee (of which the Author was also a member), and had continued the experiments to the present time, "It is necessary that there should be some explanation with regard to this, because we are using steel shells for boilers very largely, and people will expect that some one from the Admiralty should say whether this statement, derived from Admiralty experiments, has been borne out by later work." Mr. Wright replied, "We have continued the experiments from the time when Mr. Phillips left the Boiler Committee, and we have come to the conclusion that there is no difference in the rate of corrosion between iron and the mild steels we are using. By such experiments as those which he conducted, and which have been continued since, so far as we can make out, the results are pretty nearly the same." He stated, moreover, that steels could be as well protected as iron by zinc suspended in boilers. That was the justification for the present practice of the Admiralty in using mild steel for the shells of boilers. That practice was a very recent one, the Admiralty having commenced making steel boilers only within the last few years; and it was hardly right that he should speak of it when there were so many others who had had a long experience of the use of steel in boilers. His only justification in alluding to the subject was that engineers might wonder how it happened that the Admiralty report, as the Author had presented it, should not be in accordance with the present Admiralty practice. With regard to what Dr. Siemens had said as to the effect of the hard black oxide upon the surface of steel, it was true they discovered a long time ago that the effect of that oxide was very strong indeed, almost like that of copper, yet they were foolish enough (he could use no other word), in building two ships at Pembroke, to allow them to be coated with anti-fouling compo-

sition before the black oxide was completely removed. His excuse was that the portions of black oxide remaining were very small, and that the officers who were charged with the duty of getting the bottoms quite clean thought they had done so. It was not until the "Iris" had been at sea for some months that it was discovered that rust was forming under the coat of paint with which the bottom had been covered. The Admiralty had learned wisdom by that occurrence, and he believed it would not happen any more. They now took pains to clear the oxide off completely. He thought the reason why they had found it out before others had discovered it was, that it was the practice in private trade to build vessels of that kind in the open air, and it was there easier for the black oxide to get removed from the surface of the steel. The Admiralty built their ships under cover, where it did not come off so easily. Mr. Barnaby.

Mr. J. FARQUHARSON said he had a memorandum showing the importance of removing the oxide. The Admiralty were aware of the view set forth in the Paper, that mild steel was much more liable to corrosion in salt water than iron, long before the Report of the Boiler Committee was printed, and they determined to test that point specifically. The diagram shown scarcely represented the condition in which the experiments mentioned in the Paper were really made. The diagram he now produced he believed showed the actual arrangement that existed. In looking at the diagrams he was of opinion that no reliable inference could be drawn from combinations so complicated and affected by so many conditions. By Mr. Barnaby's directions it was arranged that they should try,—not surfaces partly covered with oxide and partly uncovered, in an apparatus the condition of which they knew nothing about and which was itself made of a different metal,—but plates of iron and steel of a considerable size carefully prepared, the oxide being entirely removed by two processes, first pickling it off by chemical means, and secondly, planing it off to see how far the process of removing it affected the result. The plates formerly had been tried under conditions which had led to the inference that iron corroded a great deal more rapidly than steel; but the result of the experiment when the plates had been divested of oxide on the surface was that they were practically alike; if there was any difference it pointed in favour of iron. It was a rather extended series of experiments carried on at Portsmouth with great care. It was then determined to ascertain something about the electric effect of the oxide, and another series of plates was prepared, each 2 feet long, 1 foot wide, and $\frac{3}{16}$ inch Mr. Farquharson.

Mr. Farquharson.

thick, of mild steel. Some of the plates were prepared in the way he had described—the oxide being removed by two processes. The detached plate from which the oxide had been pickled lost 4 oz. and 70 grains; the one from which it had been removed by planing lost 3 oz. and 390 grains. That was the case with two pieces of the same plate. In another experiment, one plate with the oxide removed as he had described was combined with another plate of the same size, 2 feet long and 1 foot wide, which had been cut from the same piece of Landore steel; they were placed parallel to each other, 3 inches apart, in a wooden frame, and were connected by wire, one with the oxide on, the parts where the oxide was not on being touched over with a protective varnish to prevent local action. The plate with the oxide on lost nothing; the plate in contact with it, combined electrically, lost 10 oz. 95 grains. He had before him the record of another series treated in the same way, but he would only refer to a few instances to show that there was a great amount of harmony in the results. A plate with the oxide pickled in contact with another with the oxide on, held parallel to each other 3 inches apart, immersed in the same way in Portsmouth Harbour, lost 12 oz. and 34 grains; that with the oxide on lost 75 grains—that happening from minute parts unobserved and unprotected by the varnish pitting. With another pair of plates, one with the oxide removed, combined with a copper plate of the same size and placed in precisely the same relation to it as had been the plate with the oxide on, lost 11 oz. 345 grains—which was less than the other plate where steel alone was used, showing that a tolerably compact coating of oxide was as detrimental to steel exposed with the oxide on as copper. There were a number of other experiments, the general result of which was the same. He was considerably surprised when he read Mr. Phillips' Paper. He knew that the experiments of the Boiler Committee had been continued, and he could only suppose that he was not aware of what had happened. Mr. Barnaby had rather understated the case in favour of steel. In most of the cases that had been tested by the second Boiler Committee the results were strongly in favour of steel. Having a full knowledge of the experiments conducted for the Admiralty for some years, his opinion was greatly at variance with that of the Author as to the general result of the comparison between iron and steel. No one acquainted with the electrical effects of the combination of metals would expect to find any reliable inference from such combinations as had been presented. Copper, gunmetal, zinc, iron, steel, had all been combined electrically, and

at various distances, some in contact, some supported on metal rods, some on iron, some on steel; and it was stated that the results were so much per cent. in favour of iron. For himself he would not undertake to say what the relative amount of corrosion of iron and steel was with any such combination. Mr. Farquharson.

Mr. JOHN DONALDSON could corroborate the remarks of Dr. Siemens and Mr. Barnaby, as to the evil influence of the presence of black oxide on steel plates, by mentioning two cases which had come under his notice. The practice of his firm, at the time when the boats were built, was to preserve, as far as possible, the oxide on the plates, with a view to prevent them from getting rusted, the oxide itself protecting the plate covered by it from rust. The first case was that of a boat built for service on the west coast of Ireland. For some time after leaving the yard they had most favourable accounts of her performance, but suddenly they received a letter, stating that she had one day gone out fishing, and it was as much as two men could do to keep her from sinking. The boat was examined, and it was found that the plates in the bow and in the stern, and others in the boiler and engine-room, were pitted with very small holes. It appeared as if some of the black oxide had been knocked off in the process of working the plates, and that the oxide left on had contributed to increase the rusting of those parts. At first he thought it was due to the engineer not clearing away the ashes from the stoke-hole and the soot from under the smoke-box; but an examination of the second case, that of a boat built for the Zoological Station at Naples, seemed to show that it was more the action of the black oxide, helped largely, perhaps, by the plates not being kept well painted. In that case the principal pitting took place at the bow and stern, and scarcely any in the neighbourhood of the engine-room. He therefore concluded that it was the black oxide that had been acting galvanically in oxidizing those parts of the plates that were exposed. When the plates of a boat were well painted and kept clean, very little of that action took place, as was shown in the case of the "Lightning," which his firm built some years ago, and the bottom of which they had lately scraped and painted, the plates being found in excellent condition, due no doubt to the great care taken of the vessel while in the hands of the Admiralty. Their practice now was not only to remove the scale from the plates, but to galvanise the whole of the hulls, and since that had been done there had been no trouble as far as oxidation was concerned. Mr. Donaldson.

Mr. Phillips. Mr. D. PHILLIPS said it would appear from the remarks of Dr. Siemens and Mr. Farquharson that the conditions to which the tubes were subjected were not clearly understood. He wished to point out that the tubes were screwed through the tube-plate, which formed the top of the apparatus, and that the tube-plate was covered with a non-conducting material (putty) 2 inches thick, so that the water in the condensing chamber had no admittance to it, and therefore the conditions necessary to promote galvanic action between it and the tubes, or between the tubes themselves, were not present. The lower ends of the tubes were exposed to steam only; for 4 inches above the non-conducting material they were exposed to the circulating water (fresh), and the rest to the vapours arising from the heat of the tubes and tube-plate. The level of the water in the tubes, and in the condensing chamber, and the non-conducting material on the tube plate were shown in Fig. 1.

Sir Henry Bessemer. Sir HENRY BESSEMER was sure no one could help feeling that the question brought forward in the Paper seriously affected a great deal that had been done within the last twenty years, and was well worthy of investigation. As a preliminary to his remarks he desired to say that he accepted unreservedly all the figures which had been given by the Author; he accepted his experiments as stated, and had no doubt of their entire fairness. But if he were asked from those experiments to draw the inference that mild steel in the form of a boiler such as was ordinarily used would not endure half the amount of use and resist corrosion as well as common Staffordshire plate, and that phosphorus being present in the commoner irons was the cause of its standing so well as compared with mild steel, he must entirely demur to any such conclusion. In the first place, the experiments on plates suspended inside a steam boiler appeared to him to be under totally different conditions from those to which a steam boiler was exposed when in use. A steam boiler in use had its internal flue exposed to a very high temperature on the inside, and on the outside to the water only, subject more or less to a deposit on its surface, and to a great many strains continuously by the raising and lowering of the temperature, which a suspended and insulated plate in the water did not feel or come in contact with. The external shell of the boiler also was exposed on the inside to the corrosive action of the water, and on the exterior to the corrosive action more or less of the gases of the furnace passing along the flues, and also to the escape of water occasionally from the weeping at the rivets, and so on, sometimes

Sir Henry Bessemer.

cutting large notches, or, if the boiler was well riveted, not affecting it at all. To these violent changes of temperature the suspended plate was not subjected. The deposition of scale upon the surface would not take place on the suspended plate in the same manner as in the case of a boiler. The conditions, therefore, were in reality very different, and that difference would sufficiently account for the fact that boilers in actual use did not corrode at the rapid rates that the suspended plates appeared to have done, from the evidence given in the Paper. Some twenty-three years ago he manufactured a great many boiler-plates for a gentleman who was about to make experiments upon their use, and who desired to know what was the actual working condition of those new steel plates. In one instance 50 tons of plates were made into boilers, and the result, after twenty-two years' use, was very different from that which had been described with regard to the suspended plates, in consequence of the different conditions to which they were subjected. As introductory to the experiments, he might be permitted to refer to the remarks made by Mr. Daniel Adamson, M. Inst. C.E. (than whom there was no more thorough and practical man connected with boiler work), and by Mr. William Richardson. The occasion was the discussion on a Paper which he had read on the 31st July, 1861, in Sheffield before the Institution of Mechanical Engineers, Sir William Armstrong occupying the chair. Some specimens of flanging for locomotive boilers were then exhibited, and after they had been examined by the Chairman, the remarks he had referred to were made in reply to an inquiry whether the plates from the new steel were much used.[1] The plates of some of the boilers were exceedingly thin, and if anything like rapid corrosion took place in those plates, they would soon have become too weak to sustain the pressure of 85 lbs. to which they were subjected, and would have given way. It had occurred to him that it would be well to ascertain the condition of those boilers at the present moment, inasmuch as, if corrosion had gone on at the rate stated in the Paper, in connection with some of the Bessemer steel, the plates would have been entirely destroyed in about eight and a half years, and as the boilers were made twenty-two years ago, it might be supposed that a second or third set would now have taken the place of the original ones. He accordingly sent the following telegram to Mr. Richardson :—"A Paper on corrosion of steel boilers will be discussed to-morrow at Civil Engineers;

[1] *Vide* Institution of Mechanical Engineers, Proceedings, 1861, p. 149.

Sir Henry Bessemer.

are the six boilers of my steel, made twenty-two years ago, still in use?" To which Mr. Richardson replied:—"The six boilers of your steel, made twenty-two years ago, are still in use, and have no appearance of corrosion." That was the best answer he could give to the assumption that Bessemer steel lasted about one-third the time of common Staffordshire plates. Had common Staffordshire plates been used twenty-two years ago he fancied that the boilers would be in a rather queer condition at the present time. Mr. Richardson's practice was to overhaul his boilers annually, and thoroughly investigate them; and as the boilers in question were experimental ones, and put up so long ago, he had no doubt that a strict examination had gone on in connection with them, so that Mr. Richardson would well know whether they were corroded or not. This statement was, he thought, the best evidence that could be given that Bessemer steel, and other mild steels of a similar character, were thoroughly well adapted for the manufacture of steam boilers, and might be relied upon quite as well as Staffordshire iron, notwithstanding the results arrived at by the Author.

Mr. Ravenhill.

Mr. J. R. RAVENHILL wished to preface his remarks by saying that many of the members of the Boiler Committee had been personal friends of his own for many years, and one of them, Mr. Trickett, the Chief Engineer of Her Majesty's dockyard at Keyham, for thirty-five years. No one, he believed, would venture to doubt that the Report of the Committee was in full accordance with the facts as they appeared to have been at that time. The Committee commenced its operations in 1874. Their third Report was signed on the 9th of August, 1877, Mr. Trickett having ceased to render the Committee the benefit of his services at the end of March 1875. Mr. Barnaby had stated that their own experience since was entirely at variance with the statement laid before the Institution by the Author. The question was, no doubt, a most important one. Steel had been in use, as Sir Henry Bessemer had said, in land boilers, for twenty-two years; vessels had been running between Dover and Calais for nearly the same period, and one of them, the "Samphire," was subjected to perhaps the most severe strain that it was possible for a vessel to be put to. On the day of the Admiralty trial trip the boat had been across from Dover to Calais, and had made a very rapid passage, and on the return was making a still more rapid one. The average speed was nearly 17 knots an hour. With new machinery he felt anxious that the captain should not run matters too fine in approaching Dover,

but that plenty of time should be given to reverse the engines, and stop the ship, and having explained this, he was himself down below, but the excitement on deck proved too much, and no order was given to either ease, stop, or turn astern until they had come alongside the Admiralty pier head; to turn astern was found impossible, and almost before the words could be uttered, several feet of the vessel's bow were on the rough rocky shore adjoining the pier. The vessel was soon backed off and taken into harbour, but hardly leaked. She was put on the gridiron the next day; the repairs that were necessary were of an unimportant character, but there was one material point in connection with them. The Admiralty shipwright inspecting officer, having been accustomed to wooden shipbuilding, perhaps felt a little anxious when he came to survey a steel ship, and might have had some doubt about her strength. But on examination he was amply satisfied, the certificate was given, and no further test was asked for. A few months afterwards the vessel was in collision with a ship off Dover, and she actually steamed into Dover harbour with her bows submerged, and the water for a considerable distance over her deck forward. He thought there could hardly be a stronger proof to show what steel would stand in connection with shipbuilding. In a letter from Captain Dent, of Holyhead, dated 22nd March 1881, it was stated that the steel steamers under his charge, which had been running for three years, showed no signs of corrosion. No doubt there was a difference in the quality of the steel used in the Holyhead boats from that used at Dover, but he thought it was fair to argue that if the steel was preserved, when well looked after, for three years, it would probably remain good as long as the steel in the Dover boats. The boats running across the channel had not the space between the load line and the light line, to which Mr. Martell had alluded, but the action on steel closely resembled that used in the series of experiments Table IX., set 100, where a comparison was made between Bessemer steel and Staffordshire iron, and Siemens steel and Yorkshire iron. The Bessemer steel and Staffordshire iron were exposed to the weather, and dipped in sea water daily, and for a few feet up the side of the vessel, above the water line, a very similar action went on. Any one could go to Dover and see what the effect on the vessels had been after so many years' running; but according to the experiments, there ought now to be little of the original steel left, for the comparison was 128 per cent. in favour of iron. The plates in the Dover boats were $\frac{6}{16}$ inch thick, and they were certainly a striking example of the endurance

Mr. Ravenhill.

Mr. Ravenhill. of steel. The Author had alluded to the boilers of "The Duke of Sutherland," and said it would be interesting to know their condition at the present time. In the letter to which he had alluded, Captain Dent stated, "We find no appreciable difference between our iron and steel boilers, now nearly five years old." He had been informed through another channel that these steel boilers in places showed marks of corrosion more than they did in others. So also would iron ones; and any practical man who had been in the habit of examining marine boilers, would say that on going on board a vessel fitted with eight different iron boilers, and going inside them, in no two cases would the appearances be similar. There had been instances in the cases of stays in the steam space where steel had rapidly corroded, but the same thing might also occur in iron boilers. The quickest corrosion might be expected to take place in the stays just about the water-line, and in the steam space. It would be found that a few perished very rapidly, while others, for no accountable reason, stood perfectly sound and good. There was no doubt a difference in the quality of the material, and it was much to be regretted that the valuable experiments made up to a certain date by the Boiler Committee did not go further and record the difference, if any, from a given standard, in the component parts of the metals subjected to experiment. Unless there were some such standard, makers might be easily scared. He remembered the time when a number of boiler tubes gave way the first time the fires were lighted; they were taken out, and some spare ones were substituted, and again they failed. What was the result? The chemists were set to work, and a standard of metal fixed for the future. From that time to the present the Admiralty work had been subjected to chemical tests, and it was known that if it would stand those tests there would be no further trouble with the boiler tubes. He well remembered the scare in connection with iron boilers. The plates were pitted, and, after four trips up the Mediterranean, were nearly worn away, being so thin that it was thought the boilers were not safe to go to sea. A few repairs were done; the boilers were roomy, and the parts where rapid corrosion had taken place were coated with Portland cement; the boilers then did the usual amount of work. The Committee had alluded to the action of zinc. In a Paper which he had read at the United Service Institution,[1] he stated, with the full sanction of the Admiralty, that their experiments up to that time tended to show, that if the

[1] *Vide* "Journal of the Royal United Service Institution," vol. xxiii., p. 602.

most valuable properties of zinc plates were to be obtained, they should be placed all over the inside of the boiler, at distances of not more than 6 feet apart. In conversation with the Engineer-in-chief of the Admiralty, he had been informed that their experience up to the present year was that, where zinc was properly applied in marine boilers, steel lasted as well as iron; and that they were driven to the use of zinc in iron boilers before they began to fit steel ones on board. The Author had stated, "On the other hand, the treatment of [marine] boilers might be so modified, especially with the aid of zinc properly applied, that the purer metals might be used for their construction." He was surprised, after this lapse of time since the Report of the Boiler Committee appeared, that the Author should have put such a statement before the members. His principal object in drawing attention to the subject was to prevent any prejudice against the use of steel for shipbuilding or boiler-making. With regard to shipbuilding, there were instances of owners who had had ships running for a short period, say two years, repeating their orders for steel. The very company to which the Author of the Paper formerly belonged, the Peninsular and Oriental, had now in course of construction five large vessels of steel; and the rapid increase in the use of steel for boilers was marvellous. Mr. Ravenhill.

Mr. E. MATHESON said the Author had dwelt entirely upon boiler tubes and ships; but there were other matters in connection with the corrosion of steel and iron which were interesting to many members of the Institution; he referred to structures like bridges, exposed not to salt water or steam, but to the weather. The corrosion of wrought iron was very serious, especially in cities and in railway tunnels, and if steel were still more sensitive to corrosion, it would indeed be a grave matter. It would be interesting to compare the means taken to preserve wrought iron with those used in connection with steel, and to see how one would be suited for the other. He thought that the means taken to protect wrought iron from rust were imperfectly understood. There always appeared to be an attempt to preserve the skin of the iron as it left the rolling mill, and he ventured to say that that was impossible, and was to a large extent a mistake. Wrought iron, in passing through the rolls, coming in contact with the atmosphere, was at once oxidised; it got a black scale or oxide upon it which must ultimately fall off; and although elaborate specifications were prepared for oiling or painting such wrought iron, that treatment only postponed the evil. Oiling wrought iron was, he thought, a better protection than painting, but even that did not fulfil the purpose intended. He Mr. Matheson

Mr. Matheson. believed there were only two, or perhaps three, modes of protecting wrought iron from rust. One was to keep it entirely from the air. Iron built into lime or brickwork or masonry would remain for centuries almost in the same condition as when it was put in. The second plan was that of Professor Barff, exposing the iron to superheated steam, but this was possible only with pieces of moderate size. A third plan was to remove the thin scale entirely before the painting was applied, and he thought that was seldom, if ever, done in England in any sort of structure. The only place where he knew of its being done was in Holland, where the specifications of the engineers generally described, with the greatest minuteness, how the iron was to be treated before the oil and paint were applied. The iron was treated as the galvanisers treated it in this country; it was dipped in baths of dilute acid, which removed all the black scale. After washing it was painted, and if the paint was renewed from time to time, the iron might be permanently preserved. In this country the plan was followed necessarily by galvanisers, but he believed by no one else. If the structure had parts that were inaccessible to the painter's brush, rust would be sure to destroy it. He had lately seen a curious instance of the way in which rust deteriorated structures. He had taken down a beautifully-made bridge that had been put up twenty-five years ago by Messrs. Fox and Henderson; it was the first pin-connected bridge made in England, and was placed over the Commercial Road at Stepney. The upper boom or box of the bridge had been riveted and caulked like a boiler, and was perfectly air-tight; and the inside plates, which had never been painted, were as good as the day when they were first put in, while some of the parts exposed to the atmosphere, and ineffectually painted, had deep pits bitten out in all directions, materially weakening them. The worst part was where the iron had been brought in contact with wood, the acid of which had so destroyed it that an angle-iron ½ inch thick was worn down to a knife edge. It was not often that one had the opportunity of dissecting an existing bridge, and he thought it might be interesting to mention the facts to which he had referred. Another bridge, an approach to a large terminus, put up some twenty years ago, was now being taken down (having to be widened) in the City of London; the rivet-heads were eaten away, and the T-iron stiffeners were nearly rusted away. At the present rate, in ten years he imagined the bridge would have begun to sink under its load. When he saw it there were four locomotives on it, so that it had to undergo severe strains. It would be interesting if some steel-maker or chemist would

compare steel with cast iron. Like cast iron, it had been in a molten condition, and had not undergone the intermediary process of piling and laminating which wrought iron had to undergo. Cast iron, when run into a sand-mould, got a skin on it, which was a very valuable protection, and might be permanently preserved. Steel was cast in an ingot, and it might be useful to be informed, by those cognizant of such matters, how far steel cast in a sand mould was like iron cast in a sand mould; what difference there was on the surface of the steel, because it was cast in an iron ingot mould, instead of in sand, and what alteration took place in the steel by its being re-heated and passed through the rolling mill. Apart from any chemical difference, there were these differences between iron and steel, and he felt sure there was a difference of surface caused by the way in which they were manufactured. Mr. Matheson.

Professor F. A. ABEL said the Author had stated "that the commoner sorts of iron, containing the most phosphorus, resist corrosion far better than the superior kinds; and also that the harder steels, containing the greatest amount of carbon and phosphorus, are better in this respect than the softer and finer sorts." The Author had further remarked that the conclusions at which he had arrived from the results of experiments had been confirmed by the recent analysis of some brands of metal under consideration. The subject being one of great interest to him, he had searched the Paper, but in vain, for any facts upon which those conclusions were based. The Author had very justly stated that "It is important to ascertain how far want of uniformity in composition has to do with local corrosion in metals, and particularly in steel; also how far the presence in a medium degree, or absence in a minimum degree, of impurities in iron and steel can affect their durability." Another statement made by the Author was, "that the manufacturer and the chemist, in their anxiety to produce a metal containing the least possible amount of impurities, and thus to attain a high standard of ductility, in depriving it, perhaps, to a greater degree than necessary, of elements such as phosphorus, carbon, &c., or adding to it manganese, probably thus render it more liable to corrosion." It was stated as a probability, but further on it was given as a decided fact; and he confessed that he was unable to conjecture how the probability had been converted into a matter of certainty. The Author had made a general statement with regard to the proportions of phosphorus, carbon, and manganese in irons and steels. In regard to phosphorus, his argument might be to some extent borne out by Prof. Abel.

Prof. Abel. that statement; with reference to carbon, the proportion in steel, according to his statement, was from two to three times that existing in wrought iron, and he had given the proportion of manganese as three or four times greater in steel than in iron. He imagined that the Author wished to compare the two materials together, since, in the case of phosphorus, he had referred, not to the different proportions of phosphorus contained in one and the same material, but to the different proportions contained in the two materials. Those were the only facts bearing on the above conclusion which he had been able to find in the Papers, and as, according to these, carbon and manganese were present in larger proportion in steel than in wrought iron, he should have imagined that they ought, according to the Author's conclusions, to exert their protective influence to a far greater degree upon steel than they did upon wrought iron. That was the extent to which he had received instruction in reference to the impurities contained in wrought iron and steel, which the chemist was so anxious to remove; and he confessed the conclusion at which he had arrived was that, as regarded "assumptions and theories," the Author did not stand upon much higher level than those whom he had condemned. The Author had been very severe upon those who indulged in the view that possibly galvanic action might have something to do with the deterioration of boiler plates, whether iron or steel, but he thought there were very few persons, even among those who were not what the Author had called indiscriminate partisans of mild steel, who shared that view, and who were not convinced that even in one and the same piece of plate galvanic action might come into play very decidedly in promoting the corrosion of the metal. In reply to the possible objection that more definite results would have been obtained from more extensive trials, the Author had stated that all experiments in which the conditions were not precisely similar, could not be considered satisfactory; and Professor Abel thought there were few who had experimented with a view to obtaining precision of results, who would not most heartily agree with him in that respect. But there, again, he could not quite understand how such very strong conclusions as the Author had drawn could be based upon the results of experiments made by the distribution of large numbers of plates to different ships, in which they had received all possible kinds of treatment, especially when he found that the results of those various experiments with fifty-six sets of plates were lumped together afterwards, and that the conclusions were drawn from the average loss of weight of

the plates in those remarkably various experiments. He was one of those who considered that among the most dangerously misleading figures with which practical and scientific men could possibly have to deal were so-called averages. No doubt the results of the various experiments were interesting, as illustrating the character of the corrosion caused by different treatment, such as the water used, the different practices of blowing off, and the comparative effects of chemical agents. It was, however, from those various experiments that a definite conclusion was drawn with regard to the stability of steel as compared with iron, for the Author stated, "These results clearly prove that the conclusions arrived at by many experienced engineers and chemists as to the causes of corrosion in boilers, previous to the appointment of the Boiler Committee, were erroneous." He should have been glad if a statement of those conclusions had been given, in order that their fallacy might have been demonstrated; for he should have been most anxious to learn from such an extensive and instructive series of experiments as the Boiler Committee had the power to institute, and did institute, to what extent previously existing conclusions were wrong. The Author had also stated that "in spite of these reasonings, it is undoubtedly a fact, that under almost all circumstances iron, and particularly the harder classes, is far superior to the finer steels in its resistance to corrosion, and this the experiments described by the Author incontestably prove." That was a very strong statement, but he had no doubt that the Author had considered himself perfectly justified in making it. He must, however, pardon those who were unable, from the summary of experiments which he had given, to arrive at the same conclusion. Taking even the averages upon which the Author relied, this statement was not at all well carried out, for he could hardly consider that 10 per cent. difference in average loss would be so great in practical experiments as to constitute an "incontestable proof" of the difference between the durability of two descriptions of material. Further on he found that there was only a difference of 5 per cent. to establish the same point "incontestably." With regard to the averages of the experiments made on board the many ships, there were differences, in one case between crucible steel and Staffordshire iron, amounting to 0·3 per cent. only upon the weight of the total metal employed, and in another case between Siemens steel and Yorkshire iron of less than 1 per cent. upon the total weight. He could hardly accept results of that kind as "incontestable" proof that the superiority of iron over steel had been established. Again, in some of the special experiments made

Prof. Abel.

Prof. Abel. by the Author, it had been "incontestably proved" that iron was on an equality with steel, and even that steel was superior to iron. Taking all these points into consideration, although he had read the Paper with great interest, he could not admit that the Author had in the least degree established, by the "facts" with which alone he proposed to deal, the "incontestable" superiority of wrought iron over steel as a material for boilers.

Mr. Cowper. Mr. E. A. COWPER wished to say a few words in reference to the bridge to which Mr. Matheson had alluded. He had constructed it more than thirty years ago, for the late firm of Fox, Henderson, and Co. It was in the Commercial Road, and was 120-feet span, and had been lately pulled down to increase the width of the bridge. He believed it was the first bow-and-string bridge made of iron in this country; the bow flange was of a box form, with an overhanging top section. The span of the bridge did not require that the rib should be large enough to let a man pass through. There were vertical ties and large bolts which would prevent this; therefore the box was built as air-tight as it could be—not absolutely, but so close that the air could not work in and out with freedom. In that way the inside plates, he believed, were protected very fairly, until it had been lately pulled down. Mr. Matheson had not said whether the inside plates were in a perfect condition, but he believed that they were so. In some of the outside plates, where wood had been placed against the side of the box, the iron was corroded, and in some cases very badly, no doubt from the tannic or gallic acid in the wood. But where bridges were made with laminated plates, as they were in many instances—notably in one near at hand where corrosion was going on rapidly—he imagined that in a few years there would be no plates left. It was impossible, with a number of plates riveted together, to get them all so air-tight at the edges as entirely to exclude the atmosphere, and especially the damp air coming from the chimneys of locomotives. The mode of protection suggested by Mr. Matheson was no doubt a good one, but he would suggest that a further protection should be adopted by forcing varnish or boiled oil, or whatever might be the best material, between the plates by a powerful syringe; the oil might not go all the way in, but it would go as far as the air would, and two or three injections might entirely stop the entrance of air. In that way he believed that many bridges of laminated plates which were now in a state of deterioration might be preserved from further deterioration between the plates. Thirty years was too short a life for a bridge, and some improved method of protection ought to be adopted.

Mr. W. H. BARLOW, Past President, had noticed on railways that a very much larger corrosion of iron rails would take place in a siding which was unused, as compared with the same rails in a line which was used. The only difference he was aware of was that, where the rail was used, one of the surfaces was kept to a certain degree polished; and the theory he had formed was, that galvanic action was set up between the polished and the unpolished side. In conducting experiments of the kind to which reference had been made, the greatest possible care was required to ensure that the conditions were exactly alike. It did not appear to him to be quite satisfactory to have one plate tested in one boiler, and another in another, without knowing that the particular circumstances of each were similar. The importance of the question with reference to steel was very great: the expressions in the Paper were strong, and he thought it behoved the Institution to inquire closely into the matter, so as to be sure that the basis of operations was accurate. He was sorry his personal observations did not enable him to carry the subject farther, but it was obviously important in any comparisons that were made, that the circumstances should be similar in each case. Mr. Barlow.

Mr. GEORGE ALLAN said it had been his practice, during the last eight or ten years, to recommend steel for boilers, and during that period he had sent to India seventeen or eighteen steel boilers. They were 7 feet in diameter, 30 feet in length, and had been made by Messrs. Hick, Hargreaves, and Co., of Bolton, the steel having in all cases been prepared by the Bolton Iron and Steel Company. The boilers had been tested with a considerable hydraulic pressure, and in one or two cases under steam, and they were made to stand a working pressure of 100 lbs. to the square inch, the plates being $\frac{7}{16}$-inch thick, and the end-plates $\frac{9}{16}$-inch. He had not received a single complaint from India respecting any one of those boilers; he had never been asked to send out a new plate, nor had any fault been found, although it was proverbial that if anything happened in India one was sure to hear of it; so that it might be taken for granted that all was going on well. He was satisfied from his own experience that steel could certainly be depended upon for boilers. He knew of no material more reliable, from its great ductility and its good qualities in other respects. Whilst acknowledging the experiments recorded in the Paper to be interesting and important in themselves, he was of opinion that they were not properly applicable, and did not correspond to the conditions to which boilers were subject. At the same time he had observed that the softer steel plates now in use were more Mr. Allan.

Mr. Allan. subject to corrosion than the harder steel plates of a few years ago, which had a tensile strength of 32 to 35 tons per square inch, as compared with 26 tons of that of the softer steel. With ordinary care and skill there was no difficulty in working the harder steel plates, but in the hands of unskilled workmen they were liable to failure. In proof of this, Messrs. Hick, Hargreaves, and Co., who were extensive users of the harder steel plates, had scarcely two of them rejected in a year. He attributed the demand for softer steel plates, which would stand any sort of treatment, chiefly to the general want of practical knowledge of the proper working of the harder quality; also to the fact that the government would have nothing else. This led to a plate being introduced less able to resist corrosion than the harder plates, which were always looked upon as able to resist corrosion better than iron. Now, it was presumed the iron and softer steel plates might be taken as about the same in this respect. An exceptional case of corrosion in a steel boiler might be met with just as in iron boilers. It had been the common practice for the last ten or fifteen years among all the leading Lancashire boiler makers to use steel plates for the furnace flues, even when they adhered to iron in preference for shells. If steel was not fitted for boilers, or was liable to excessive corrosion, he maintained it would have been found out long since; but all the leading makers had gone on using steel more extensively every year, one firm—Messrs. Hick, Hargreaves, and Co.—alone having used in the last twenty years about 12,000 tons for boilers, and with the most satisfactory results. He could not, therefore, admit that the Author's experiments, carried out as they were, in his opinion, under conditions not to be found in practice, to be of much practical value. Further in support of his views, he might point to the fact that both the Cunard and the Allan Steamship Companies had recently built the largest addition to their respective fleets—the "Servia" and the "Parisian," of 10,000 and 5000 tons—wholly of steel, including the boilers; and it was not likely the owners would have adopted steel unless they had been perfectly satisfied that it was a reliable material in all respects, including its ability to resist corrosion.

Mr. Samson. Mr. PETER SAMSON remarked that the Paper was bristling with facts which were exceedingly interesting and useful to engineers, especially to those who were entrusted with the maintenance of such structures as bridges, ships, and boilers. At the same time engineers ought to be exceedingly cautious in drawing deductions from those experiments, otherwise they might, without ground, get alarmed and scared from the use of mild steel. He

Mr. Samson.

thought it would have added to the value of the Paper if the loss from corrosion had been given per unit of time as well as per unit of surface, because it was impossible to compare one experiment with another, or to compare the experiments with the actual corrosion going on in boilers unless that were done. He had calculated the loss of weight of the iron plates as given in the Tables per square foot of surface per month, and he had found that it averaged 55·6 grains, the greatest loss being 170 grains, and the lowest 10·9 grains. That corrosion, although it might appear large was small in amount when compared with the active corrosion going on in some boilers. Taking the average corrosion of the experimental plates as a standard by which to arrive at the durability of a $\frac{1}{2}$-inch plate, 1 foot square, if corroded on one side only, he found that it would take more than two hundred years to corrode the plate entirely away. Comparing this with the average life of a well-kept marine boiler, which was only about ten years—although it was not an uncommon thing for a $\frac{1}{2}$-inch plate in a boiler to be corroded away in a very few years—it was evident that the conditions under which the experiments were made, and those actually going on in boilers were entirely different; and the question arose, what effect the difference of conditions had on the results of the experiments? It was important to note that the percentage in favour of iron was 45·4 in the case of the tubes referred to in Table II., and only 10·9 in the case of the feed-water heater plates, where the rate of corrosion was about 70 per cent. greater. It would be exceedingly interesting to know the Author's views as regarded the corrosion being so little in the experimental plates compared with that in actual boilers. Referring to the experiments which the Author had made at home, he thought those results would be found useful and interesting, but they required some explanation. In those referred to as set 98 the corrosion in the first twelve months was considerably higher than that during the second twelve months, and as there was no apparent reason why it should be so, especially as the plates must have been scraped and cleaned for weighing at the end of the first period, he thought it would be useful to have the Author's explanation on that point. It would also be interesting to have his opinion as to why the corrosion in the experiments marked 102 was so much less than in those marked 98. Possibly it might be due to the water in the former series being kept in a vessel without being changed, and if that was the case it would tend to prove that the water in boilers should be blown out as seldom as possible. Referring to the experiments with the crucible

Mr. Samson. steel, it would be found that the plate which was placed in the water-butt corroded more than that placed in the tank, and that the plate in the kitchen boiler corroded less than the plate in the tank. The difference might have arisen in this way: in the water-butt, the corrosive agents were very active, owing to their not having previously come in contact with a substance for which they had an affinity, and combined freely with the experimental plates suspended therein. They were then carried on to the tank, where the second set of plates were placed, but being weakened by their first attack, less corrosion occurred, and they finally passed into the kitchen boiler weaker still, and therefore less able to combine with the last set of plates.

Mr. Giles. Mr. A. GILES, being connected with steam navigation, confessed to having had a considerable scare after reading the statements in the Paper with regard to the excessive corrosion of steel as compared with that of iron. That scare was somewhat modified by what Dr. Siemens had stated. But the two statements being so conflicting, he had applied to a gentleman who had the designing and construction of the boilers of the fleet with which he was connected (the Union Steam Company), and he had been informed that for the last three years steel had been practically adopted, instead of iron, for boilers; and that the result had hitherto been most satisfactory. The steamers ran to the Cape of Good Hope, and the boilers were worked at from 80 to 90 lbs. pressure per square inch of surface.

Mr. Woods. Mr. E. WOODS said it had been stated by Mr. Matheson that the practice of preparing boiler-plates by the removal of scale had not been adopted in this country. It might be known to many members that at the London and North-Western railway works at Crewe steel had been extensively adopted in the construction of locomotive boilers, and Mr. F. W. Webb, M. Inst. C.E., had informed him that he made a great point of preparing plates in the way to which Mr. Matheson had referred: he either immersed them in a solution of sal-ammoniac or brushed them over with that solution, so as perfectly to remove the scale. The practice had been attended with excellent results, not only in enabling the joints of the plates to be made more secure and steam-tight, but also in preventing the tendency to corrosion in the interior of the boiler.

Mr. Matheson. Mr. MATHESON remarked that he had referred to plates for bridges, not for boilers.

Mr. Atkinson. Mr. W. ATKINSON, commenting upon the observation of Mr. Barlow as to the difference in duration of rails in use and those not in use, said the explanation might possibly be of a mechanical character.

When a rail was in use the motion of the locomotive and the carriages removed all the rusty particles, and, thus left, the surface more rapidly dried by the action of the air. It was well known that corrosion, both in wood and iron, took place in a great measure in consequence of the presence of moisture. The same explanation probably applied to the destruction of iron in a bridge where it came in contact with wood, owing probably to the increased dampness of the surface of the iron, due to the presence of wood. A similar illustration might be found in wood itself. Larch sleepers, when laid down without the bark having been taken off, deteriorated much more rapidly than those from which the bark had been removed, and he believed that was entirely due to the absorption of moisture in the bark. Mr. Atkinson.

Mr. D. PHILLIPS in reply observed that his sole purpose in writing the Paper had been to lay before the Institution facts which had come to his knowledge regarding the comparative corrosion of iron and mild steel. He had no wish to depreciate mild steel. True, the Paper showed that that metal had defects; but these, he was of opinion, could be counteracted with further knowledge. It would not do the cause of mild steel any good to conceal its faults, for without clear knowledge of the defects of steel it would be impossible to remedy them. Many of the criticisms had been wide of the mark. Whilst the Paper dealt chiefly with the corrosion of iron and steel having bright surfaces, considerable time had been spent in discussing the mechanical qualities of steel, and its liability to corrode with or without black or magnetic oxide. Mr. Phillips.

He could not but admire the convenient way in which Dr. Siemens had attempted to prove from the figures in the Paper that its conclusions were erroneous. Dismissing the tube and disk experiments as worthless, and skipping the experiments in the two tugs and the feed-water heater, and those with Lowmoor iron and Bolton steel, he observed that in the test of the Landore steel and the Lowmoor iron, the latter proved only 4·8 per cent. better than steel; but this was in fresh water and only for six months. Referring to Table VII. and the remarks following, he said that in this case the iron lost more than twice as much as the steel; but then the iron mentioned as having been tested in a former experiment was under trial over twice the time that the steel was. Ignoring the experiments in ocean and coast-going steamers, perhaps the most important of all to those engaged in steam shipping, Dr. Siemens proceeded to pick out from Table IX. such results as suited his purpose. In set 98, he compared the

Mr. Phillips. Landore steel with the Yorkshire iron, whilst in set 99 he compared it with Staffordshire iron. Passing over sets 100 and 101, in which both the steels gave bad results, he wound up with set 102. Now this was hardly an impartial way of treating the matter. To take into consideration only such facts as confirmed one's own opinions was a species of special pleading upon which Dr. Siemens could not be congratulated. In sets 99 and 102 the corrosion was scarcely perceptible. The D.D. 102, to which Dr. Siemens drew attention, had a patch of cinder in it, which was picked out before testing, but after it was weighed; the loss of weight should therefore have been approximately reduced. In calculating the percentages in Tables VIII. and IX., the two steels and the two irons were compared, the difference between each steel being but trifling. The results obtained, after a little over two years' trial, from the metals tested in the tube apparatus, were considered by Dr. Siemens to be valueless; but when he was better acquainted with the conditions to which the apparatus and the tubes had been subjected, this opinion would probably be modified. Mr. Phillips possessed, from a scientific point of view, only a scanty knowledge of the effects of electricity on metals; but he claimed to have a fair amount of knowledge as to the nature of corrosion in marine boilers and its causes, and he failed to see why, in the tube experiments, with metals so closely allied to each other, one metal should feel the effect of electricity more than another. He thought it would be admitted that neither in the steam chamber nor in the condensing chamber were there present conditions such as would promote galvanic action between the iron of the apparatus and the tubes, or between the tubes themselves, nor after the experiment was any such action to be perceived. At, and a little above, the water level in the condensing chamber, the tubes suffered severely, but below and above that point there was scarcely any corrosion. Again, in the steam chamber the surfaces, especially of the cold-drawn tubes, were scarcely affected. There were no disks or rods in any of these tubes. The conditions necessary to promote galvanic action inside the tubes were also absent, except perhaps in set 2, which contained salt water. The other three sets contained fresh water. In set 2, galvanic action could only take place between the iron plugs and the bottom ends of the tubes, but there were no signs of such action. If, as Dr. Siemens remarked, the common iron alone was compared with the Bessemer steel tubes, the difference was nearly 200, not 300, per cent. in favour of the iron; but in Table II. the losses in all the tubes were given, and in Table III. the losses

in ten samples of each metal, under precisely similar conditions. In calculating the percentages resulting from them, he had given the true results. The tube apparatus had been designed by him at the suggestion of the Chairman of the Boiler Committee, Admiral C. Murray Aynsley, for testing tubes of various kinds of metals. Mr. Farquharson had nothing to do with it, and his remarks as to magnetic oxide showed that he did not understand the conditions under which the tubes had been tested. Mr. Phillips.

Mr. Phillips could not understand Dr. Siemens when he said "there were substances, compounds of iron, manganese, and silicon, sold for steel, which no doubt corroded very rapidly." The metal apparently referred to by Dr. Siemens was made by the Bolton Steel and Iron Company, on the Bessemer principle, and was considered by most practical men to be as good, in every way, as Landore steel. The weighing of the specimens in the experiments had been carefully done, chiefly by Mr. Tookey, one of the members of the first Committee, and by Mr. Ireland, one of the members of the second Committee; every plate, disk, or tube having been separately weighed.

As regarded the effect of magnetic oxide on steel, Dr. Siemens did not make it clear whether iron suffered from its oxide in the same manner and proportion as steel was said to do, nor as to the conditions under which this action took place. From what Mr. Phillips had been able to gather in this direction, the oxide could only affect a metal to which it was partially attached in salt water at ordinary temperatures, its effect in cold fresh water, and in fresh and sea water of high temperatures, such as in marine boilers, being absolutely nil. Further, every practical engineer knew only too well that this magnetic oxide in a marine boiler, especially below the level of the water, soon disappeared, much sooner, indeed, than could be wished. With the exception of the small plates, and the welded tubes, all the specimens in the experiments were effectually freed of their oxides, either by planing, filing, or grinding, so that the remarks of some of the speakers as to the black oxide were hardly to the point. According to Dr. Siemens the fact, if fact it were, that black oxide materially assisted the corrosion of steel, was a recent discovery of Mr. Barnaby, or of one of his staff, but not in connection with the working of marine boilers. Professor Williamson had, however, pointed it out to the Committee in 1874. It might prove of value to shipowners and builders, but if not it would not want companions in the limbo of neglected discoveries. The first volume issued by the Boiler Committee was full of theories as to

Mr. Phillips. galvanic action, which, with the better knowledge now existing of the working of boilers, were considered unworthy of serious consideration.

The remarks of Mr. Traill and Mr. Martell contained nothing new and nothing to comment upon, except perhaps the instance of extraordinary corrosion mentioned by the latter. Mr. Martell attributed this, as many others would do, to galvanic action between the iron rivets and the steel plates. Had the action taken place below the light water-mark, there would be some reason for attributing it to galvanic action, but in his opinion had the rivets been of the same material as the plates, a similar corrosion would have taken place. Mr. Martell had remarked, in May, 1879, "that it was not uncommon to find soft iron rivet points in iron ships somewhat pitted or worn within the surface, but the converse action of the plate wearing round the rivets was peculiar." This seemed to confirm Mr. Martell's view that the softer or purer metals did not resist corrosion so well as the harder sorts, though the action would, in such cases, be assisted by a sort of breathing or springing of the plates in a line with the rivets, especially if the plates were thinner than they would have been if of iron, by which, and friction, the paint was soon removed. Mr. Martell had no doubt often seen the sides of iron ships corroded similarly, though not to such a serious extent, after a long voyage in the tropics; he had himself seen many, amongst others two old iron hulks in Bombay harbour, completely riddled a little above the water line from the effect now of air, now of salt water, and want of attention. According, however, to the experience of Messrs. Martell, Barnaby, and Donaldson, deterioration went on in steel hulls which never occurred in iron hulls. In one case this was attributed to galvanic action between the iron rivets and the steel plates; in the other two cases to galvanic action between the steel plates and their oxides. Mr. Barnaby got over the difficulty by removing the magnetic oxide by pickling the plates, and Mr. Donaldson by galvanizing them with zinc. Why should this be necessary with steel hulls, and not with iron hulls? Practical men, he thought, would pause before they adopted either plan, and would consider how it was that the oxide on iron plates did not produce the same effect as that on steel plates.

It had been mentioned by Mr. Barnaby, not for the first time, that the results of some experiments carried out by the Admiralty contradicted those given in the Paper. In Paris, in 1878, Mr. Barnaby said that the Admiralty "had made some ex-

periments extending over four years, and although at first the pieces of steel suffered more loss than the pieces of iron, when they were put unpainted on the bottom of the ship in salt water, as time went on they discovered that the loss did not continue, and that so far as these experiments went steel was at least as good, and it appeared to him to be better, than iron."[1] In London, in 1879, he said "in the matter of oxidation in salt water, we have found by a series of trials, extending over about three and a half years, that the rate of oxidation of three plates of iron of the same brand, differed more among themselves than they differed from steel; that when the surfaces of steel plates are carefully freed from the black oxide produced in the rolls by a wash of weak acid or otherwise, the surface corrosion in salt water is very uniform; that when the surface oxide is left on, the effect of the oxide on the neighbouring bared metal is as strong and continuous as copper would be."[2] Now he was curious to know what experiments Mr. Barnaby referred to. Experiments had been made by the Admiralty with iron and steel plates at Portsmouth and at Devonport between 1874 and 1877, to test their comparative durability in sea water and in bilge water. The specimens tested and the results obtained came under the notice of Admiral Aynsley, Mr. Tookey, and himself; they ascertained that the steel plates tried at Portsmouth lost 80 ozs. 341 grains, and the iron plates 61 ozs. 52 grains, or 24 per cent. less. In the experiment at Devonport, which lasted a much shorter time than that at Portsmouth, the steel plates lost 43½ ozs., the iron plates 26½ ozs., or 64 per cent. in favour of the iron. The dockyard officers reported that the corrosion in the steel plates was more severe and irregular than in the iron. Surely these experiments were not those to which Mr. Barnaby alluded. In a letter addressed to the Controller of the Navy, dated the 6th of June, 1877, the Committee pointed out the confirmation the results obtained at Portsmouth gave to their own conclusions. He would ask, too, why these results, and those of other experiments since carried out by the Constructor's Department had not been made known? In such an important question the Mercantile Marine was as much interested as the Admiralty.

Mr. Phillips.

Some time had been devoted by Sir Henry Bessemer to show the different conditions to which plates suspended in boilers, and boilers themselves, were subjected. That was hardly necessary.

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[1] *Vide* The Journal of the Iron and Steel Institute, 1878, p. 429.

[2] *Vide Ibid.*, 1879, p. 53.

Mr. Phillips. One of the objects of the Committee's experiments was to ascertain the comparative endurance, as regarded corrosion, of different metals when under similar conditions, and this object they had attained. Sir Henry Bessemer had quoted Messrs. Richardson and Adamson, and it was always interesting to hear the experience of such practical men. But these gentlemen had to deal with land boilers, worked with water comparatively harmless to the materials of which they were composed. Mr. Adamson had been principally concerned with the construction of boilers; and he would ask why the results of the experience of these gentlemen, or of others, with iron boilers and steel marine boilers, had not been given? Mention had also been made by Sir Henry Bessemer of some steel boilers at Oldham, which had lasted twenty-two years, and which were now said to show no signs of corrosion, though this last remark could hardly have been seriously meant, and he opined that had these boilers been made twenty-two years ago of Staffordshire iron they would now have been in a very dilapidated condition. When the Boiler Committee visited Oldham in November, 1874, Mr. Richardson was engaged in removing and resetting iron boilers which had already done duty for more than eighteen years, and which were, he had been told, still at work. The shells of these boilers were, as usual, of ordinary iron. Again at Wigan, in 1875, he had seen some iron boilers which were more than thirty-one years old, working at pressures of from 60 lbs. to 70 lbs. to the square inch, the front ends of the flues only, over the fires, having been renewed; these, he was informed, were still at work. The following was a copy of a letter, dated 7th April, 1881, which he had received from Mr. Mason, Superintendent Engineer of the Furness Railways:—"Dear Sir—Replying to your favour of yesterday's date, the boiler of 'Firefly,' paddle steamer, Lake Windermere, was put in in 1848, that of the 'Dragonfly' in 1850; both were broken up last year. Plates (internally) good, having the bloom still on them. Boilers of 'Walney' were put in in 1868, taken out in 1878. Steel boiler completely done. Iron boiler might have lasted three or four years longer with care.—Yours, &c., R. Mason." This vessel had since been fitted with two iron boilers. In 1876 he brought with him from one of the boilers on Lake Windermere a piece of iron tube which had been in use rather more than eighteen years. On the water-side of the tubes, furnaces, &c., there was very little corrosion, but the surfaces exposed to the action of fire, sulphur and the atmosphere, had suffered a great deal, especially round the lower part of the fronts. Here were

cases of iron boilers lasting over thirty years on board steamers, as well as on land. Mr. Phillips.

It had been remarked by Mr. Ravenhill that if steel wasted as quickly as the specimens in set 100, "there ought now to be little of the original steel left" of the Dover boats. These boats made runs of about one hour and three-quarters' duration, allowing of their sides being examined and painted daily, if necessary, whilst the set of plates (100) were under a very severe test, and not protected—not even by their oxides; both sides of the experimental plates were wetted daily and exposed to the weather, and it was only to be supposed that they would suffer more from corrosion than plates in ships' sides painted and taken care of. He could not admit that the report received by Mr. Ravenhill from Captain Dent gave such evidence as was desirable in these matters. Indeed, he had heard that the steel boilers in the "Duke of Sutherland," one of the Holyhead boats, had suffered more than the iron boilers.

With regard to Mr. Matheson's remarks, if iron and steel were kept dry, or well looked after and painted, they would suffer but little, if any, corrosion; also with care the magnetic oxide would remain attached to the surfaces of iron structures, under ordinary conditions, for years, and would while it remained, effectually retard corrosion.

In reply to Professor Abel he contended that the results of the experiments he had described confirmed his conclusions. If the method of giving averages were unfair, the gross results would still uphold this view. He would refer any one desiring fuller information concerning the ocean plate and tube experiments, and the experiments in the tugs, &c., to the Blue Book just issued by the second Admiralty Boiler Committee (Appendices P, Q, and R). Professor Abel went on to say that since there was more carbon and manganese in steel than in iron, these elements should afford steel greater protection than iron. Carbon undoubtedly did so, but the part manganese played in this respect was doubtful, probably the reverse; taking, however, all the so-called impurities in iron and steel together, there was a greater sum total of foreign matter in common iron than in mild steel, and these foreign impurities or ingredients might be the cause of common iron corroding less than mild steel. Professor Abel said that he stated this as a fact; that was not so; he stated as a fact that the metals which contained most impurities, especially those containing the most phosphorus, resisted corrosion better than the more refined sorts. More than one scientific man supported

Mr. Phillips. the views he had advanced as to the class of metal which suffered most from corrosion; and Dr. Frankland held the same opinion as himself regarding galvanic action in boilers. He would refer to the summary of the evidence given before the Boiler Committee in 1874, by such authorities as the late Dr. Letheby,[1] Dr. A. W. Williamson,[2] Dr. E. Frankland,[3] Dr. J. Percy,[4] Mr. G. J. Snelus,[5] and Mr. W. Weston,[6] and from speeches made at the meetings of the Iron and Steel Institute in 1878–9, by Mr. I. Lowthian Bell,[7] Dr. Siemens,[8] and Mr. E. Riley,[9] and it would be seen what different conclusions such gentlemen came to. He regretted that Professor Abel should have confined his remarks to criticism without endeavouring to throw any light on the subject of the Paper.

Two of the experiments described by Mr. Phillips showed only 5 and 10 per cent. in favour of the iron, and this it was said was not "proof incontestable," that iron was superior to steel as regarded corrosion. If even these percentages were added to the 13, 20, or 25 per cent. reduction in the sectional area of steel plates and scantlings in ships or boilers accepted by the Board of Trade and by Lloyd's, which matter had been conveniently forgotten in the discussion, or if the corrosion were assumed to be equal in the metals, the result would be, if not fatal, very damaging for steel.

The greatest care was taken that the specimens in each experiment should be exposed to exactly the same treatment. With regard to the ocean-plate experiments, when fifty-six sets of test plates had been subjected to the various sorts of treatment of boilers now in practice, and furnished a percentage of 21·3 in favour of the irons over the mild steels, it was not only fair, but reasonable, to infer that iron on the whole withstood the corrosive effects of those treatments better than steel. That the treatment of boilers might be so modified as to alter this state of things he had already suggested, and indeed had often put practically to the proof.

In reply to Mr. Samson's queries regarding the results of the experiments given in Table IX., the greater corrosion in sets 98 and 100 during the first period of their trial than in the second period, was due in his opinion to the weather in the summer of

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[1] *Vide* Minutes of Evidence, p. 554. [2] *Ibid.*, p. 559. [3] *Ibid.*, p. 564.
[4] *Ibid.*, p. 640. [5] *Ibid.*, p. 630. [6] *Ibid.*, p. 144.
[7] *Vide* The Journal of the Iron and Steel Institute, 1878, p. 446.
[8] *Ibid.*, p. 457. [9] *Ibid.*, 1879, p. 106.

1879 being so much more changeable than in 1880. Mr. Samson had furnished the reply he should have given as to the greater corrosion in set 98 than in set 102, viz., that the vessel containing set 98 was much larger than that containing set 102, and that the water in it was constantly changed. The tank and boiler containing the crucible steel were small, and the water in the boiler was kept at a temperature of from 120° to 212° during about thirteen hours daily, which would account for the difference in the corrosion in the three plates. Mr. Phillips

It had been calculated by Mr. Samson from some of the experiments described in the Paper, that it would take two hundred years to corrode boilers entirely away; several cases were mentioned in the Blue Book in the ocean-plate experiments, when a $\frac{3}{8}$-inch plate would be entirely gone in from two and a half to five years, while other plates would last more than thirty years, both sides of the plates being exposed to the water in the boilers. In other instances extraordinary differences would be found as regarded the amount of corrosion sustained by one metal compared with others of the same set, besides those given in the Paper. In set 24 the loss of the steels was more than twice that of the irons; in set 32 more than half as much again; in set 33 the loss of the Landore steel was more than twice that of the Bolton steel; in set 66 the steels lost nearly three times, and the Lowmoor iron nearly twice as much as the Staffordshire iron.

He had been informed that the experiments carried out and concluded some time ago by Mr. Parker, Chief Engineer Surveyor to Lloyd's, confirmed the results given in the Paper, the percentage in favour of the irons, taking all the results, being over 19, and in favour of the rough over the bright specimens 12. It was to be regretted that the conditions and results of these experiments in detail were not made known to those interested immediately they were obtained.

In conclusion he would ask why it was that iron tubes had been nearly always substituted for steel tubes in steel boilers, and why iron tubes were now put into almost every boiler, even though made otherwise of steel? Why the Admiralty should now be going back (as stated by Mr. Barnaby) to the use of iron furnaces and combustion chambers, whilst making boiler shells of steel? And why composite boilers of iron and steel should be made at all, especially by the Admiralty, after Mr. Farquharson's discovery as to the effect of magnetic oxide on steel, and the galvanic action which was asserted to be set up between iron and steel? Neither Mr. Farquharson nor Dr. Siemens threw light on the effect, if any,

Mr. Phillips. of this oxide on iron, nor as to the action between iron and steel, nor between these metals and their oxides at high temperatures in marine boilers. If Mr. Farquharson's discovery, or the theories of galvanic action were to be relied on, there would by this time have been very little steel left in the composite boilers made by the Admiralty, and mentioned in the Paper. He believed that when the question as to the effect of magnetic oxide had been more practically considered, it would be found that the local corrosion was not due in iron or steel to galvanic action, but to other causes, frequently to perfect protection being afforded, for a time, to parts of the surface by the now much abused oxide, the adjoining parts being unprotected, or to want of homogeneity, or uniformity in composition, or both. When portions of surface were so protected as to be comparatively unaffected, the difference between them and the adjoining affected parts was most pointed, and to unpractised eyes very deceptive. Some of the longest-lived marine boilers had either brass tubes or back copper tube plates, or both.

Correspondence.

Mr. Adams. Mr. W. A. ADAMS had been a strong advocate for the use of ingot iron, especially when compressed by the Whitworth process, for gun barrels, and one of the advantages put forward by him had been the comparative freedom from oxidisation as compared with Damascus and other iron barrels. Shooting on a wet day this had been most marked, the iron barrels becoming hourly red with rust, and the steel showing little difference.

Mr. Mace. Mr. C. MACE observed that formerly he had experienced much trouble from the pitting and corroding of iron boilers. In 1878 he applied zinc plates, after the manner of the Author's patent, and from that time to the present he had had no trouble in that respect. Zinc had been applied to the boilers of twenty-one steamers under his charge, and had in every case given satisfaction.

Mr. Macnaughtan. Mr. P. MACNAUGHTAN stated that, during the last two years, several ships belonging to the British India Steam Navigation Company had been fitted with boilers, the shells and tubes of which were of iron, and the furnaces and tube plates of steel, manufactured by the Steel Company of Scotland. These vessels were employed in India. The reports which he had from time to time received regarding the steel furnaces, &c., were very satisfactory; no corrosion had been observed upon them, and the absence of blister-