The Relative Corrosion of Iron and Steel under various Conditions.

INTRODUCTORY.

In 1881 I had the honour of reading to the Institution of Civil Engineers a Paper* " On the Comparative Endurance of Iron & Mild Steel when Exposed to Corrosive Influences," which was based upon the results of the Investigations of the First Admiralty Boiler Committee, and of experiments which I had myself carried on after the dissolution of that Committee. These results proved, as I contended, that iron withstands corrosion far better than steel, and the commoner irons better than the superior brands; but the discussion which followed showed that there was little disposition to accept such a conclusion.

With this discussion I fully dealt in my reply. To deal here with all the papers that have since been read on the same and kindred subjects,† would be out of the question, but reference to one of them cannot be omitted. A Paper entitled " The Relative Corrosion of Iron and Steel," by Mr. Parker, then Chief Engineer Surveyor of Lloyd's Register, read,‡ soon after mine, before the Iron and Steel Institute, appears to have been regarded as a complete refutation of all that I had said. In the discussion which followed, Sir F. Abel, Mr. White, of the Admiralty, Sir Henry Bessemer, Mr. Martell, of Lloyd's Register, Mr. Snelus, and others, expressed great satisfaction at the contrast which it presented to mine. To those who accepted Mr. Parker's

* Minutes of Proceedings of the Institution of Civil Engineers, Vol. lxv., p. 73.

† The following may be mentioned (in addition to Mr. Parker's) "On the Corrosive effect of Steel on Iron in Salt water," by Mr. Farquharson, read at a meeting of the Institution of Naval Architects, in 1882; "A Brief Review of the Progress of Mild Steel," by Mr. Martell, at the same Institution, in 1886; and "On the Corrosion and Protection of Iron and Steel Ships," by Mr. Vivian Lewes, read also at the same Institution, in 1887.

‡ Journal of the Iron and Steel Institute, 1881, p. 39.

conclusions without criticism, there was no doubt a great contrast but as I contend the contrast between that gentleman's conclusions and the results of his experiments is equally great. To the proof of this contention a little time may be profitably devoted.

Mr. Parker's conclusions may be stated in his own words. In his concluding remarks he says:—"It would perhaps not be far wrong, speaking generally, to say that the different pieces of iron differed as much among themselves as they did from the steel; and certainly the effect produced on my mind, after carefully weighing the results of the experiments, has not been to raise any apprehension that steel boilers or steel ships are likely in the future to corrode to any serious extent more rapidly than iron."* The effect produced upon my own mind was somewhat different.

Three of Mr. Parker's sets of bright discs were suspended in sea-going boilers, and are thus comparable with the fifty-six sets of plates suspended in sea-going boilers at the recommendation of the First Boiler Committee, the losses of which are given in Table VIII. of my Paper of 1881.†

The Committee's experiments gave the following percentages in favour of the irons:—

Common Iron over Yorkshire Iron	..	9·6
,, ,, Mild Steels ..	..	27·1
Yorkshire Iron ,, ,, ..	..	16·0
Both Irons ,, ,, ..	..	21·3

Mr. Parker's experiments gave the following much larger percentages in favour of the irons:—

Common Iron over Yorkshire Iron	..	13·9
,, ,, Mild Steels ..	..	43·6
Yorkshire Iron ,, ,, ..	..	26·0
Both Irons ,, ,, ..	..	30·4

that is to say, nearly 50 per cent. more than in the Committee's experiments.

In the case of one of his sets (viz., the D set) Mr. Parker admits that the steels lost 50 per cent. more than the Lowmoor Iron, and the Lowmoor Iron 50 per cent. more than the Bowling

* Journal of the Iron and Steel Institute, 1881, p. 53.

† Minutes of Proceedings of the Institution of Civil Engineers, Vol. LXV., p. 82.

Iron, or 40 per cent. more than the average of the other irons. The figures may be put otherwise thus—the steels lost 98 per cent. more than the average of *all* the irons, and 115 per cent. more than the common irons; and then it might be asked if to these percentages had been added the reductions (varying from 12 to 25 per cent.) allowed at the time by Lloyd's Register and the Board of Trade in the scantlings of steel boilers, what would have become of the steel?

Mr. Parker's remaining three sets of plates were exposed to cold sea water, to bilge water, and to the atmosphere respectively. The steels came out best of all in the bilge water, where they lost slightly less than the Yorkshire irons, but the percentage in their favour in this case was less than ·6, whilst they lost nearly 8 per cent. more than the common irons. From these percentages Mr. Parker concludes that "it is safe to assume that bright steel exposed to the sea and bilge water corrodes no faster than iron."

Finally the set exposed to the weather gave the following percentages in favour of the irons:—

Common Irons over Yorkshire Irons	..	5·2
" " Mild Steels	..	46·4
Yorkshire Irons " "	..	39·0
Both Irons " "	..	40·8

Now if, from the percentage of ·6 in favour of the steels over the Yorkshire irons in bilge water, it was safe to assume that steel corrodes no faster than iron, one would have thought that from a percentage of 40 and over in favour of the irons in the atmosphere, it would have been much safer to assume that steel corrodes much faster than iron when exposed to the weather. But apparently this was not the effect produced upon Mr. Parker's mind, as the only remark he makes in regard to this set of discs is that, "the steel *appears* to have lost considerably more than either the Lowmoor or any other iron."

Encouraged therefore by Mr. Parker's Paper and feeling satisfied, in spite of the reception my own had met with, that the results enumerated therein were correct and the views based upon them not far from the truth, I determined to institute further experiments in order to elucidate the points at issue. With these experiments this Paper will principally deal, and it will be convenient to divide it into as many parts as there were series of experiments.

The first part will deal with the series commenced eleven years ago—in 1879—of which the particulars and the results for two years were given in Table IX. of my former Paper,* and the second and third parts will give the particulars and results of two other series, which lasted from 1881 to 1888, and from 1886 to 1889 respectively.

The same letters will be used as brief names for the metals, as were used by the First Boiler Committee, viz.:—

J for the Crucible Steel.
N „ Bessemer Steel.
Y „ Siemens Steel.
D „ Yorkshire Iron.
B „ Staffordshire Iron.

PART I.

In my paper of 1881 was described a series of experiments, upon which I had been engaged since the dissolution of the First Admiralty Boiler Committee, and which had for their object, amongst others, the testing of the comparative durability of iron and steel when exposed to various conditions. Two of the five sets of plates experimented upon, viz., Nos. 99 and 102, have, unfortunately, been lost; bnt the remaining three sets, viz., Nos. 98, 100, and 101 have been kept exposed, with the few days interval necessary for cleaning and weighing, to the same conditions as before, and have thus been under test for 10 years all but 21 days, in the case of sets Nos. 98 and 100, and for 9 years all but 21 days in the case of set No. 101.

Each of these three sets consisted of five best boiler plates, viz., one of Firth's crucible (J), one of Bessemer (N), and one of Siemens steel (Y), one of Yorkshire (D), and one of Staffordshire iron (B), all bright. Each plate was 4in. by 4in. by $\frac{3}{8}$in. thick.

No. 98 set was suspended, as shown in Figure 1, in rain water in a butt supplied from the roof and standing in the open. Of No. 100 set, the Bessemer steel and Staffordshire iron were dipped in sea water daily, and for the rest of the time exposed to the weather, whilst the Siemens steel and Yorkshire iron were exposed to the weather only. Of No. 101 set, on the other hand, the Bessemer steel and Staffordshire iron were dipped in fresh water daily, and for the rest of the time exposed to the weather, whilst

* Minutes of Proceedings of the Institution of Civil Engineers, Vol. LXV., p. 84.

the Siemens steel and Yorkshire iron were, together with the crucible steel, suspended in a small tank feeding a boiler in the kitchen, and supplied by hand with water from the butt. The crucible steel, of No. 100 set, was suspended by itself in the boiler, in which, during the day, the temperature often rose to boiling point. The chief, and probably the only, difference between the conditions to which the three crucible steels were exposed, was thus one of temperature.

The mode of suspension of sets Nos. 100 and 101 is shown in Figures 2 and 3. The plates immersed in water were suspended on glass rods, separated from one another by glass ferrules, the remainder on wooden rods.

The plates were cleaned for weighing after the first and again after the second year, but afterwards only at the end of the several periods specified in Table I. This may, to some extent, account for the greater proportionate loss of weight during the first two years, though it is to be observed that the loss in the first year was much greater than in the second year.

On the plates dipped in sea water and on those dipped in fresh water daily, but especially on the former, the crust formed by corrosion blistered in places and portions of it fell off, thus rendering it advisable to remove the crust altogether. These plates were therefore, in addition to the cleaning referred to above, scaled—not thoroughly cleaned—every year; and in order that all the plates exposed to atmospheric influences might be treated alike, the plates exposed to the weather only were also scaled annually.

The results are given in Table I., and photographs of the plates taken after test are appended.

TABLE I.

No. of Set.	Letter marked with and kind of metal.	Kind of surface before testing	Condition exposed to, &c.	Area of exposed surface. Before testing.	After testing.	Loss of Weight during 1st period of 730 days.	2nd period of 1063 days.	3rd period of 1049 days.	4th period of 744 days.	Whole time of 3631 days.	Average loss per square foot of exposed surface per annum. 1st period of 730 days.	2nd period of 1063 days.	3rd period of 1049 days.	4th period of 744 days.	Whole time of 3631 days.
				oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.
98	J Crucible Steel ..	Bright all over	Immersed in rain water.	37·9	37·1	·787	·758	·776	·479	2·800	1·497	·999	1·002	·912	1·084
	N Bessemer ,, ..				37·1	·750	·769	·810	·540	2·870	1·425	1·014	1·046	1·028	1·110
	Y Siemens ,, ..				37·9	·734	·682	·709	·435	2·560	1·394	·900	·916	·828	·991
	D Yorkshire Iron .				37·2	·734	·687	·712	·433	2·566	1·395	·905	·917	·822	·988
	B Staffordshire ,,				37·2	·649	·625	·642	·390	2·305	1·235	·819	·827	·742	·887
100	N Bessemer Steel ..	Bright all over	The weather, and dipped in sea water daily.	37·9	32·5	3·533	6·045	5·514	3·638	18·730	6·713	8·639	7·861	7·908	7·770
	B Staffordshire Iron				35·9	1·547	2·501	2·723	1·776	8·547	2·940	3·360	3·613	3·476	3·371
	Y Siemens Steel ..		The weather only.		37·2	·846	·999	·940	·591	3·376	1·608	1·329	1·211	1·119	1·306
	D Yorkshire Iron ..				37·1	·458	·679	·708	·432	2·277	·870	·897	·912	·821	·889
† 101	N Bessemer Steel ..	Bright all over	The weather, and dipped in fresh water daily.	37·9	34·5	·521	2·784	3·065	2·006	8·376	1·980	3·751	4·183	4·107	3·754
	B Staffordshire Iron				36·8	·193	·694	·902	·564	2·353	·734	·915	1·177	1·082	1·021
	Y Siemens Steel ..		Immersed in rain water, kitchen tank		37·1	·308	·729	1·006	·462	2·505	1·169	·961	1·296	·879	1·083
	D Yorkshire Iron ..				37·2	·286	·699	·766	·473	2·224	1·088	·920	·984	·899	·957
	*J Crucible Steel ..				37·1	·654	·570	·990	·623	2·837	1·242	·753	1·279	1·186	1·092
98	J Crucible Steel ..	Bright all over	Rain water in butt	37·9	37·1	·788	·758	·776	·479	2·800	1·497	·999	1·002	·912	1·084
100	J ,, ,, ..		,, water in boiler		37·2	·517	·427	·716	·440	2·100	·984	·561	·834	·832	·811
101	*J ,, ,, ..		,, in kitchen tank		37·1	·654	·570	·990	·623	2·837	1·242	·753	1·279	1·186	1·092

* In Table XI. of former Paper as Number 99, and is marked 99. Minutes of Proceedings of the Institution of Civil Engineers, Vol. lxv., p. 84.
† Set 101 was under test 365 days less than the rest, except the J.

In the appearance, after testing, of the plates immersed in rain water in the open (set 98) there was nothing striking to notice. The edges of the irons, especially the upper edges, are scored with minute grooves, contrasting unfavourably in this respect with the steels, which however are not entirely free from this action.

Of the steels in this set, the crucible is the most evenly and the Bessemer the most unevenly affected, whilst as regards loss of weight, the difference is trifling; but between the Siemens and the Bessemer there is a difference of 12 per cent. in favour of the former. Turning to the irons, it will be seen that between the Yorkshire iron and the Siemens steel there is practically no difference; but that between the Staffordshire iron and the Siemens steel there is a difference of 11·7 per cent.; and between the Staffordshire iron and the Bessemer steel a difference of 25 per cent. in favour of the iron.

Turning to the two plates of No. 100 set which were exposed to the weather only, there is found to be a much higher percentage in favour of the iron, the Siemens steel losing nearly 47 per cent. more than the Yorkshire iron, whilst of the two plates dipped in sea water daily and for the rest of the time exposed to the weather, the percentage in favour of the Staffordshire iron over the Bessemer steel reaches over 127 per cent. At the rates at which the latter plates have wasted, it would take 23 years more for the iron and only 4½ years more for the steel to disappear altogether, although the iron was laminated on both sides.

The Bessemer steel and Staffordshire iron of No. 100 set, were dipped in fresh water daily and for the rest of the time exposed to the weather; and here the difference in favour of the iron is much greater, amounting to 276 per cent., whilst in appearance also the iron is a long way to the good, being wonderfully well preserved. On the other hand, the steel is very unevenly affected, and shows want of uniformity in its composition right across the plate about two-thirds down, where the action is much more severe than in the immediate vicinity.

It should be mentioned here, that all the plates exposed to atmospheric influences (viz., N, B, Y, and D 100, and N and B 101) suffered considerably more along the lower than along the upper edges, in consequence, no doubt, of the longer period during which the lower parts were exposed to moisture, whilst the plates were drying after rain, or after being dipped in water. The remaining plates of set 101, viz , the Siemens and crucible steels and Yorkshire iron were suspended in the kitchen tank, and the same remarks that were made regarding No. 98 set, suspended in the water-butt, apply to these, with the addition that the Siemens steel had suffered more and the Yorkshire iron less in the tank than in the butt, the difference in favour of the iron in the tank being 13 per cent.

The appearance and loss of weight of the third crucible steel (J 100) suspended by itself in the boiler, would seem to indicate that the plate had not always been completely immersed, as it has suffered in a most extraordinary way along the bottom, the corrosion gradually diminishing to almost nothing at about one third the distance up, and also—to a less degree—along the top and for about one-third of the distance down, whilst the middle parts are only slightly affected.

Looking at the results generally it appears that the irons, although not of the commoner class, have, in every case withstood the tests better than the steels; that where the conditions were not of a trying nature the differences were slight; but that where the tests were severe the superiority of the iron in withstanding corrosion was incontestably demonstrated, as in the cases of the plates dipped in salt and those dipped in fresh water daily, and exposed for the rest of the time to the atmosphere. Such conditions are not however of the severest type met with in ordinary practice. High temperatures and the intermittent wetting of surfaces which constantly occur in the Stokeholds, Engine-rooms, &c. of ships, coupled with the unavoidable want of care, and neglect to thoroughly clean and paint them periodically, would be, and actually are, attended by greater mischief.

PART II.

The second series of experiments was commenced in 1881 and lasted until the end of 1888, a period of over seven years. It will probably be considered of greater value than the first, as the plates tested were larger and the objects in view more comprehensive. These were (1) to ascertain the comparative endurance of iron and mild steel when exposed to the ordinary action of the sea; (2) to ascertain whether the mill scale left upon iron, or steel, has any injurious effect upon bare surfaces in its proximity; and (3) to ascertain whether iron and steel act upon each other injuriously when connected *galvanically*, as it is termed, and immersed in sea water.

The test plates were six in number, two of Bessemer boiler steel, two of Yorkshire, and two of B B Staffordshire boiler iron. Each was as nearly as possible 6in. by 6in. by $\frac{3}{8}$ in. thick. One of each sort of metal was bright all over, whilst the others were bright on one side and the edges only, with as much of the mill scale as possible left on the rough side; and, in order to compare the action going on on the bared rough surface near the mill scale, with the action on bared surface in the proximity of paint such as is ordinarily used for protective purposes, half of each of the bright sides of these partially rough plates was protected with paint laid on in streaks as shown in Fig 4.

The area protected by scale was unfortunately small, especially in the steel, but it was sufficient to test the point in view.

The plates were secured on an iron bolt which was wrapped round with cloth and consequently insulated. They were separated from each other and from the nuts at either end by ferrules $1\frac{1}{4}$in. long, all being tightly screwed up by means of the nuts as shown in Fig 4.

During the first three years the ferrules were of iron and the plates thus constituted what is called a "galvanic group;" but during the second three years the ferrules were of bamboo cane and the plates thus insulated. At the end of this period, as I had started another set of experiments to further test the question of galvanic action, the iron ferrules were replaced and remained till the conclusion of the experiment; thus enabling comparison to be made between the results of the first three years and those of the last year.

Thus secured on the bolt the plates were suspended in Cardigan Bay in a covered culvert, of which diagrams are given in Fig. 5, and of which the following is a brief description:—

On the slope between high and low water marks, on this part of the Welsh coast, are built a number of fish traps, called "Goryds," consisting of stone walls, something like a quadrant in plan, with their ends from 500yds. to 700yds. apart, their convexity being towards the sea and their height at the deepest point about 6ft. These "Goryds" are provided with culverts to let the water run out on the ebb and in on the flow of the tide, and the culverts are fitted with gratings to prevent the escape of the fish.

In one of these culverts, situated at about neap tide low water mark, the plates were suspended. Two difficulties, however, at once presented themselves, viz.: to ensure the plates being always covered with running water and to keep the culvert clear of gravel and sand without opening it, a very laborious operation. Both objects were attained by concreting the seaward side of the wall, and by fitting to each end of the culvert a portable grating and a sluice. By means of the outer sluice the water, which even at lowest ebb tide was more or less running in consequence of the numerous pools to landwards, was always kept at a height of not less than 1½in. above the plates; whilst by means of the inner sluice it could, when occasion required it, be dammed in at the ebb of the tide, and then, as soon as the tide had receded a little below the level of the bottom of the culvert, both sluices were removed and the water allowed to rush through, thus most effectually scouring it. This operation was performed about every six weeks in fine and oftener in boisterous weather, and was found to answer its purpose so well that it was only necessary to open the culvert when the plates were to be removed and replaced. Between the bottom of the inner grating and the bottom of the outer sluice there was a difference in level of about 14in., equivalent to a fall of 1½in. to the foot in the culvert.

The plates were taken up in the May and October of every year, when they were carefully cleaned and the portions of the partially black plates, which are coloured red in the Figure, repainted with, as a rule, eight coats. At the same time the area of mill scale remaining was ascertained as accurately as possible. On the iron plates the scale was exceedingly thin and it was, consequently, difficult to trace its boundary; but in the case of the steel plates, as will be seen by the casts, there was no such difficulty, as the scale was of more than ordinary thickness, and, excepting that it was in two distinct layers (a singular phenomenon), very compact.

The positions of the plates on the bolt were changed every time they were taken out, those on the wings being shifted to the centre, whilst those in the centre took the place of those on the wings, &c.; and on replacement in the culvert the whole group was turned round. The plates may therefore be said to have been on equal terms in regard to currents, &c., all through.

The results are given in Tables II. and III., and photographs of the plates, taken after test, are appended.

TABLE II.

No. of plate.	Letter marked with and kind of metal.	Kind of surface before testing.	Area of exposed surface.* Before testing.	Area of exposed surface.* After testing.	Loss of Weight during:— 1st period of 388 days.	2nd period of 338 days.	3rd period of 337 days.	4th period of 333 days.	5th period of 337 days.	6th period of 339 days.	7th period of 369 days.	Loss per square foot of exposed surface* per annum during:— 1st period of 388 days.	2nd period of 338 days.	3rd period of 337 days.	4th period of 333 days.	5th period of 337 days.	6th period of 339 days.	7th period of 369 days.
			Square inches.	Square inches.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.
1	N Bessemer Steel	Bright all over	80·2	75·5	3·277	2·918	2·431	2·866	2·436	1·890	2·236	5·535	5·658	4·728	5·944	4·924	3·857	4·219
1	D Yorkshire Iron	Bright all over	81·4	78·8	1·547	1·161	1·348	·838	1·375	1·253	·894	2·659	2·291	2·668	1·722	2·791	2·540	1·671
1	B Staffordshire ,,	Bright all over	78·8	76·2	1·554	·897	1·101	·791	1·261	1·252	·799	2·586	1·714	2·108	1·578	2·487	2·458	1·444
2	N Bessemer Steel	Bright and partly protected by paint on one side, and rough and partly protected by scale on the other side.	47·6	54·1	1·807	1·868	1·691	1·689	1·831	1·519	1·854	5·014	5·845	5·253	5·269	5·577	4·443	4·880
2	D Yorkshire Iron	Bright and partly protected by paint on one side, and rough and partly protected by scale on the other side.	33·9	56·5	·689	·466	·687	·576	·920	·952	·791	2·872	2·060	2·594	1·639	2·575	2·734	2·039
2	B Staffordshire ,,	Bright and partly protected by paint on one side, and rough and partly protected by scale on the other side.	32·5	55·3	·737	·489	·705	·390	·852	1·033	·793	2·946	2·026	2·497	1·129	2·312	2·737	1·999

* By " exposed surface " is meant surface unprotected either by paint or mill scale, *i.e.*, bare metallic surface exposed to the action of the sea.

TABLE III.

No. of plate.	Letter marked with and kind of metal.	Loss of Weight during				Average loss per square foot of exposed surface * per annum during			
		1st 3 years of 1063 days.	2nd 3 years of 1009 days.	7th year of 369 days.	Whole time of 2441 days.	1st 3 years of 1063 days.	2nd 3 years of 1009 days.	7th year of 369 days.	Whole time of 2441 days.
		oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.
1	N Bessemer Steel	8·626	7·192	2·236	18·055	5·307	4·908	4·219	4·981
1	D Yorkshire Iron	4·056	3·466	·894	8·416	2·539	2·351	1·671	2·335
1	B Staffordshire Iron	3·552	3·304	·799	7·655	2·136	2·174	1·444	2·054
2	N Bessemer Steel	5·366	5·039	1·854	12·259	5·370	5·096	4·880	5·183
2	D Yorkshire Iron	1·842	2·448	·791	5·081	2·507	2·316	2·039	2·359
2	B Staffordshire Iron	1·930	2·275	·793	4·998	2·489	2·059	1·999	2·235

By "exposed surface" is meant surface unprotected either by paint or mill scale, *i.e.*, bare metallic surface exposed to the action of the sea.

Casts were taken of all the plates when new and after each year's immersion. On the table are those taken at the end of the first, third, fifth, and seventh years respectively; whilst those of the steels when new, and after the second, fourth, and sixth years are at hand and open to inspection. Too much space would have been required to exhibit the other casts of the irons, and that to very little purpose, the differences in their appearance annually being very trifling.

Examination of the casts of the steel plates and of the plates themselves will, at once, bring to notice the extraordinary uneveness which, during the first half of the fourth year, began to show itself about an inch from the lower edge on the stamped side of the bright plate N 1, and which became more and more marked every year succeeding. This and other patches in the steels were much more evenly and much less affected than other parts of their surface, and were also brighter after cleaning, as if they were harder or, from some other cause, less susceptible to corrosion, proving in a most conclusive manner, as I think, a want of uniformity in the composition of the metal.

In regard to the irons, there is little to be said beyond drawing attention to the dirtiness and very inferior quality, not perhaps in composition, but certainly in manufacture, of the Yorkshire samples (D. 1 & 2), as evidenced by the severe laminations, especially between the surface layers and those beneath them. This can be seen in the casts taken of the plates after the first year's test, which show that portions of the surface layers were missing. These portions were cut out before weighing, as a thin blade could be introduced between them and the next layer. Grooving in the edges, very common in iron, caused either by cinder or want of uniformity in the composition of the bloom from which the plates were made, also began to show itself at about the same time, and developed more and more every year. It will be admitted that, with all these defects, a worse piece of plate for the purpose of testing, with other metals, could not have been selected.

The Staffordshire plates (B 1 & 2) were certainly better in respect both to uniformity and soundness, as evidenced by the very trifling extent of grooving in the edges, but they were exceedingly dirty.

The partially black steel plate (N 2) appears to have suffered a little more than the irons from blistering of the paint during the first twelve months. This must have been due to something other than want of care, probably to inferior paint, as every plate was most carefully cleaned with benzoline on each occasion before the paint was applied to the allotted parts. Only a blunt knife and a file card were used to remove the paint and rust all through.

The casts of the rough side of the partially black steel plate (N 2), especially the one taken at the end of the sixth year, show, more distinctly than any of the others, that the mill scale was in two distinct layers, and that, after portions of the surface layer became detached, the bottom layer remained for a considerable time and afforded to the surface it covered equal protection. The cast last taken of this plate, and the plate itself, show how well the scale adhered to the metal, and how well, for nearly seven years in the sea, it served as a protection to the parts it covered, without any apparent detriment to the surface in its proximity. A few small spots of the scale still remain.

Adverting now briefly to the injurious effect alleged by some to be exercised by steel upon iron through galvanic action, there appears to be in the results of these experiments no indication of any such injurious action. It is true that during the first three years of contact the loss of weight was rather more in both metals, but only to a trifling extent, and this in itself is no proof. Where there is galvanic action between two metals, one of them is, as I understand, more or less preserved at the expense of the other, and therefore for the theory to hold good, the loss in the irons during contact should have been greater than during the period of insulation, and the loss of the steel less.

If on the other hand refuge be taken in the older and converse theory, that it is iron which acts galvanically on steel, and in support of this the slightly greater loss in the steel plates during the first three years of contact be adduced, the reply is: (1) that the difference is trivial, and (2) that during the last year when the plates were again in contact, the loss in the steels was less than during the second three years when they were insulated.

Moreover, there was in the appearance of the plates all through nothing to indicate galvanic action. The slightly increased action round the holes which was first observed in the steels during the third year when the plates were in contact, but which became more marked during the succeeding years of insulation, I believe to have been due to vibration and friction caused by the plates having become slack on the bolt during the second half of the third year. Where, through oxidation, a crust forms at the junction of two metals (even when those metals are precisely the same) and through vibration or other causes this crust is disturbed, greater action, as most practical men know, takes place on the newly exposed surface, and it is to some such cause as this that I attribute the slightly increased action above referred to.

Turning next to the question of mill scale, there seems to be little, if anything, which can be regarded as proof of the theory, with many an accepted fact, that the scale upon steel injuriously affects bare surface in its proximity. The loss of the partially black steel was, it is true, rather more than in the bright steel, but only to the extent of ·223 per cent. per square foot of exposed surface per annum, whilst there was nothing to indicate any difference between the action on the side partially covered with scale and the action on the side partially covered with paint. I would invite gentlemen interested in the subject to test the accuracy of my examination by inspecting the plate, and, in doing so, would call particular attention to the small patches of surface on the black side. These, although unprotected and surrounded by scale from the first, do not appear to have suffered one whit more than the bare surface remote from the scale. In the case of one of these patches—the narrow and nearly vertical strip running down from the upper edge on the left of the hole—an additional test was possible, as it could be compared with the surface at the lower edge to which from the first there had been no scale near. For, as the portions of surface on the other side of the plate opposite to these parts were protected by paint, it was possible by gauging the thickness of the plate at those parts, to ascertain where the action had been the more severe. As the result of careful gauging no difference in thickness could be discovered, or if any, to the advantage of the surface near the scale; the difference in appearance between the upper and lower parts being merely due to the contrast between protected and unprotected surfaces. It may, however, be remarked in passing that both in this and the bright steel plate, the lower parts showed a slightly smoother surface than the upper parts.

Finally the results show an extraordinary difference in behaviour between the steels and the irons, the loss of the steels being 120 per cent more for the first three years when the plates were in contact; 124 per cent more for the second three years when they were insulated; 154 per cent more for the last year when they were again in contact, and 126 per cent more for the whole period of seven years. No words can add to the force of these figures. If they do not go to prove in a most conclusive manner that iron withstands corrosion far better than steel, some very satisfactory explanation of them is surely called for.

PART III.

The Third Series of experiments is, as I think, more comprehensive and important than either of the others, though the plates were not so long under test as could have been wished.

The special objects in view were:

(1) To ascertain, as definitely as possible, the effects upon each other (if any) of iron and mild steel when attached in a manner similar to that in common practice, and immersed in the sea.

(2) To ascertain the effects, both upon the plates and upon the bolt heads, of attaching steel and iron plates together with steel and iron bolts, with the steel heads in the iron plate and the iron heads in the steel plate on the one hand, and with the steel heads in the steel plate and the iron heads in the iron plate on the other; and

(3) To ascertain the effects of scale upon iron and upon steel, but especially upon the latter, when attached to one another and when insulated.

In order to test these points, three steel (Y 1, 2, and 3) and three iron plates (B1, 2, and 3), were bolted together, with a 2in. lap, in couples, each couple consisting of a steel and an iron plate, and suspended, together with the plates comprising Series II., in the culvert before alluded to. The bolts were arranged as follows: in No. 1 couple, the steel heads were in the iron plate and the iron heads in the steel plate; conversely in the No. 2 couple, the steel heads were in the steel plate and the iron heads in the iron plate; and in No. 3 couple, the heads were as in the case of No. 1 couple. The intention was to put one iron and one steel head in each of the No. 1 plates, but an unfortunate error in marking the bolts, as indicated in Table V., prevented this being done. The bolt heads were countersunk, and all were meant to be flush with the surfaces of the plates, but only in Nos. 1 and 2 couples were they sufficiently well fitted for this to be the case; in No. 3 couple, the heads did not fill the countersinks, and the bolts therefore were not weighed. The mode of attachment was thus similar to that in common practice, with the exception that the plates instead of being riveted were, for convenience' sake, bolted together. . . . . . Whether they constituted what are termed *galvanic couples* I do not know, but that they were in metallic contact there can be no doubt, as the surfaces of the laps (and as a matter of course the edges) were bright, and the joints were carefully caulked and made water-tight.

In addition to the coupled plates, one iron (B 5) and one steel (Y 6), duplicates of those in the combined couples, were suspended separately and insulated, so as to enable comparison to be made between the combined and the uncombined plates; and to these, single plates of best Yorkshire iron (D 4) and Siemens furnace steel (Y 7) were added.

As in the former series, the plates were of a kind used in boilers and were consequently of somewhat superior and more ductile quality than those used in shipbuilding. The steels were manufactured by the Steel Company of Scotland, on the Siemens principle, and the iron plates were of B B Staffordshire, with the exception of D 4. The steel bolts were made from strips cut from the same plate as the experimental plates themselves, whilst the iron bolts were of ordinary rivet bar. The nuts were of iron and such as are in ordinary use.

The coupled plates were a trifle under 13 inches long, by 6 inches wide, by $\frac{9}{16}$ inch thick, whilst the insulated plates were $12\frac{5}{8}$ inches long, by $5\frac{5}{8}$ inches wide, by $\frac{9}{16}$ inch thick, except the steel Y 7 and the iron D 4, which were $\frac{3}{8}$ and $\frac{7}{16}$ inch respectively. The aggregate surface, bright and black, was, of the steels 5·8, and of the irons 5·86 square feet. Both couples and singles are shewn in figs. 6, 7, 8, and 9.

In No. 1 couple (Y 1 and B 1) both iron and steel were bright all over; in No. 2 couple (Y 2 and B 2) the iron was bright all over, but the steel only partially so, the mill scale being left on portions of the surface on either side; whilst in No. 3 couple (Y 3 and B 3) the iron was partially bright on both sides, and the steel bright on one side and partially on the other, the remaining surfaces being covered with scale artificially produced by heating the plates to nearly a white heat and then putting them in a heap of sawdust, where they remained until cooled. Of the single plates the two irons (D 4 and B 5), and the steel (Y 6) were bright all over, whilst the steel Y 7 was partly bright and partly covered with scale artificially produced as described above.

The edges of the scale (excepting the small spots) were at the outset filed as even as practicable, so as to render it easier to measure the areas it protected, and every care was taken to preserve it when the plates were cleaned. This was done, and the area of the scale remaining measured, at the end of the several periods specified in Table IV. These measurements were not, and could not be precisely accurate, but they were sufficiently so for all practical purposes.

On the table are casts of the partially scale-covered plates (Y 2, 3 and 7, and B 3), taken after the first year's immersion, which show more clearly than any description the limits of the scale; and comparison of which, with the casts taken at the expiration of the experiment, will show the extent of the loss of scale between the two periods.

The results of this series are given in Tables IV. and V., and photographs of the plates taken after test are appended.

Before dealing with the results, I would call attention to the gradual falling off—especially in the last period—of the losses of the steel plates. During each of the first two periods the plates were once roughly cleaned on the beach, and once thoroughly cleaned for weighing; but when, in December, 1888, Series II. was taken up for good, the return tide did not admit of the rough cleaning of the Series III. plates then due—they could only be turned round in the culvert—and from this time till September, 1889 (when they were finally taken up), they remained undisturbed. As there can be no doubt but that a clean surface suffers more from oxidation than a surface covered with a crust formed through corrosion, the falling off of the losses in the steels may have been due, in part, to this fact; and this seems to receive some confirmation from the gradual falling off of the losses in the immersed plates in Series I.

Taking first the question of the effects upon each other of iron and steel attached and suspended in the sea, there seems in these results to be no indication of any such injurious action upon the one metal or the other as is alleged.

It is true that on the surfaces adjacent to the joints of the coupled plates, there is a certain amount of grooving, but to prove that this was due to galvanic action, it would be necessary that the grooving should at least be more severe in one metal than in the other, whereas, taking into consideration the comparative loss, this is not the case. Moreover, on the ends of the plates where joined face to face, and which had been filed even and smooth, there is a total absence of grooving, and of anything indicating galvanic action. Neither is there, upon examination of the bolt heads, any indication, either in the plates or the bolts themselves, of one or the other metal acting injuriously upon its companion.

Making comparison now between the coupled and the uncoupled plates, it will be seen that between the coupled bright steel (Y 1) and the uncoupled steel (Y 6), there is scarcely any difference in appearance, and the percentage in favour of the uncoupled plate is only 4·8; that between the partially scale-

TABLE IV.

No. of plate.	Letter marked with and kind of metal.	Kind of Surface before testing.	Coupled or uncoupled.	Area of exposed surface.* Before testing.	Ater testing.	Loss of Weight. 1st period of 350 days.	2nd period of 353 days.	3rd period of 459 days.	Whole time of 1162 days.	Loss per square foot of exposed surface* per annum. 1st period of 350 days.	2nd period of 353 days.	3rd period of 459 days.	Whole time of 1162 days.
				Square inches.	Square inches.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.
1	Y Siemens Steel ..	Bright all over	Coupled	145·1	142·6	3·936	3·661	3·934	11·530	4·073	3·760	3·159	3·617
1	B Staffordshire Iron	,, ,, ...		147·3	145·4	1·626	1·307	2·454	5·388	1·658	1·324	1·933	1·663
2	Y Siemens Steel ..	Partly covered with scale on both sides	,,	76·6	91·8	2·971	3·256	2·727	8·954	5·820	5·472	3·310	4·726
2	B Staffordshire Iron	Bright all over		147·3	145·2	1·983	1·383	2·652	6·018	2·021	1·401	2·092	1·855
3	Y Siemens Steel ..	Partly covered with scale on one side, bright the other ..	,,	114·7	117·6	4·038	3·868	3·967	11·874	5·285	5·000	3·863	4·638
3	B Staffordshire Iron	Partly covered with scale on both sides		93·0	95·8	1·032	0·914	1·331	3·277	1·665	1·439	1·591	1·570
4	D Yorkshire ,,	Bright all over	Uncoupled	158·0	156·0	2·935	2·534	3·142	8·611	2·790	2·388	2·306	2·476
5	B Staffordshire ,,	,, ,, ...	,,	158·1	157·6	2·828	2·228	2·684	7·740	2·683	2·100	1·961	2·217
6	Y Siemens Steel ..	,, ,, ...	,,	158·1	156·3	4·181	3·290	4·538	12·010	3·900	3·100	3·325	3·450
7	Y ,, ,,	Partly covered with scale on both sides	,,	78·5	88·1	2·917	2·748	2·775	8·441	5·581	4·983	3·607	4·606

* By "exposed surface" is meant surface unprotected either by paint or mill scale, *i.e.*, bare metallic surface exposed to the action of the sea.

TABLE V.

No. of Bolt.	Letter marked with and kind of metal.	Countersunk head in.	Loss of weight during whole period of 1162 days.	Loss per square foot of exposed surface† per annum.	Mean loss.
			oz.	oz.	oz.
*1^{1}	Y Siemens Steel	Iron plate B 1	·077	3·661	4·119
1^{11}	,, ,, ...		·097	4·577	
1^{111}	B Rivet Iron	Steel plate Y 1	·052	2·477	1·978
*1^{1111}	,, ,, ...		·031	1·481	
2^{1}	,, ,, ...	Iron plate B 2	·048	2·281	2·094
2^{11}	,, ,, ...		·044	1·911	
2^{111}	Y Siemens Steel	Steel plate Y 2	·074	3·500	3·863
2^{1111}	,, ,, ...		·090	4·227	

* 1^{1} marked B and 1^{1111} marked Y by mistake.

† By " exposed surface " in this case is meant the surfaces of the heads and points which were exposed to the water.

covered steels which were coupled (Y 2 and 3), and the partially scale-covered steel which was uncoupled (Y 7) there is practically no difference; and that the bright coupled iron (B 1) suffered considerably less—about 33¼ per cent.—than the bright uncoupled iron B 5. For this difference, it is difficult to account altogether, but B 5 seems to have suffered considerably more in and around the holes, and appears to have been dirtier and less homogeneous. The difference in favour of this plate over the Yorkshire iron, D 4 is 11½ per cent., the corrosion in the latter being very peculiar—in spherical lines—as if the plate had been made of a very heterogeneous bloom.

Turning next to the question of the effects of scale, it is to be observed in the first place that there can be no doubt but that the scale artificially put on the steel plates, Y 3 and 7, and the iron plate B 3 was of the same nature as that found on metals which have gone through the hands of a smith. This sort of scale has not before, so far as I know, been alluded to in discussions upon the corrosion of iron and steel, and it would be interesting to know in what respects it differs, if at all, from mill scale.

In contrasting those bright surfaces which were in proximity to the scale with those surfaces having the scale still on, two things should be borne in mind; (1) that in this, as in every similar case, the very perfect protection afforded by the scale to the surfaces it covered, makes the corrosion of the adjoining bare surface appear, by contrast, more severe than in the bare surfaces remote from scale; and (2) that in removing the scale and filing those parts bright, a considerable amount of metal would also be removed. Thus in the case of each of the partially scale-covered sides of the coupled plates, there was along the joint a strip ½in. wide on the one side, and another strip 2in. wide on the other side, as shown in Figs. 7 and 8, which were at the outset filed bright; and, consequently, a small shoulder was formed along the edge of the scale-covered surface making the corrosion of the bright strips appear deeper than it really was. It is at the parts in proximity to those bright surfaces which were protected throughout (such as along the joints on the one side and round the nuts on the other side) where the depth of the corrosion is accurately shown. It is hardly necessary to point out that although metal was also removed with the scale from the sides that were bright all over, this did not in any way tell against the bright surfaces, as they were filed flush all over, as a matter of course.

Comparing first the losses per square foot of exposed surface it will be seen that there is a percentage of 32·7 in favour of the bright coupled steel Y 1, over the partially scale-covered coupled steels Y 2 and 3 (between which in this respect there is not much difference) and, that if to these be added the single steels, the loss of the partially scale-covered plates (Y 2, 3 and 7) is still 31·5 per cent. more than in the bright plates (Y 1 and 6).

These figures taken by themselves tell, it must be admitted, in favour of the theory that the mill scale has an injurious effect, but as in the case of the steels in Series II., there are grounds for doubting whether the greater loss per square foot of exposed surface in the scale-covered steels, was due to the presence of the scale.

In the first place it is to be remarked that it is only in the steels that the scale-covered plates have lost more per square foot of exposed surface than the bright plates. In the irons the reverse is the case, the partially scale-covered plate B 3, having lost far less than any of the other irons, whether coupled or uncoupled (from 12 to 41 per cent.). In the second place, in the case of one at least of the scale-covered steels, viz., Y 7, there is little doubt but that want of uniformity in composition had something to do with its comparatively greater loss; for as will be seen from the plate itself, the upper half (with the holes in it) is very patchy and much more severely and unevenly corroded on either side than the other half. How far the thorough annealing process to which, in addition to the manufacturers', the steel plates (Y 3 and 7) were subjected had to do with their behaviour, it is hard to tell.

And then again—and this is a very important fact invariably overlooked—the mean of the absolute losses of the steels Y 2 and 7, which had only a little under one-half of their surfaces covered with scale, was 35 per cent. less than the mean absolute loss of the bright steels, Y 1 and 6. Similarly, the absolute loss of the iron, B 3, with only 34 per cent. of its surface scale-covered, was over 94 per cent. less than the mean absolute loss of the bright irons B 1, 2 and 5. In steel or iron structures, especially those which are not periodically examined with a view to preservation, this would constitute a very considerable advantage in favour of the scale-covered metal.

If now, turning from the losses, the appearance of the plates is examined, it will be seen that there is nothing to indicate that the comparatively greater corrosion in the partially scale-covered plates is due to the presence of scale. Although for instance, the steel Y 3, with one side bright and the other side partially covered with scale, is rougher and more acted upon generally than the bright steels Y 1 and 6, yet there is no perceptible difference, either in the nature or the severity of the corrosion between the surface in close proximity to the scale and that remotest from it; and the same may be said of Y 2. Again it will be observed that along the chamfered edges, deprived of their oxide at first, of the partially scale covered steels Y 2 and 7, where the scale is still perfect and where, if scale is injurious, increased action might surely be looked for, there is no indication of any such increased action whatever.

Nevertheless, the greater loss per square foot of surface of the partially scale covered steels will doubtless be taken, by many, as proof of the injurious action of the scale. It may be so, but any who quote these experiments as proof of the supposed increased action in the presence of scale, should remember to add that the extent of such increased action, so far as these experiments go, is far less than has been alleged, and that along with such proof, go the various questions above raised. These are points which, if the detractors of scale are correct, press for solution, and I believe that that solution will be found in the want of uniformity of composition, or in the process of manufacture of the steel, rather than in the presence of the much abused scale.

The specific points to test which Series III. was instituted, have now been dealt with, and there remains for consideration the old question as to the comparative corrosion of iron and steel under the various conditions of this series of experiments, and to this no uncertain answer is given.

In No. 1 pair of bright plates the steel lost, per square foot of surface per annum, about 117 per cent. more than the iron, and the iron was much more evenly affected; in No. 2 pair the loss of the steel was 155 per cent, in the No. 3 pair 195 per cent, and in the three pairs taken together over 156 per cent greater than in the iron. Comparing the bright single plates there is a percentage of 55 per cent. in favour of the Staffordshire iron B 5, and of 39 per cent. in favour of the Yorkshire iron D 4, over the steel Y 6; whilst the Staffordshire is better than the Yorkshire iron to the extent of $11\frac{1}{2}$ per cent. The losses of the bolts in couples 1 and 2, correspond very nearly with those of the respective plates, as shown in Table V.

These percentages and the results generally as given in the Tables, seem to me to prove, as clearly as experiments can prove, that whether bright or scale-covered, Iron is, under the most various conditions, without doubt, far superior to Steel in its power to withstand corrosion.

CONCLUSION.

I have now described my experiments and I think I may claim for them—whatever may be thought of the inferences drawn, that they have been conducted with the utmost care and with impartiality; and that the long period over which they have extended, and the conditions under which they have been carried out, entitle them to consideration. Here it will not be out of place to briefly review the controversy in regard to the comparative corrosion of Iron and Steel.

It is a significant fact, in connection with this controversy, that, although the greater corrosion of steel has been strenuously denied, various theories have been advanced as explanations of this greater corrosion. Thus, in the earlier stages, it was said that the manufacturers could not, as yet, produce steel of sufficiently uniform quality, but that with experience this defect would be removed Then was started the galvanic action theory :—Iron was said, by means of galvanic action, to act injuriously on steel in contact with it. This did yeoman service until eclipsed by the later and now fashionable idea, that it is galvanic action between the black oxide and the steel which it covers, which is the root of all the evil.

It will be convenient to take these three explanations *seriatim*, remarking in passing that they are so many tacit admissions of the point at issue.

The first may be disposed of in a few words. Manganese appears to have been considered the chief difficulty in the way of producing steel, which should be ductile and at the same time withstand corrosion. Thus in 1878 the late Sir William Siemens attributed the greater corrosion of some steels to "excess of manganese," which he said should not be present to a greater extent than ·1 or ·2 per cent.* In 1882 Mr. G. J. Snelus was inclined to ascribe the difficulty which he had experienced with pitting in steel to irregular diffusion of the manganese.† And Mr. Farquharson, of the Admiralty, in describing some experiments, which will be referred to in more detail later on, said, "In almost every case there are evidences of local action between one portion and another, a sure indication that the manganese is not evenly diffused throughout."‡

This being so the question arises, has the manufacturer succeeded in producing a ductile steel free from excess of manganese and uniform in quality?

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* Journal of the Iron and Steel Institute, 1878, p. 43.
† Journal of the Iron and Steel Institute, 1881, p. 66.
‡ Transactions of the Institution of Naval Architects, 1882, p. 145.

The answer, so far as my knowledge goes, is No! or at any rate not to anything like the necessary extent, as from numerous analyses, which have been brought to my notice, I find that the per centage of manganese varies from ·25 to 1·05.

On the question of the general homogeneity of steel Mr. Farquharson may again be quoted. Speaking in 1885 he said, "that the Admiralty practice of 'pickling' steel plates in order to remove the oxide had, on one occasion, disclosed laminations to such a serious extent as to necessitate the condemnation of 100 large plates intended for a ship then building;"* and the results of the experiments I have described upon plates manufactured by leading firms in the years 1876, 1881, and 1886 show a great want of uniformity on the part of the steels.

The theory that steel is, by means of galvanic action, injuriously affected by iron in contact with it, was put forward more especially when steel was in its infancy, and was not trusted for riveting, and seems to have continued so long as the blame could be thrown upon iron rivets, &c.

In 1881 the late Sir William Siemens and Mr. Riley both attributed the less favourable results with steel in the French Navy to the use of iron rivets.† Three years earlier Mr. Parker, in referring to two cases of extraordinary corrosion in steel—one in which some steel tubes, fitted in a nest of iron tubes, lost in nine months 70 per cent. of their weight, the iron remaining almost as perfect as when new; and another in which some steel tubes in an iron boiler pitted through and had to be removed after a fortnight's steaming—said, "It would appear as if some galvanic action were set up when the materials were so placed together."‡ Mr. Martell, in 1881, mentioned a steel vessel riveted with iron in which, though not a year old, the plates between the rivets had deteriorated so much that the rivet points protruded "some distance beyond the steel" and "thought it might probably be due to galvanic action" between the two metals. §

So far as I can tell there seems to have been no special reason in these cases for the suggested explanation. The reasonings seem rather to have been in this wise:—there is the Iron in contact with the steel, and there is the corrosion in the latter, *perhaps* galvanic action between the two metals is at the bottom of it. Unfor-

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* Minutes of the Proceedings of the Institution of Civil Engineers, Vol. lxxx., p. 151.
† Tranactions of the Institution of Naval Architects, 1881, p. 139-40.
‡ Journal of the Iron and Steel Institute, 1878, p. 76.
§ Minutes of Proceedings of the Institution of Civil Engineers, Vol. LXV. p. 102

tunately for this theory the facts have not always been in this sequence and the contrary instances come from an unexpected quarter; from the advocates of the galvanic action theory themselves

In 1880 Mr. Parker referred to some boilers with steel shells, iron furnaces and combustion chambers, and brass tubes, in which though they had been running for two years, and "excessive corrosion or pitting in one of these materials might have been looked for," nothing more was observable "than would be expected in iron boilers of the same age." *

This instance, however, though sufficiently to the point, is as nothing compared with the remarkable results of some experiments before alluded to, which were detailed by Mr. Farquharson to the Institution of Naval Architects in 1882. I shall not, I hope, be considered as giving in my adherence to galvanic action theories when I say that Mr. Farquharson's announcements *electrified* all interested, for he showed to the satisfaction of many, as it seems, that there was galvanic action indeed, but that it was all the other way, that it was the steel which acted injuriously on the iron. Whilst in the single plates tested the steels lost 12 ounces 59½ grains, and the irons 11 ounces 136½ grains, or some 360 grains less than the steels, in the "electrically combined" couples the steels lost 4 ounces 186 grains only, and the irons 21 ounces 56 grains, or nearly five times as much. And this is not all, for Mr. Farquharson added that "had the plates been placed edge to edge and contact maintained, the iron would certainly have suffered much on the edge next the steel." †

I think it is a matter of regret that Mr. Farquharson did not give any details as to the quality or make of the plates tested, and that they should have been so very thin ($\frac{3}{16}$ of an inch only), also that experiments which produced such interesting and remarkable results were not allowed to continue for a longer time than the very short period, six months, during which they lasted.

However, there seems to be one clear result, and that is, that for those who accept the conclusion that Steel galvanically deteriorates Iron, the opposite theory is no longer tenable as an explanation of the greater corrosion of steel; and it would be interesting to know how such gentlemen would account for the extraordinary cases of corrosion of this metal before referred to, which at the time they occurred were attributed to the galvanic

* Transactions of the Institution of Naval Architects, 1880, p. 222.

† Transactions of the Institution of Naval Architects, 1882, p. 144.

action of Iron. Black oxide might, perhaps, be suggested, but in one instance at least, viz., that mentioned by MR. MARTELL, of the corrosion round the rivet points of the plates of a steel ship riveted with iron, this would not be admissible, for, as explained by that gentleman, the hammering of the rivets would certainly have beaten all the oxide off.

Strangely enough, amongst those who appear to have regarded the results announced by MR. FARQUHARSON as of little moment, are the Admiralty Officials themselves, for they continued long after to have boilers for ordinary pressures made of iron and steel; whilst in 1885 MR. THORNYCROFT informed the Institution of Civil Engineers that he was then making Torpedo Boat Boilers with fire boxes and stays of iron and shells of steel. *

Even without disproof of the "galvanic action of iron" theory, some other explanation of the corrosion of steel became necessary in consequence of the substitution of steel for iron rivets, and latterly the idea has gained ground that it is galvanic action between the steel and its oxide that is accountable for rapid corrosion in the former. Started in 1879, by the announcement of SIR N. BARNABY, "that when the surface oxide is left on" its effect "on the neighbouring bared metal is as strong and continuous as copper would be,"† the theory has been widely and readily accepted, and when extraordinary corrosion in steel has been brought to light, has been often given as an explanation. It will be interesting to deal with some of these explanations a little in detail.

In 1887, at the Institution of Naval Architects, MR. RAILTON DIXON asked MR. MARTELL to give the meeting his experience as to a vessel built some eight years before, entirely of steel, which "was found to be greatly corroded in the bunkers, underneath the engine seats, and the water ballast chambers near the engine room"; * * * "the flanges of some of the angle-irons" having "entirely disappeared and the tie-plates being eaten away in holes."‡ MR. MARTELL, after confirming MR. DIXON's account of the extent of the corrosion went on to say that, "on looking at a portion of the interior plating of the after-part of the vessel, where it had not been coated with paint or anything else" * * * "you could see the mill scale on it just as it came from the rolls. We know a very great deal more now on this subject than when

* Minutes of the Proceedings of the Institution of Civil Engineeers, Vol. LXXX., p. 135.

† Journal of the Iron and Steel Institute, 1879, p. 53.

‡ Transactions of the Institution of Naval Architects, 1887, p, 261.

this vessel was built, that this black oxide, if left on, will in connection with moisture, soon set up galvanic action which will cause a very rapid deterioration, and I have no doubt in my own mind that the great wasting in this vessel was owing, in a great measure, to that cause."*

Whether or not it is true that galvanic action is set up to an injurious extent between steel and its oxide, there are probably many like myself who will have very great doubts as to the great wasting in this case being due to that cause. From Mr. Martell's account, it would seem that he had to look about before he found—*in a place where oxidation had not occurred*—any trace of the oxide; and where, as in this vessel, steel, in the course of eight years is, in some parts, riddled into holes, and in others entirely gone, it may very pertinently be asked how long it must have been since the oxide disappeared from those parts? In places such as engine rooms, stokeholds, water ballast chambers, and coal bunkers intermittently exposed to the action of air, water, and wet coals, it cannot be long before the oxide drops off, especially from the vertical and under surfaces, and when it is off, what harm can it do to the surfaces it once protected so well?

But black oxide, it would seem, has more still to answer for. In his paper in 1884, Mr. John described how he had noticed rust rising "in little mounds" on the outside of a steel vessel which had been launched but a few weeks, and continued—"I carefully scraped a number of them off with my knife without injuring the paint, showing that although the rust thrown out formed a little hemisphere of ¼in. diameter, the hole in the paint was not more than the size of a pin's head, while, in each case, it was easy to pick out a little loose particle of black oxide imbedded in a little pit in the plate, and you could almost see the galvanic action going on."† I, too, have often seen such rust spots in new iron ships on their arrival in Indian waters, after a voyage round the Cape, but I suggest for consideration that they are due, not to galvanic action, but to minute surface blemishes (such as cinder spots or laminations) having been covered with paint at a time when, from exposure to the weather during the building of the ship, they contained more or less air and moisture, the oxidation having, most probably, long set in. Small pieces of cinder or slag pressed into the surface of iron are known to drop out (if not bound in) after exposure to sea-water or moisture through oxidation of the metal; and from a statement made by Mr. Farquharson, it appears that the Admiralty practice of "pickling" has discovered

* Transactions of the Institution of Naval Architects, 1887, p. 261.

† Journal of the Iron and Steel Institute, 1884, 149-50.

in steel plates pits $\frac{1}{4}$in. deep, where "lumps of oxide,"* as Mr. Farquharson says, had been rolled in. I had not before heard of oxide—which is usually understood to be a film—being found in "lumps," and would suggest that the pieces discovered were cinder or slag; but, however this may be, the defects disclosed would, with the laminations before referred to, have assuredly been attributed, had the plates been exposed to sea-water without the pickling, to galvanic action between the steel and its oxide.

This part of the question would not be complete without a reference to the black discs of Mr. Parker's experiments. "It will be seen," says Mr. Parker "that the black discs which lost least scale have corroded to a greater depth than the corresponding bright discs, and this can only apparently be accounted for by the galvanic action set up. The relative size of the exposed and protected (black scale) surfaces must have had some influence on the galvanic currents." This, by itself, is reasonable enough, but Mr. Parker has more to say on this point. "There is," he says, "no practical difference between the loss of the black and of the bright discs exposed to the atmosphere, and it is evident that here at least no galvanic action could have taken place."† Why evident, I would ask? Has it not been reiterated that in the presence of moisture alone, magnetic oxide will set up galvanic action, and is there no moisture in the atmosphere and no rain in London? Surely there is a certain amount of disingenuousness, not to say ingratitude, in calling in the aid of galvanic action wherever the oxide acts, or rather is supposed to act, injuriously, and when, as in those cases, it does *not* do to say to this old friend, there is no place for you here.

It must be borne in mind that the assertions made in regard to the galvanic action of the black oxide are not vague, but very definite assertions, though it must be admitted that there is a certain amount of disagreement amongst them. In 1879, Sir N. Barnaby stated that "the action of oxide on steel was as strong and continuous as that of copper,"‡ and in 1881 Mr. W. H. White contradicted the idea that this was a "speculative belief," and said that it was based upon experience and many careful experiments which "made it as certain as one could be about anything, that the black oxide, if left on portions of steel plates, would cause pitting." § Nevertheless the effects produced by this certain knowledge upon

* Minutes of of the Proceedings Institution of Civil Engineers, Vol. LXXX., p. 151.
† Journal of the Iron and Steel Institute, 1881, p. 51.
‡ Journal of the Iron and Steel Institute, 1879, p. 53.
§ Journal of the Iron and Steel Institute, 1881, p. 68.

the minds of the Admiralty officials appears to have differed very little from the effects produced by a speculative belief; for in 1881, Sir N. BARNABY stated that two ships had been coated with composition and one of them allowed to go to sea "before the black oxide was completely removed." *

In 1879, Sir N. BARNABY said that "when the surfaces of steel are carefully freed from the black oxide, the surface corrosion in salt water is very uniform," † and in 1882 this was confirmed by Mr. WHITE after, as he said, "six years experience." ‡ But in 1885, Mr. FARQUHARSON stated that another of the many results disclosed by the Admiralty process of "pickling" steel plates was, "that the steel when entirely freed from its surface oxide did not wear evenly."§

In the face of such conflicting statements from the advocates of the theory themselves, I may well be excused for thinking that the day is not far off when it will join its predecessor in deserved neglect. The basis upon which the very positive statements made on the point have rested, appears to be of the most shadowy description ; generally amounting to this, that in some cases where there has been excessive corrosion of steel, black oxide has been present. If black oxide is as strong and continuous in its action as copper, and is capable of causing parts of ship's frames, boiler bearers, &c., to disappear in 8 years, what ought to have been the extent of the corrosion in the partially scale covered surfaces of the test plates in Series II and III of my experiments, which lasted over 3 and 7 years respectively? The results, however, notwithstanding the greater loss of the partially scale-covered steels in Series III, are quite at variance with such alarming statements.

I cannot help thinking that much of the alleged pitting in steel partially covered with scale exists in appearance only. In a bright plate, under ordinary circumstances, corrosion will go on more or less evenly all over the surface and the greatest depth will by no means represent the full depth of corrosion, but in partially scale-covered plates the scale will, barring rough usage, adhere for years, affording to the surface it covers perfect protection, and if this surface be contrasted with those parts which have been without scale from the first, the corrosion will, of course, appear

* Minutes of Proceedings of the Institution of Civil Engineers, Vol. LXV., p. 104.
† Journal of the Iron and Steel Institute, 1879, p. 53.
‡ Minutes of Proceedings of the Institution of Civil Engineers, Vol. LXIX, p. 35.
§ Minutes of Proceedings of the Institution of Civil Engineers, Vol. LXXX, p. 152.

deeper than in a similar bright plate. The comparison however is illusive, and it is to be doubted whether the whole secret of the supposed injurious action of the mill scale does not lie here.

There remains to be dealt with the general question of the comparative power of iron and steel to withstand corrosion.

One of the chief objections taken to the experiments formerly described by me was, that they were upon small pieces of metal subjected to conditions different from those which occur in actual practice. Remarking in passing that such criticism cuts at the root of all experiment, it will be well to enquire what have been the results of actual experience during the past 10 years.

On this point there will be many here who will be able to give the Institute much more information than I can. It seems to me that where cases of extraordinary corrosion in steel have occurred, there has often been needed a certain amount of pressure in order to bring the facts to the knowledge of the public. Nevertheless some cases in point have come to light.

In the first place it should be remarked that if the results of Mr. Farquharson's experiments are accepted as proof that steel galvanically affects iron, all those cases in which formerly the corrosion of the steel was attributed to the presence of iron rivets, &c., must now be accepted as proof that steel corrodes, or at any rate in the instances named corroded, much more rapidly than iron, and this in spite of its galvanic influence upon iron.

Then there is the entire steel ship already referred to in which, after 8 years, parts were riddled into holes, and parts completely eaten away. Two causes have been suggested as contributory to this alarming state of things, viz.: negligence and black oxide. That there is persistent negligence in the treatment of ships, bridges, &c., in regard to corrosion, there can be no doubt. Indeed the negligence invariably commences *before* the structure is built, in not taking care to prevent oxidation setting in at those parts of the plates, angles, &c., which have lost their oxide, and in failing to remove the rust from such parts before painting. But is there the slightest reason for supposing that the neglect in the case of steel has been greater than in the case of iron? On the contrary, so many warnings have been given in regard to steel, that it may reasonably be supposed that the reverse is the case. Then in regard to the black oxide explanation, there have been cogent reasons given for doubting whether the oxide could have been guilty to any appreciable extent of the corrosion in this vessel. Indeed

Mr. Martell appears to have had some misgivings on this point himself, for he went on to say, "I must admit it was the first case "I had seen of such considerable wasting in steel, and it somewhat "altered the opinion I had previously formed. Up to that time, "I had been of opinion that the wasting of steel was not more "rapid than of iron, but I could not help thinking that, when the "steel is worked of fine scantlings, and when parts such as angles "project from the surface, and are not continuously coated, oxidation "soon commences, and it would appear that wasting goes on more "rapidly in steel in that case than in iron."* Bearing in mind the strong opinions in the opposite direction that have been expressed by Mr. Martell, these will be regarded as important admissions, and none the less so, because they are made in such guarded language.

The fact mentioned by Mr. Thos. Davidson in 1886, that he had advised the substitution of steel for iron in propeller shafts, but that the steel corroded so rapidly in some cases that they had to be replaced by iron† may here be appropriately quoted; and this receives striking confirmation from the unanimity with which it was decided at a recent meeting of this Institute, that one of the principal objections to steel propeller shafts was their greater liability, as compared with iron, to corrode.

The following tells very much the same tale. On a recent visit to Barry and Newport, Monmouthshire, I was informed that the dock gates at the former place were of iron below, and of steel above the water; and that at the latter place the gates for the new entrance and the extension of the Alexandra Docks were being made wholly of iron, the reason given in each case being that iron withstands the action of salt water much better than steel

Here are a few facts of actual experience which give similar results to those of my experiments, and which could doubtless be supplemented by many others, whilst if experimental proof is needed, I would quote the experiments made by Mr. Parker and Mr. Thos. Andrews ‡

Reviewing the whole case, I think I have nothing to retract from the conclusions I drew from my former experiments. Indeed the remarkable change of opinion that seems to have taken place in regard to galvanic action between steel and iron, removes

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* Transactions of the Institution of Naval Architects, 1887, *p.* 261.

† Transactions of the Institute of Engineers and Shipbuilders in Scotland, *Vol.* 29, *p.* 182.

‡ Minutes of Proceedings of the Institution of Civil Engineers, *Vol.* LXXXII., *p.* 295

one of the chief objections raised to some of those experiments, notably in the case of the 56 sets of bright plates suspended in sea-going boilers.

I said then, and after further careful experiments extending over several years I contend now, that it is undoubtedly a fact that under almost all circumstances iron, particularly if of the harder class, is far superior to the finer steels in its power to resist corrosion, both local and general; that as regards uniformity of composition and temper, steel has probably more than its fair share of praise; and that when the question of oxide comes to be more practically considered, it will be found that local corrosion in steel and iron is not due to galvanic action but to other causes. What the cause of the greater corrosion of steel may be I do not know, but I believe that eventually it will be discovered that it lies in the composition of the metal itself.

All the test plates are at hand and open to inspection by those interested.

CHAIRMAN'S REMARKS.

(Mr. G. W. Manuel).

I have listened with much interest to Mr. Phillips' paper, and examined the experimental tests he has so carefully carried out in order to ascertain the comparative durability of Iron and Steel, when exposed to the action of sea water. It is a matter of special importance to Engineers and Ship-builders, as the Hulls of our noble vessels—of which we are so justly proud—both in the National and Merchant Navy are chiefly constructed of these Materials.

Mild Steel, since 1879, has largely taken the place of Iron, owing to its superiority over Iron in *tensile strength, as well as ease* in working, either hot and cold.

The tensile strength of Iron generally, in former use for Ship building, was about 20 tons per square inch, and that of Steel 26 tons; but the elastic limit of this steel being 15 tons, it was considered by Lloyd's rules that 20 % reduction could be made in favour of steel.

Therefore a vessel whose hull weighed 1,000 tons, would have, if built of steel, 200 tons more dead weight capacity than one built of iron of same dimensions;—an important consideration for the Ship-owner.

This 20 % reduction—allowed for the superiority, by strength, of steel over iron—is now *reduced*, and may be reduced further owing to the *corrosion* of steel in some of the internal parts of the steam vessel being *greater* than that of iron, such as Bunkers;—more especially when plates and frames, also bulkheads, stringers, and beams, are heated by the Boiler, and when the coal may have been put on board damp or wet;—Bilges of Engine-room; and, especially, the Stoke-hold, when exposed to moisture from sea water; the inside plating and framework of Tanks, and tops of tanks under Boilers, where also access is not easy for painting.

The corrosion in these parts during a long voyage of four months, or it may be eight months, or when ships are but a short time at home,—is sometimes considerable, as they cannot be painted sufficiently to prevent corrosion, and in many cases not painted at all owing to the time at command being too short.

Corrosion is greater, under these circumstances, on steel than iron, and is borne out by Mr. Phillips' practical experiments, and it may be necessary, where corrosion thus takes place, to construct those parts of the Steamer's hull of iron instead of steel, and this can be done without any detriment to either metal, a fact also proved in practice, and by Mr. Phillips' experiments. It would be well worthy of the Scientist to endeavour to find an antidote against the corrosion of Steel under such conditions inside a Steamer.

Meanwhile, we are indebted to Mr. Phillips for bringing the subject in a practical manner before us, and for which he is deserving of our hearty thanks.

Mr. W. W. WILSON'S Remarks.

(*MEMBER*).

In the paper just read, Mr Phillips gives us the results of a series of very carefully conducted experiments, extending over a long period, and which no doubt have cost him a very great amount of time and trouble. But there is one condition under which I think it is a pity he had not some of his specimens tried, so that we might also have had some reliable data, as it is one which is often brought under the notice of Marine Engineers.

Referring to Part I., of the paper, and in it to N and B specimens in No. 100 set, we observe that the loss by corrosion of the steel N, as compared with the iron B, is very considerable indeed, but I should have wished to have seen some data as to their relative losses, had they, instead of being merely exposed to the weather after dipping in the sea water, been exposed to the influence of artificial heat.

It is under the latter conditions that I find the greatest amount of corrosion goes on, such for instance as in side coal bunkers over the Boilers, where, underneath the shoots, we have the plates daily drenched with more or less sea water on one side, and the opposite side exposed to the heat from the boilers. I observe, that in Bunkers such as I have mentioned, the plates, steel more especially, so exposed will waste through a thickness of $\frac{5}{16}$in. to $\frac{3}{8}$in. in from three to four years, and even less sometimes, whereas away from these parts there is often to be found but a slight scale of rust in the same time, even although exposed to occasional contact with damp coal.

I can give no exact data as to the relative differences of the corrosion of the two materials, but from general observation I can say, that there is no doubt that the Steel wastes much faster than the Iron, although there is also no doubt, that in the places mentioned the iron too corrodes very fast.

Hence my remark that it is a pity we had not had the benefit of results under those conditions, and conducted with the same care and attention which MR. PHILLIPS has evidently bestowed on his experiments.

At the end of the third paragraph of page 20, MR. PHILLIPS says.—"There can be no doubt but that a clean surface suffers more from oxidation than a surface covered with a crust formed through corrosion." Now, if such is the case (and there does seem to be some evidence in its favour), I should say that it would be better to let the corrosion scale remain on the material, rather than remove it, as being the least of two evils, that is, unless a particularly good job be made of *cleaning all scale* off, and *thoroughly* protecting the cleaned surface with some good anti-corrosive paint. In this connection, I cannot but think that in too many cases, the supposed saving of a few pounds in not thoroughly cleaning and repainting the insides of vessels periodically, is the cause, ultimately, of heavier cost being incurred, both in time and material in effecting repairs. My opinion is that there should be a regular system carried on, and that periodically, say, every twelve months (or oftener where the material is exposed to some extraordinary influence), all steel work should be thoroughly cleaned and repainted, and if such were done, I am perfectly convinced that there would be a decided extension in the life of the material.

With regard to Steel in the construction of Boilers, my experience is that no more corrosion takes place than in those constructed of Iron, but this I think is attributable to the fact, that Boilers are, as a rule, better cared for than the Hulls of vessels, and every precaution is taken for the prevention of corrosion.

MR. W. J. NOWERS BRETT'S REMARKS.

(*ASSOCIATE*).

The experiments conducted by MR. PHILLIPS, upon the relative corrosion of iron and steel, bring the much discussed question of the respective values of their durability very much nearer an answer. Indeed, every day, examples can be cited by practical Engineers, especially those engaged in Marine iron and steel work, and they all point to the greater endurance of pure iron when exposed to sea water, the atmosphere, or bilge water, and the decaying refuse it contains.

Perhaps the more rapid corrosion of steel will eventually be proved to be caused by galvanic action between the molecules of iron and carbon. May it be possible that while the presence of carbon will not account for deterioration, it might be accelerated where it has once begun by the presence of carbon?

The question of the rapid corrosion of steel and cast iron being due to galvanic action between the molecules of iron and carbon, can be better discussed by an Electrical Engineer. If the electrical potential of iron is greater than that of carbon, when these are combined in cast iron or steel and exposed to moisture, galvanic action must ensue; and experiments with these molecules on a large scale may throw more light upon the subject. If it could be proved that the relative corrosions of cast iron and steel, agreed with the ratios of the electrical properties of carbon and iron, one of the causes of corrosion could be treated in order to check the action.

The corrosion of metals is certainly a very important subject and deserves special study. Although decay must gradually overtake everything, still, when we know the cause, it may be possible to greatly retard corrosion or any abnormal or preventable waste; and when we have in existence gigantic structures, such as the Forth Bridge, the magnificent "Ocean Greyhound" and the heavily built Ironclads of the present time, their preservation will greatly enhance the value of the capital expended on their construction.

Mr. J. M. Gray's Remarks.

(*VICE-PRESIDENT*).

The inquiry which Mr. Phillips has undertaken is most important.

Steel is a stronger material than iron, but it has the name of being more rapidly eaten away, by natural chemical action, when its surface is imperfectly protected. To what extent this difference exists has been only hazily understood. In the paper now before us, we have valuable definite information and no rash generalizations of theories of galvanic or chemical action. That unprotected steel corrodes more rapidly than iron, and that the commoner brands of iron corrode *less* than the highest priced iron has long been known, and these experiments confirm this. To put the results in another form—with steel, unprotected, and exposed to the weather and to sea water, corrosion advances at the rate of one inch in depth in 82 years, while with iron under the same conditions the advance is at the rate of one inch in depth in 190 years. When exposed to the weather and fresh water, it is 170 years for steel and 630 years for iron. When always immersed in sea water, the periods are 130 years for steel and 310 years for iron. When always immersed in fresh water, the periods are 600 years for steel and 700 years for iron. So far, this is a corroboration of general opinion.

In regard to the effect of mill scale, the information now furnished by MR. PHILLIPS is, however, remarkably different from what has for some years been believed. Mill scale is a perfect protection to the part covered by it, but it is said to be very detrimental, through galvanic action, to the parts of the same plate upon which there is no scale. MR. PHILLIPS' experiments show that the detrimental effect of mill scale, if there be any such effect, is much less than the plate picklers have represented it to be. The corrosion periods, as above, were :—for steel immersed in sea water, 180 years without scale and 140 years with patches of scale. With iron, under similar conditions, the periods are 400 years without scale and 350 years with patches of mill scale.

It may be as MR. PHILLIPS suggests, that the slight difference observed, with mill scale and without, may be due to want of uniformity in the composition of the metal, but the experiments are not conclusive on that point.

When we read Table II., we see that the information contained in it has been obtained, by incessant supplication, for seven years. In Table No. I., we see that several of the questions were repeated before the Infinite every day for 3,631 days, and the answers obtained have been exhibited to us as written by the finger of the Author of all wisdom Himself. This has been done by MR. PHILLIPS, not as the labour of a hireling, but as a voluntary work of devotion in the cause of Truth. Let us remember this when we read his report, and the dry figures will appear to us in a more interesting form. The work of calculation in preparing the Tables is ten times greater than it appears to be when only superficially examined, and for all he has done MR. PHILLIPS deserves our admiration and gratitude.

Mr. JAS. ADAMSON'S Remarks.

(*MEMBER*).

It has given me much satisfaction to hear Mr. Phillips read his valuable Paper, which deals both with facts and fancies, facts from experiments, fancies from theories. While the former may not exactly correspond with experiments from experience in actual working, we may consider them relatively to the actual conditions under which vessels *are* worked. and find how far they agree in the results with what has been observed in practice.

The various theories advanced by Eminent Authorities go to prove that considerable difference of opinion has existed, as to the durability of the two materials, some even boldly declaring that in cases where severe corrosion has set in on Steel Plates and Frames, it has been due to carelessness on the part of those in charge, to a considerable extent.

I do not refer to this in order to attempt to disprove it, but would point out that it is a well known fact, that some Steel Ships, under the same conditions, waste away very much faster than others. This indicates difference in quality or treatment, or possibly both. The season of the year during which plates may have been set and riveted, and ultimately painted, probably assists in facilitating corrosion or otherwise.

Reasoning by analogy, it may be expected that Steel under the same conditions as Iron *would* waste away more rapidly, but it is more than reasonable to suppose that different treatment, and anti-corrosives, may be found which will correct the greater tendency of the finer material. It remains for us to exhaust every means to discover, either the proper treatment or the anti-corrosive. For every evil there is an antidote, what that antidote is in the case of Steel and Iron corrosion we may hope to assist in discovering, by pointing out as Mr. Phillips and others have done—all honour to them—the results of researches and experiments.

Steel Ships have been known to remain afloat for 6 or 8 months or even longer, after leaving the Builder's hands, and when ultimately placed in Dry Dock have been found almost bare of paint, the plates unprotected, and very badly pitted all over. Cases such as these, of course admit of easy remedy : *i. e.*—Every new Steamer, *especially* Steel, should be placed in Dry Dock within a reasonable time after launching, and thoroughly scraped, and all bare or partially bare portions of the plates carefully painted, when dry, with an approved paint or composition. This involves also another question besides that of deterioration,—which is of sufficiently serious moment—it is that of efficiency. The smoother the Hull, the less the skin resistance of the whole Ship, so that when the surface becomes uneven,—due to the pitting or small local points of corrosion, the greater the skin resistance, and consequent greater loss of efficiency of the vessel as a whole, equivalent to a greater consumption of coal for the same speed of ship.

The question of how to deal with Ballast Tanks, Frames and other internal portions of Steam Ships, especially in the Region of extreme heat, is a very important one. The market is full of all sorts and varieties of paints and compositions, each professing to be *the* best, and it would be of considerable value to us to have an evening or two devoted to the subject of discussing such, and when experiences can be considered, bearing upon the whole question of how, and what to apply, as an anti-corrosive.

In some cases, the Bottoms of the Boilers lie so close to the plates or frames, that there is no proper circulation of air to keep the extreme heat from constantly acting upon them along with Bilge water and gas. In other cases the Boilers are so hemmed in, that the heat is confined in the spaces below the Boilers, with a similar result. In order to correct this, to a certain extent, the Bottoms of the Boilers have in some instances been covered with a non-conductor. By reducing the heat in the spaces below the Boilers—by the application of non-conducting material—it serves the double purpose of preventing radiation from the Boiler shell and removing one of the causes of severe corrosion.

It has been referred to in the Papers as an observation of Mr. Martell, that Steel of light scantling corrodes faster than Iron of the same light scantling. Such, at least, I apprehend to be the meaning, and I have heard similar opinions expressed. Cases have been cited where $\frac{1}{4}$in. or $\frac{5}{16}$in. Steel Plates, in launches and similar vessels have wasted away very rapidly. I have seen specimens so wasted, and was inclined to attribute the severe corrosion, in the one or two such cases I have seen, to the class of material which was in contact with the plates, and a similar effect would have taken place with Iron Plates, but, probably, to a less extent, due to the finer material yielding to corrosive influences more readily.

It has been stated, or even laid down as an axiom, that the nearer the material is to the ore, the better able is it to withstand corrosion, so also the further away from the ore, or the higher the refinement the less able is it to withstand the wasting influences at work.

I read the observations, made at the time referred to in the Paper, where it was stated that the whole of the Steel Framework of a Steamer, in the stokehold, 8 years old, had almost disappeared. I noticed the comment made upon this, and one possible result was, after investigating the case in question, and others, the scantlings for steel steamers were increased, as remarked upon by Mr. Phillips. I have seen cases similar to that referred to, probably nearly as far gone in extent—in the stokehold below the Boilers—and from what I have observed of the respective conditions of Iron and Steel, in the region of extreme heat and moisture from the Bilges or sea water, as in the stokeholds of Steamers, I should say that Iron will last 20 to 30 per cent. longer than Steel, granted the same care to be exercised in both cases. It has been my opinion for some years that Iron is preferable to Steel for the Stokehold Floors and Angle Irons, and Ballast Tank tops below the Boilers. I know cases where this opinion has ruled in respect to the Stokehold Framework below the Boilers of Steel Ships being renewed in Iron in place of Steel.

If the bottoms of the Boilers are covered with a good non-conducting material, no doubt the severe corrosion would be lessened, and this can be done with advantage also to the Boilers themselves.

I have had the pleasure of several conversations with Mr. Phillips during the course of his experiments, and it has been a matter of congratulation to me that he has given us his Paper and the benefit of his Researches, and I venture to hope he will see that his labour has not been lost or his time spent in vain.

Mr. A. W. ROBERTSON'S Remarks.

(*MEMBER*).

I feel it necessary to tender my quota of thanks to Mr. Phillips for the very able paper he has read, in which he brings before us the relative Merits of Iron and Steel to resist corrosion. The exhaustive experiments, extending over such a long period, and under such varying conditions, entailing such careful and close attention, must be considered valuable data for the guidance of Engineers in future.

Mr. Phillips asks us to give expression to our experience of Iron and Steel, but particularly the latter. No doubt, many of us could give considerable experience were it not that we were in a great measure under the ban of diplomacy and felt it to our advantage to keep quiet. However, I may mention an experience when I was a Junior Engineer on board a Steamer "many years ago." The boiler was made of iron, and at the end of each voyage it was washed out inside with fresh water and left open to the action of the atmosphere, with the surfaces all bared. Whether this treatment was the sole cause of the excessive pitting or not, I am not in a position to say, but in about six months after leaving the works the boiler had to be lined inside. Since then I have never seen such rapid corrosion either in iron or steel. And I might say have never seen such treatment.

The prevailing opinion seems to be, and it is borne out by Mr. Phillips' experiments, that Steel is more susceptable to corrosion than Iron under similar conditions. Such opinion is received as a fact on the East Coast by those shrewd gentlemen who have got to do with Steam Trawlers. Most of these craft, if not all, being of Iron, principally, as I understand, for the reason given, *i.e.*, the greater liability of steel to corrosion.

We must all recognise the very serious loss to owners of ship property due to corrosion both in Iron and Steel, and in many cases there may be doubts as to whether it is the result of carelessness in not properly cleaning and drying the plates before applying the paint, the fault of the paint itself, or the inherent weakness of the metal to give way readily under certain conditions; still the evil is done and the loss incurred, and to assist that evil and lessen the loss, I feel satisfied that if our ships were built in the various parts as accessible as possible, and all put under the supervision of one deeply impressed with the necessity of having all parts thoroughly cleaned and dried before painting, and all painted with most approved paint, as frequently as was compatable with the ordinary working of the ship, we would find that to be one of the best cures for excessive corrosion.

Mr. PHILLIPS' Reply.

Gentlemen, I thank you for your courteous and attentive hearing.

I regret very much that time has not admitted of a longer discussion, as I had hoped that many specific facts from the large experience of those present would have been elicited, which would have thrown valuable light on the various points raised by my paper. I note, however, with much satisfaction, that the general opinions which have been expressed, and which are derived from actual experience, confirm my contention that under similar conditions steel corrodes faster than iron; and that our Chairman is of opinion that it may be necessary to construct certain parts of a ship of iron rather than of steel, and that this may be done without detriment to either metal. This opinion, which I believe to be now pretty general, sets at nought, it need hardly be observed, the theory that injurious galvanic action is set up between iron and steel when in juxtaposition.

I do not wish to pose as an alarmist in regard to steel, nor am I for a moment blind to its great merits. With proper treatment, steel may, without doubt, be effectively protected, especially—with the aid of zinc—in boilers. My contention is simply that under similar conditions iron will withstand corrosion far better than steel. If, for instance, boilers were treated now as 18 years ago, the results with steel would be far and away worse than with iron; whilst, to come to now-a-days, the practice is growing to substitute iron for steel in those parts of a ship's hull where, as our Chairman has said, neglect is often unavoidable, or, in other words, where the conditions are severest. I cannot help believing, too, that at bottom it is this greater corrosion of steel which is the cause of the decrease in the reduction allowed by Lloyds in the scantlings of steel vessels, &c. What the extent of this decrease is, however, I have been unable to ascertain, some informing me that in stokeholds and engine rooms the reduction now allowed ranges from 5 to 15 %, whilst others aver that it has been altogether abolished.

Mr. Brett has referred to the greater endurance of "purer iron," and to the comparative corrosion of cast iron and steel. The latter question is of relatively small importance for constructive purposes, whilst the term pure iron must be taken as comparative only. Again, whilst the better class of irons corrode less than steel (which is after all a purer iron still), irons of the cruder and harder class corrode least of all, or at least so all my experience and all the experiments I have had to do with go to prove, and so all practical engineers admit.

For Mr. McFarlane Gray's flattering remarks I must express my especial thanks; but I must confess that I cannot quite follow his figures. His way of putting these is certainly graphic, but it presupposes that the corrosion in a plate will be evenly distributed all over its surface, whereas, of course, this is not the case, especially in the steels. Whilst the partially scale-covered steel plates show a slightly increased loss as compared with the bright plates, the reverse is the case with the partially scale-covered iron plate.

In his reference to this plate MR. GRAY has slightly erred.

I concur with MR. WILSON in thinking that, unless the crust due to corrosion is completly removed and the surfaces beneath thoroughly protected, it would be better to let the crust remain. MR. WILSON has suggested that it would have been well if artificial heat had been added to the conditions to which the N and B plates of No. 100 set, series I. were subjected; in this I concur with him also, but the large expenditure of time and personal labour involved in conducting the experiments rendered such addition impossible. It is only reasonable to suppose, however, that exposure to high temperatures (as in stokeholds) would have largely increased the injurious effects produced by the alternate dipping in sea water and exposure to the weather to which these plates were subjected, and a case in point is the steel vessel mentioned in my paper, in which parts of the frame work had entirely disappeared in 8 years.

To this question of heat under boilers, &c., Mr. ADAMSON also refers, as well as to the question of anti-corrosives. Into the latter subject I refrain from going, beyond the remark that the partially-painted plates in Series II show how both iron and steel, even when bright, can, with due care, be protected from corrosion when immersed in the sea. Extreme heat and want of circulation of air should in one direction be less with cylindrical than with the now extinct rectangular boilers, which were laid flat on floors or bearers, and placed either end to end or against bulkheads or bunkers; but, on the other hand, the increase of temperature due to an increase of pressure from 30 to 80lbs. to the square inch—and with higher pressures we have hardly had to deal—is about 50°. With triple expansion engines, again, the temperature is so minimized as to be not much, if any, worse than with low-pressure engines. My experiments go to prove, however, that the more severe the test the greater the corrosion of steel as compared with iron; and if it be remembered that the almost miniature scantlings of the old iron steamers of from 1000 to 2000 tons seldom, if ever, required repairs until the boilers were taken out after from 8 to 12 years' service,—and that in the Indian seas,—whilst the stokehold framings of the modern steel steamers of from 6000 to 8000 tons have had, in many cases, to be repaired after 7 or 8 years service, it will be seen that actual experience tells the same tale. Mr. ADAMSON, in fact, has seen many such cases, and is of opinion that iron will last from 20 to 30 per cent. longer than steel, and consequently that iron is preferable to steel for certain parts of ships' hulls.

It will not be out of place here to mention the extraordinary behaviour, recently brought to my notice, of two boilers made wholly of steel. The first was between 6 and 7 years old, and for about 3 years it was well protected by zinc, but the use of zinc had then to be discontinued. It was found to have suffered in the most extraordinary way at the back of the combustion chamber, internally. The plates, which were originally $\frac{7}{16}$in. thick, were reduced generally to $\frac{1}{4}$in., and in places were corroded through. The most defective parts were found to be in some places hard and brittle, in others soft and ductile, whilst the stays, originally $1\frac{1}{2}$in. diameter, were reduced, close to the nuts, to under $\frac{3}{4}$in., as the specimens I have here show. In the second case the combustion chamber had cracked, and when a part of the defective plate was being cut out the crack went on extending in various directions, being presumably another of those cases in which, to use the late Mr. SAMUDA's words, steel plays "fantastic tricks."*

Mr. ROBERTSON has remarked that many could give the results of considerable experience were it not that they "were in a great measure, under the ban of diplomacy, and feel it to their advantage to keep quiet," and I cannot but say that in this, I think, there is much truth. That it should be so cannot too much be regretted, for it is precisely the experience of practical men that is most needed, more especially as on this iron and steel question certain officials have committed themselves so far on the side of steel as to render them doubtless more or less reluctant to admit the truth of facts which tell the other way.

* Journal of the Inst. of Naval Architects, 1882.

REMARKS AND OBSERVATIONS

Made by several well-known Scientists, Engineers, and others in response to invitations issued after the Paper was read.

LONDON,
June, 1890.

I regret my inability to have been present at the reading of MR. PHILLIPS' paper on the "Relative corrosion of Iron and Steel." As a member of the Admiralty Boiler Committee to which he alludes, I know that the experiments which he records have been most carefully and impartially conducted.

Experimental data are still required, to show whether the inferior ability of so called Steel, as compared with Iron, to resist ordinary corrosion, be due to a minimum of phosphorus, want of homogeneity, or difference of structure. Iron or steel in *dry* air does not rust Iron or steel in water *free from air* does not rust. It is the combined action of air and moisture, which mostly contributes to the corrosion. There are accessories to ordinary corrosion; among these, in large towns, is sulphurous acid formed during the combustion of coal containing iron-pyrites (the smell of this gas is familiar to all travellers by the underground Railways).

In attributing the corrosion of iron to this or that cause, much confusion has resulted in the mis-application of the same line of reasoning to results which have been produced under different circumstances; that which is true of the corrosion of iron or steel in structures such as bridges, girders, cranes, &c. in the open air, and in this or that water at the ordinary temperature, may not be true of the same iron and steel, when forming part of a steam boiler. Such a boiler may be regarded as a close vessel, to which we can admit and from which, therefore, we can exclude what we please. The temperature of the whole boiler when under steam will be more than sufficient to insure dryness of the outside surface, and if a rational treatment in working be adopted there need be no more deterioration than ordinary and unavoidable "wear and tear" inside.

I must not go into details; these will be found in the facts which were obtained by the Admiralty Boiler Committee, and in the recommendations which were made by that committee to the Lords of the Admiralty, in the direction of improvement in the treatment and working of boilers in H. M. Navy. That improvement, and consequently, diminished expenditure would follow the adoption of those recommendations was an absolute certainty.

No condition exists more fatal to unprotected iron surfaces, than moisture and unlimited access of air. Familiar examples may easily be found, indeed, we might parody the old proverb "Tempus edax rerum," by saying "Oxygen edax Ferri," which is strikingly shown by the experiments to illustrate Mr. PHILLIPS' paper. The destruction of boiler plates sometimes commences *before* their manufacture into boilers, and were a tenth of the care bestowed upon them which we see in the case of polished machinery made of the same metal, there would be much less ground for attributing a very simple result, to such obscure causes as galvanic action or fatty acid.

CHAS. TOOKEY.

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WORTLEY IRON WORKS,

NEAR SHEFFIELD,

June, 1890.

The paper by MR. DAVID PHILLIPS on "The Relative Corrosion of Iron and Steel" is one of considerable interest in connection with an important branch of Marine Engineering. The value of the experiments is enhanced by the length of time during which the metals were exposed to the action of the sea water, and much credit is due to the author for the patient perseverance evinced throughout his investigations. The general conclusion at which the author arrives after his exhaustive series of experiments, is, that wrought iron "under most various conditions, is far superior to steel in its power to withstand corrosion." I may name that this is in accordance with my own conclusions on this subject, based on an extended series of experiments independent of those of MR. PHILLIPS. Having, during the last 25 years, devoted considerable attention to the study of the various aspects of the corrosion of metals, not only in sea water and tidal streams, but also in connection with colliery, mineral and other waters, it may perhaps be of interest in connection with MR. PHILLIP's research briefly to allude to some of my results. These have been mostly published in the following papers :—

"Relative Electro-Chemical Positions of Wrought Iron, Steels, and Cast Metals in Sea Water and other Solutions." (Trans. Roy. Soc. Edin., 1883).

** "Galvanic Action between Wrought Iron, Cast Metals, and various Steels during long exposure in Sea Water." (Proc. Inst. C.E., 1884).

* "Corrosion of Metals during long exposure in Sea Water." (Proc. Inst. C.E., 1885).

"The Electrolytic Corrosion of Metals in Sea Water." ("Iron," Vol. XXXIII., May 24th, 1889).

"Action of Tidal Streams on Metals." (Trans. Mid. Mining Institute, 1890).

A clear and comprehensive understanding of the difficult question of corrosion, like other matters, can only be obtained by regarding it from many points of view, and by bringing a steady accumulation of facts to bear on such an intricate and knotty subject. The results I arrived at, in course of a long series of observations, on the relative corrosibility in sea water of Wrought-iron, soft Bessemer steel, hard Bessemer steel, soft Siemens-Martin steel, hard Siemens-Martin steel, soft Cast steel, hard Cast steel, Puddled steel, Tungsten steel, and various cast metals were as follows :—

The experiments on simple corrosion, in which bars of wrought-iron, steels, &c., were exposed singly and separately, without liability to galvanic action, other than local, to the action of sea water for various periods exceeding two years, indicated a greater tendency to corrosion on the part of all the various steels than the wrought-iron. This remark also applies to the comparative behaviour of the steel and wrought-iron plates experimented upon. A reason for the steels corroding more than the wrought-iron, in

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** A Telford Medal and a Telford Premium were awarded to the Author for this Paper.

* A Telford Premium was also awarded to the Author for this Paper.

the case of simple corrosion, may perhaps be that the internal structure of steels is complex, and sometimes may exhibit several species of crystalline carbides of varying composition permeating the whole. This would of itself constitute a local source of internal galvanic disintegration.—The appearances of the first commencement of corrosive action, and also at the termination thereof confirm this view.

In connection also with this view, it will be found interesting to study a paper by the late MR. J. SPEAR PARKER, on "The varying conditions of Carbon in Steel" (*Chemical News*, Vol. 42, 1880, p. 88); and also the research on "The Cellular Structure of Steel," by MESSRS. OSMOND AND WERTH, of the Creusot Works, recently communicated to the French Academy of Sciences. See also the recent researches of DR. H. C. SORBY, F.R.S., on "The Microscopical Structure of Steel." (Proceedings of the Iron and Steel Institute.)

The results of my gravimetric experiments, both on simple corrosion and galvanic corrosion, which are a near approximation to what occurs in actual experiences, extending over several years, in the course of which different varieties of wrought-iron and steel were employed, of the compositions described in the above papers, and which were manipulated in the three distinct forms of drawn rods, rolled bars about 3in. diameter, and rolled plates, together with my other electrical experiments, concur in indicating, generally, less liability to corrosion on the part of the wrought-irons employed than in the case of the steels. It was also generally noticed that the corrosion was increased in the steels, in proportion as the percentage of combined carbon was greater.

The general results I obtained in course of the above experiments, show considerably less tendency to corrosion on the part of wrought iron than any of the steels, the advantage in favour of the iron as compared with the steels, amounting roughly to 25 per cent. and upwards, for the period of 2 years and 10 weeks during which the metals were under observation. Further, I found that the galvanic action between the wrought-iron and steels, induced a largely increased total corrosion in the several metals. The extent of the E.M.F. between the metals, which was ascertained by the use of delicate galvanometers, was found to be considerable. The above results are further confirmed by a series of many thousands of galvanic experiments which are recorded in the above papers. The additional observations made by my electric method of research, recorded in detail in above papers, on various metals, viz.:—Wrought-iron, soft Bessemer steel, hard Bessemer steel, soft Siemens-Martin steel, hard Siemens-Martin steel, soft Cast steel, hard Cast steel, Puddled steel, Tungsten steel, and various Cast metals exposed in sea water during considerable periods of time, further showed that the steels were more acted upon than wrought-iron.

It was my privilege some years ago, to observe another aspect of the corrosion of metals not previously noticed, which is liable to occur in tidal streams, or under similar circumstances where the different parts of a metallic Structure, Vessels, Boilers, &c., may be exposed to the action of waters of dissimilar salinity. Thus, the effect of the gradual rise and consequent inward flow of salt water, and the outward flow of fresh water, has a general tendency to arrange the waters of a tidal stream into long, overlapping, wedge-like layers or formations, the lower containing denser salt water, and the upper more fresh water. This disposition of the waters is modified very considerably by currents, inter-diffusion, and numerous other conditions. The arrangement and diffusion of the salt and fresh water, may not necessarily at all places in the stream, be of an even character, almost isolated bodies of salt and fresh water not improbably accumulating in the numerous creeks, basins, or other indentations along the shores, the general contour of a stream, the influence of rainy or dry seasons (affecting the proportion of fresh water), the fact of its estuary being either long, deep, and narrow, affording little fall, or, on the contrary, of a wide, shallow character, the state and times of tide, &c., and many other circumstances, also variously modify the diffusion results.

From the foregoing, it will, however, be readily understood that the upper and lower portions of a metal Structure, or Vessel, &c., although composed throughout of the same metal, would be exposed to eletrolytic disintegration, from the galvanic action of two solutions of different composition on the same metal.

Analytical examination of the composition of the waters, throughout the length of the tidal stream, during diffusion of salt and fresh water consequent on tidal action, reveals a very considerable difference in the proportion of saline constituents, between the water at the surface and that at the bottom, during certain times of tide. This difference amounting sometimes to nearly 100 per cent., and it may frequently be either much greater or less, according to tidal fluctuations.

Some particulars from my paper relating to the composition of the Thames water will be found in the following table.

THAMES WATER, JANUARY, 1878.

LONDON BRIDGE.			GREENWICH.			CROSSNESS.		
Depth from Surface.	Tide.	Chloride of Sodium in water.	Depth from Surface.	Tide.	Chloride of Sodium in water.	Depth from Surface.	Tide.	Chloride of Sodium in water.
		Grains per gal.			Grains per gal.			Grains per gal.
Surface	1 hour flood	1·98	Surface	2 hours flood	2·39	Surface	4 hours flood	91·95
Middle	,, ,,	3·46	Middle	,, ,,	2·47	20ft. 0in.	,, ,,	109·50
			27ft. 0in.	,, ,,	2·80	40ft. 0in.	,, ,,	117·46
Surface	½ hour ebb	2·36	Surface	2 hours ebb	3·95	Surface	½ hour ebb	104·48
Middle	,, ,,	2·72	13ft. 6in.	,, ,,	3·89	17ft. 6in.	,, ,,	110·16
Bottom	,, ,,	2·44	27ft. 0in.	,, ,,	4·14	35ft. 0in.	,, ,,	213·70
			Surface	3 hours ebb	3·05	Surface	1½ hour ebb	101·43
			11ft. 0in.	,, ,,	4·86	17ft. 0in.	,, ,,	130·35
			23ft. 0in.	,, ,,	2·93	34ft. 0in.	,, ,,	189·18

Somewhat similar action to that above described probably also arises in connection with the plates of a vessel, one side of which is exposed to the action of sea water, the other to that of bilge water, or water of different composition to the sea water. I have also made numerous experiments to investigate the relative corrodibility under powerful electrolytic action, of wrought-iron and various steels, under the influence of nascent oxygen, in sea water. The relative ratio of corrosibility under such action, being roughly represented by the following figures: Wrought-iron, 14; soft Cast steel, 19; Bessemer steel, 20; Puddled steel, 19; Puddled steel, *Chilled*, 22; hard Cast-steel, 25; Cast metal, 26. In course of a long research recently communicated to the Royal Society on "Electro-chemical effects on magnetising Iron," Parts I, II, & III (Proc. Royal Soc. 1887, 8, & 9) I observed indications that Magnetization exerts an influence tending to increase the corrosibility of steel in certain solutions, which metal, as is well known, after once having been magnetized retains more or less permanent magnetism. At the present time Vessels are mostly built of steel instead of wrought-iron, and inasmuch as the power of magnetic retention in steel far surpasses that of iron, it follows that steel Vessels may gradually become permanently magnetic from the influence of the Earth's magnetism, when pursuing their voyages in certain directions.

With the more recent introduction of steel for Ship-building it will be seen that another factor of disturbance is probably introduced in relation to the ship's compass.

Having shown that there are indications that magnetic influence tends to increase the corrosion of steel, we may possibly herein find an additional cause of the greater corrosibility of steel vessels, compared with iron ones, when long exposed to the action of sea water. From the preceding observations and references it will be seen that galvanic action, in its various aspects, is a considerable factor tending to increase the corrosion of the various Steels, Wrought-iron, and Cast metals. I am therefore under the impression that Mr. Phillips is inclined to attach too little importance to injurious effects arising from the local galvanic action. I have frequently observed in course of practical experience, that corrosion mostly starts from a number of centres or nuclei, and this is generally subsequently confirmed by the appearance of the various steel and wrought-iron plates, and this effect is chiefly due to local galvanic action between parts of the same plates, of slightly different chemical composition or physical structure.

In connection with this, reference may be made to the honey-combed corrosion of steel plates of the S.S. "Livadia" and other instances. Having had a long practical experience of the corrosive action not only of Sea water, but also of various Acid and other Mineral colliery-waters, on Colliery or Mill Boilers, Boiler-tanks, &c., and having endeavoured to carefully study the different aspects of corrosion, I thought it perhaps desirable to offer these few observations in connection with the interesting paper of Mr. David Phillips. I feel that Engineers and Metallurgists are greatly indebted to him for the results of his valuable and exhaustive research.

THOS. ANDREWS, F.R.S., M. Inst. C.E.

THORNTON HEATH,

June, 1890.

In reply to your invitation regarding MR. PHILLIPS' excellent paper, I would draw attention to a remark of Mr. Martell, quoted in the paper. "I could not help thinking" he says, "that *when the* "*steel is worked of fine scantlings*, and when parts, such as angles, "project from the surface and are not continuously coated, "oxidation soon commences, and it would appear that oxidation "goes on more rapidly in steel, in that case, than in iron."

To the general observer, it is not patent what the fineness (or otherwise) of the scantlings has to do with the matter. It is conceivable, that in pieces of iron or steel of fine scantlings, corrosion would be greater proportionately than in pieces of greater bulk, though even this is by no means obvious and would require, I should think, much experimental proof for its establishment. But what Mr. Martell appears to mean is, that the wasting in steel goes on more rapidly than in iron, when, and only when, the metals are worked of fine scantlings, and this is a proposition which appears to me wholly untenable.

This remark of Mr. Martell is interesting also from another point of view. It was stated at the meeting, that that gentleman had denied that the abolition of the reduction in the scantlings of steel vessels &c., formerly allowed by Lloyd's, had anything to do with the greater corrosion of steel. Surely this is very strange, in view of Mr. Martell's admission that when steel is worked of fine scantlings, it corrodes more rapidly than iron. Are we to understand that for reasons altogether apart from corrosion, steel is not to be of finer scantlings than iron, and in addition, that steel corrodes more rapidly than iron? If so, steel is truly in a sore plight and we may next expect to hear of an increase in the scantlings of steel, or of a decrease in the scantlings of iron. The only possible answer appears to be that which I have suggested as Mr. Martell's meaning, viz., that it is only when of fine scantlings that steel corrodes more rapidly, and that as the finer scantlings of steel have (from quite other causes) been disallowed, it may be expected in future not to suffer more than iron. An answer which I think may be left to answer itself.

Another point which impresses me strongly is the extraordinary contradictions in the evidence of the Admiralty Officials quoted. What can be more astonishing than the admission made to the effect, that although it was known *of a certainty* that the effects of black oxide on bare steel is as strong and continuous as that of copper, yet two ships had been coated, and one of them allowed to go to sea without the oxide being completely removed. Regarding this, one of two explanations seems possible; either the professedly certain knowledge was mere supposition, or there was culpable negligence somewhere, in allowing the vessels to be coated, with the black oxide on.

Upon the immense pains which Mr. Phillips has been to in conducting the experiments he has described, too much praise cannot be bestowed. No one who has read the paper can fail to see what a vast amount of care and patience must have been needed to carry out, with that unfailing regularity which was essential, all the operations in connection with the changing, cleaning, re-painting, &c., of the plates; and when it is remembered that the experiments lasted—not for a poor six months—but for three, seven, and ten years, it will be recognized how much all who are interested in the question (and who are not?) are indebted to the Experimenter for his persevering efforts to arrive at the Truth.

ARTHUR F. TAYLOR.

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ACTON,

June, 1890.

I do not complain of the references, which Mr. PHILLIPS has done me the honour to make, to a paper read by me long ago, at the Institution of Naval Architects, but regret that in that paper I failed to make my meaning clear, which must be taken as an apology for now having to refer to that now ancient document, at greater length than would otherwise have been necessary. To persons familiar with the laws of electrolytic action, the results which electrified some of my distinguished audience, as he thinks, were not very surprising. The electrical combinations were designedly so arranged, as to make the results, if any, appreciable.

These Admiralty experiments, it should be noted, had a much narrower scope than those described in the paper, and if you will excuse me saying so, rested on a broader and more certain basis. The primary object of the experiments was to test the effects of mill scale, on adjacent bare steel, when such action was continued for a considerable time. We were long familiar with the scoring and uneven wear of Wrought-iron, and had traced its origin to a cause in the process of Manufacture, which did not apply to mild steel, which, at this early period of its use, had shewn, not scoring, but uneven wear of a very marked kind, known as *pitting*. The mill scale, if acting electrically on adjacent parts, it was considered, might produce the form of pitting which actually occurred, in practice. The main object was to settle this point definitely.

In all laboratory experiments it is of the greatest importance, that the basis should not only be distinct and clear, but as broad as possible. In this case it was necessary to ascertain whether pitting from the corrosive action of salt water actually occurs when the mill scale is completely removed by any practical method, and secondly to ascertain definitely what the practical value of such action is if long continued, and thirdly to get a comparative value with the known effect of copper under identical circumstances. It may here be noticed that if we, who arranged the tests, merely desired to know whether there is electrical action between the mill scale and any adjacent bare steel or iron—a point on which the author of the paper seems still in doubt—we had the means of actual proof at hand, but we had no such doubts, we desired to know how such well known action is effected by time and its own products. The experiments extended over $2\frac{1}{2}$ years, not six months as stated, in error, in the paper under notice, and the plates were so arranged that at each examination the electrical action could be measured direct. All the plates tested were each 24in. by 12in. by $\frac{3}{16}$in. They were arranged parallel, and near each other, in a grooved wooden frame, completely insulated from each other; one series of the bright plates had the oxide removed, by planing and filing smooth, another had the oxide scale removed, by pickling in dilute acid as for galvanizing, for reasons that need not be explained here, as the results of the two shewed no difference in the two methods adopted in removing the scale. The plates to be used with mill scale were carefully selected, with as few blemishes in the scale as possible, and these blemishes, where they existed, were carefully coated with waterproof varnish as were the edges of every plate in the series, whether with scale on or otherwise, for reasons that will appear hereafter. The coupled plates were connected by a narrow iron strap at the top, thoroughly protected by waterproof varnish. All the Iron plates in the experiment were of one kind, B B Staffordshire, and all the Steels, Siemens, Landore. We did not then attempt to fly so high as to compare Yorkshire with Staffordshire iron, or different makers of mild steel, believing that differences that may exist are modified by care in the process of manufacture, and will vary according to the process, rather than by the country in which it takes place, in other words, that such variations as may occur are due to the foreign matter in the iron, and not to the ore from which it is made.

The general result of these experiments was that no pitting occurred in mild steel when freed from the mill scale; that the loss of weight from corrosion of clean mild steel and clean iron, under identical conditions and circumstances did not differ much; and that the action of mill scale is considerable and continuous, about equal to that from combined copper of the same surface. It was noticeable that the wear of the insulated clean steel plates was not uniform over the whole surface; in some cases the wear on certain parts was so small, that the file marks were still to be seen, SIR W. SIEMENS' attention being called to this, he expressed the opinion that it arose from the uneven mixture of the manganese, an opinion that other observations made since has confirmed. Since these experiments, the necessity of removing the mill scale from steel plates that may be exposed to the corrosive action of salt water, has never been doubted by the Admiralty. The cases noticed by SIR N. BARNABY shew no wavering practice. The ships referred to had already been plated with unpickled plates.

Some remarks of mine, quoted in par. 2 page 27, were intended to illustrate an unexpected advantage of the pickling process, and had no reference to the want of homogeniety of mild steel. The point is of some practical importance, as discovering a surface defect covered by the mill scale. The origin of this, not uncommon defect, is a cavity in the surface of the ingot in the process of casting. If this cavity is not gouged back far enough, before rolling, the metal draws over it, forming a sort of feather in the finished plate. In the case referred to, many of these extended the whole length of the plate, and although none were very deep, some extended $\frac{3}{8}$in. from the surface in a slanting direction.

The author of the present paper is very tender on what he calls galvanic theories. It should here be clearly understood, that the Admiralty experiments were not based on *any* theory, the presence or absence of electrical action in any specified combination of metals, as this can be determined in a few minutes with absolute certainty, not only as to its existence, but, its exact amount for the time being; such in brief were the Admiralty experiments and their object. It is quite possible to infer too much from them, they were after all but a big laboratory experiment, the results of which differed widely from those given in the present paper, as might be inferred from a careful comparison of the methods adopted. The bare perusal of MR. PHILLIPS' paper, brings forcibly to mind the unwisdom of the man spoken of in Holy writ, who built a house on the sand, with the difference, that in this case the foundation is narrow as well as sandy, he seems to have been lavish only in time and labour and a very miser in material.

The first Series, Sets Nos. 98, 100, 101, consisted of six plates 4in. by 4in. by $\frac{3}{8}$in;—no two plates being of the same kind of material. Here then a single plate of a few superficial inches, is made to do duty for all its kind, which should have suggested great care in arrangement, but instead, they seem to have been strung together in the most unintelligible way, without any attempt to ascertain that they fairly represent their respective classes, or to eliminate local differences in the plates. They seem to have been purposely chosen thick, thereby introducing a possible source of error, from the oxide laminae always exposed in the cross section of rolled iron, and important enough in small plates like these, to make any inference or comparison, on the basis of loss of weight, misleading.

As regards the results shown in Table I., it would appear that the letter-press has gone wrong in a way which makes any attempt to correct them too much for me. If for example we change the sub-heading which appears as oz., in columns 5 and 6, to inches, to harmonize with the general heading "Area," we but get from one horn of the dilemma to another. In set No. 98, for example, plate J loses in the test 2·800 oz., and 0·8 square inches in surface, whilst plate Y, with a loss of 2·560 oz. loses no surface at all, again if we alter the general heading "area" to oz. to harmonize with the sub-heading, the weight of the plates, viz. 37·9 oz. is impossible for the size stated, we therefore give up the attempts to guess the meaning, only remarking, that it is curious that in an experiment on so small a scale as to size, it should have been assumed that the different metals are all of the same specific gravity. If the Staffordshire Iron plate really weighed 37·9 oz. the same size of Yorkshire would weigh 39·781 oz., an error that would reduce the apparent difference in their loss, when weighed afterwards.*

Coming next to Series II., consisting of three varieties of metal, we find these six plates are not only made to show the relative endurance, under a variety of conditions of exposure, but also the effect of mill scale on mild steel; and in the arrangement of the plates relatively, he assumes what he sets out to prove, and accomplishes the novel feat of making a galvanic couple of three plates, all different to one another; with such an arrangement it is needless to discuss the results further than to observe, that they are impossible as shewn in the table which also shews that the Bessemer plate 1, is apparently reduced in superficial area 4·7 square inches by a loss in weight of 2·360 oz., which is absurd.

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*By Printer's error *oz.* was placed for *square inches* in Table I. (It was specially noted that the copies of the paper issued for discussion purposes were only proof copies). This obvious error was corrected in the original proof, but overlooked by the compositor in second proof, copies were thus unfortunately issued with the error referred to, but corrected subsequently. In either case, however, the table showed a loss, not in surface, but in *exposed* surface, and this loss was due to corrosion.—J.A.

Series III is considered the most important and conclusive, as confirming the author's previous experimental results, here it is evident the author has not only attempted too much, but has failed to see the full meaning of the results. He has already arrived at the general conclusion, that iron under a variety of conditions of exposure, loses less than steel, and now he apparently is not surprised to find, that it loses less when coupled to bright steel, than when it is not, and his method of testing the effect of mill scale is to couple a plate, only partly covered by scale, to an iron plate all bright; in other words, he finds work for the scale to do on the bare parts of its own plate, and estimates its effects on the iron plate. It is noteworthy that he finds it necessary to explain away the slight scoring that might be expected in such a combination as he adopted, and which is the only effect to be anticipated from such an arrangement of metals, differing but slightly from one another electrically, but if they differed widely, the arrangement is such that no arithmetic could have shown its value. It is a well known law of electrochemical action, that the amount of work of any couple, varies as the squares of the distances between the surface of the active metals; in this case, the surfaces were not parallel and it would vary as did the surfaces per unit of distance, yet the effect is estimated by arithmetically calculating on the whole area of surfaces unequally excited.

In speaking of the protection given by the mill scale, Mr. Phillips may be surprised to hear that he is unconsciously *admitting* its electrical influence, as any other kind of protection can only be from keeping the corrosive liquid out of contact with the metal, as in the case of water proof paints. As a matter of fact the scale is not water proof, and its protective effects are due to the polarisation of the atoms of the liquid, whereby the oxygen constituent, is turned away from the surface of the steel, in the manner explained by Faraday long ago. It is much to be regretted that so much labour and time should have been spent on experiments, from which so little can be learnt with certainty.

J. FARQUHARSON.

Aberayron,

September, 1890.

Having from the beginning taken more than ordinary interest in Mr. Phillips' experiments, and having assisted him on several occasions in putting down and taking up the plates comprising Series II and III, a few words from me will not perhaps be inopportune. I need not point out how very valuable the results of his investigations will be to engineers, civil and practical; but my object pincipally in penning these remarks is to bear testimony to the extraordinary care and trouble taken, and perseverance shown by Mr. Phillips throughout, whilst carrying out, to him personally, the rather thankless task which he undertook to further inquire into the question of comparative Corrosion of Iron and Steel. In fact had his "bread and cheese" depended solely on the results of his investigations, he could not have been more diligent and careful. I am not judging of this from the labour, which none can fail to discern, he has bestowed in calculating and tabulating the results given in his paper, however simple his tables appear to be; but I speak from what I have actually witnessed from beginning to end. Mr. Phillips trusted *no one* but himself in everything where care was necessary. Except keeping the culvert in repair during his absence in winter, his eyes were never off the object he was engaged upon. No one can fail to see the amount of labour involved in cleaning, weighing, painting, and taking casts off the test-plates half-yearly, all of which he appeared to look upon rather as an amusement than otherwise, but which I, though an engineer, could not otherwise than be often surprised at.

Of the relative endurance of Iron and Steel I have had no practical experience, but from what I have witnessed, from time to time, in the behaviour of the metals experimented upon by Mr. Phillips, I could not, irrespective of the figures giving the losses, come to any other conclusion than that the advantage was *very* considerably on the side of Iron.

The thanks of the engineering profession, steamship owners, and metallurgists, are due to Mr. Phillips for his valuable paper, the value of which is much enhanced on account of his disinterested motives.

B. E. HOWELL.

—‡o‡—

Aberayron,

September, 1890.

Business of a pressing nature prevented my having the pleasure of attending the meeting at which Mr. Phillips read his most interesting paper upon the "Relative Corrosion of Iron and Steel under various Conditions." I much regret the circumstance of my unavoidable absence, as it was my earnest desire to be present, that I might bear an impartial testimony to the faithfulness to truth and extreme accuracy, with which those of the experiments of which I was an eye witness were carried out at Aberayron. As to the general and relative merits of the various arguments advanced in the discussion, I must say at once that my knowledge of iron and steel is merely that of the thirty years' experience of a plain practical engineer, derived chiefly from the use of them in engineering works, and that such highly-scientific causes of corrosion as, galvanic action between the plates and fatty acids, are to me veiled in a considerable amount of obscurity, and are surrounded by an Abracadabra-like halo of mystery.

Looking at the exposed plates from a practical point of view, it undoubtedly appears to me that the lower qualities of iron are more free from corrosion, under all conditions to which they may be exposed in engineering works, than are the highest qualities of iron, and especially more than is mild steel; and until someone more clever than I am, can prove the contrary, or show some error in Mr. Phillips' experiments, I feel compelled to accept the above deduction as based on established fact.

Whatever conclusions may be arrived at by those holding different opinions upon the subject, of this I am certain, that the greatest care was taken to keep the plates continuously under the exact conditions required for the experiments, and when I saw the plates which were immersed in the sea finally removed, the structure in which they were exposed had undoubtedly been kept in and under the exact conditions in which it had originally been built, and as described in the paper and diagrams.

Opinions may differ as to the deductions to be derived from the experiments, but there can be no two opinions as to the extreme care, impartiality, and patient attention which has been throughout bestowed by Mr. Phillips upon the conduct of these long experiments, and every engineer engaged in works of construction should be grateful to him for the extra store of experience which he has gratuitously placed at the disposal of the profession.

G. A. HUTCHINS,

M. Inst. C.E.

ADMIRAL MURRAY AYNSLEY'S Remarks.

The results of the Admiralty Boiler Committee's experiments fully bear out those of Mr. Phillips' experiments, which (the former), with but one exception, pointed to the fact that the purer the metal the more is the corrosion, and, consequently, steel:—as the purer metal, suffers most in all comparative experiments between iron and steel, it being borne in mind that from the way iron is manufactured, there must be laminations more or less marked, and that at the edges where these mostly show themselves, the corrosive action is more severely felt, and also against a more or less imperfect surface, than against that shown by steel.

I am inclined to believe that the presence of a certain amount of phosphorus is necessary to give resistibility to corrosion, and that the pains taken to eliminate this from steel, either by the mode of manufacture, or by the selection of the iron for conversion, leads to less resistibility of the steels to corrode.

Mr. Phillips remembers, no doubt, the case of the "Crampton Iron," when Mr. Crampton himself, after his iron had been tested and not knowing whose it was, said "That man knows how to make bad iron." This iron showed by the hot and cold tests that while it was free, or nearly so, of phosphorus, it had a very large percentage of sulphur, consequently, as its corrosion was worse than any of the other irons, sulphur did not give it resistibility.

I have only to add that I consider that Mr. Phillips' experiments are most valuable, as showing the necessity of chemists and steel manufacturers going thoroughly into the question as to the cause of the difference in the corrosion of the two metals, and ascertaining what changes, or steps, are necessary to obviate it.

C. MURRAY AYNSLEY.

Mr. PHILLIPS' Reply to Correspondence.

I cannot help feeling disappointment that Mr. Tookey, than whom, as an expert chemist and a member of the First Admiralty Committee, few are better qualified to express opinion on the various points raised, should have said so little of a definite nature. Especially should I have liked to hear his opinion as to the galvanic effects of iron and steel upon each other when connected together as in practice, as to the alleged injurious galvanic action of black oxide, and as to how far the evident want of homogeneity displayed by some of the steel plates might be due to excess, or want of diffusion, of the manganese, and I should have thought that the appearance of the experimental plates and the tables of losses of weight would have assisted him in coming to some conclusion.

However, in regard to the main question, Mr. Tookey has no doubt as to the inferiority of steel to iron in withstanding corrosion, and one or two other of his remarks are eminently suggestive. Thus, he seems to consider that what has been due to bad treatment of boiler plates, &c., has been readily attributed "to such obscure causes as galvanic action or fatty acid," and names as the possible causes of the inferiority of steel "a minimum of phosphorus, want of homogeneity and difference in structure"—apparently excluding galvanic action. As to the part which phosphorus plays in corrosion, authorities are much divided. In 1881 I ventured to suggest—not as having original knowledge on the subject—that the superiority of Crude iron over finer iron and steel might be due to the presence in the latter of a minimum of impurities, and especially of phosphorus, and for doing so, was severely taken to task by Sir F. Abel. Yet Dr. Percy—no mean authority—considered that phosphorus played an important part in this respect.

To Mr. Andrews, who is not an experimenter only, but a metallurgist, an engineer of considerable experience, and a large manufacturer of metals, and who thoroughly understands the question of the corrosion of metals in all its phases, all members of the Institute will, I am sure, feel much indebted for his valuable and exhaustive observations.

To me it is eminently satisfactory to know that the results of the experiments and observations of such an authority, spread over a space of 25 years, coincide with mine—in so far as they are comparable—in showing the great superiority of iron over steel under the most various conditions in withstanding corrosion, a superiority which Mr. Andrews puts roughly at 25 per cent. and upwards, and which was manifested, not only when the test pieces were exposed separately, but also when they were galvanically attached, and when tested by the electric mode of research; and it is all the more satisfactory, because Mr. Andrews considers that galvanic action plays a great part in corrosion, whilst I have held that for practical purposes it may be neglected.

On this point, Mr. Andrews—very courteously—expresses the opinion that I attribute too little importance to the injurious effects of galvanic action. It may be so, and I have not wished to take up a dogmatic attitude, but whilst not for a moment adopting the absurd position of denying the existence of such action, the conclusion I have drawn from experiments and experience is that in actual practice its effects, if any, are trivial, and that the cause of the greater corrosion of steel must be sought elsewhere.

The case of the Crampton iron mentioned by ADMIRAL MURRAY AYNSLEY—with whom I had the honour of being associated on the Admiralty Boiler Committee—I remember very well, and to his descriptive paragraph I have nothing to add, whilst I have already referred to the question of phosphorus.

To MR. HOWELL, who often very kindly assisted me in the conduct of my experiments, and to MR. HUTCHINS, who was an appreciative witness of them, I tender my best thanks for their flattering remarks in regard to my labours. To have such testimony from such eye-witnesses is to me a most lively satisfaction.

MR. FARQUHARSON's remarks are characterized by that polish and urbanity which so much distinguish him. His statement that my reason for considering the third series of experiments "the most important and conclusive," was because they confirmed my previous results, and his suggestion that I *purposely* chose the plates of Series I. thick in order to introduce a possible source of error, would, perhaps, be best left unanswered, but, as they distinctly impugn my good faith, I feel bound to rejoin. First, then, my reason for choosing the plates of Series I. $\frac{3}{8}$-inch thick was simply that they were at hand and prepared for testing, and as $\frac{3}{8}$-inch approximates to the average thickness of plates in general use by engineers for constructive purposes, I fail to see any objection to them on the score of thickness; whilst, secondly, I never spoke of the Third Series as being more *conclusive* than the others—the word is MR. FARQUHARSON's own, though he conveniently attributes it to me:—what I did say was that I thought them "more *comprehensive* and important" than the others, and my reason for thinking so was that the plates were larger, that they were connected together as in actual practice, and that the points proposed to be tested were more in number.

In my paper I had occasion to refer to some experiments described by MR. FARQUHARSON in a paper read by him at the Institution of Naval Architects in 1882, which had for their object to test "the Corrosive effects of Steel upon Iron in salt water," and which, as the annexed quotations from the paper will show, lasted *only six months*. "Although," says the paper, "the "Admiralty practice does not involve combinations of iron and steel "to any great extent, the question raised *last year* was considered "of sufficient importance to test by actual experiment, the results of "which I am now permitted to bring before you," and goes on further, still referring to the same question, "the whole series so "arranged were placed in Portsmouth Harbour, and left undisturbed "*for six months*, when they were taken up and again weighed." To these experiments MR. FARQUHARSON—perhaps discreetly—does not refer, but some other experiments referred to incidentally in the same paper he is at some pains to describe, and takes occasion to remark that they lasted not six months but 2½ years, a denial which, if not misleading, is purely gratuitous. As to its accuracy, I, of course, accept MR. FARQUHARSON'S word, but it is strange that in his paper it is stated that "the results went to show that there is practically no diminution at the end of *six months* immersion, &c."

The object was to test the effects of mill scale, on adjacent bare steel, and the results, says MR. FARQUHARSON, went to show (1) That the action of mill scale is as strong as that of combined copper of the same surface, and (2) That pitting does not occur in steel freed from scale. In contrast to this second statement we have, six lines lower down, MR. FARQUHARSON'S admission that "the wear of the *insulated clean steel plates* was not uniform over the whole surface," and the further statement, already quoted, that one of the results disclosed by pickling was that steel "when entirely freed from its surface oxide did not wear evenly;" whilst, as regards the first, which had been put forward as a positive fact by SIR N. BARNABY in 1879, the last-named gentleman admitted in 1881 that two vessels had been coated with composition before the black oxide had been completely removed. This remarkable admission MR. FARQUHARSON disposes of by the remark that these cases showed "no wavering practice," as "the ships had already been plated with unpickled plates." Why steps were not taken before coating to remove the oxide, known, as alleged, to be as injurious as combined copper, MR. FARQUHARSON does not condescend to inform us, and we are left to form our own conclusions as to the difference between Admiralty "certain knowledge" and Admiralty "speculative beliefs."*

MR. FARQUHARSON goes on to remark that I am very tender on galvanic action theories, and takes occasion to inform us that the existence of electrical action in any specified combination of metals can be determined with absolute certainty, a piece of information of which he appears to consider us ignorant, and himself and Admiralty Officials alone the proud possessors. It will

* See Page 32.

be well, therefore, for me to explain that by galvanic action theories, I do not mean the assertion that galvanic action exists between steel and iron, or steel and its oxide, but that it has the alarming effects which have been ascribed to it—in short, that in actual practice its effects are so slight that they may be neglected. My remarks refer to any action existing between steel and iron, or between steel and its oxides, and not to galvanic actions in general.

I come now to MR. FARQUHARSON's remarks on my experiments. MR. FARQUHARSON compares himself to the man who built his house on a rock, and me to the man who built his house on sand, the comparison is strengthened by the well-known facts that Admiralty Officials generally are celebrated for their foresight and freedom from all mistakes. When, however, we descend from allegory to dry facts, it appears that the difference between my experiments and the Admiralty experiments which are contrasted with them was, that in the one set some plates were insulated and some connected by ferrules, or iron and steel bolts, whilst in the other, some plates were insulated and some connected by narrow iron straps.

MR. FARQUHARSON's criticisms of Series I. are chiefly confined to a printer's error, the nature of which must have been perfectly obvious to him. If criticism is to be reduced to this level, it would be easy to rejoin with questions as to some of MR. FARQUHARSON's remarks. It might, for instance, be asked whether when he speaks of "superficial area," he is aware of the existence of "linear area," or "cubical area," and it would be interesting to know what is the precise nature of "tracing an origin to a cause." To spend time on such questions, however, appears to me to be childishness, and it is not surprising to me therefore, that MR. FARQUHARSON should have found the arrangement of the plates unintelligible. As, however, this is most clearly set forth (at page 7), I submit that the want of intelligence in this respect is not mine, and content myself with remarking that no plate was compared with another, unless they had been under the same conditions. The statement that no two plates were of the same kind of material is untrue, as a glance at Table I. will show. Untrue also is the statement that the plates were all assumed to be of the same specific gravity. The area of exposed surface before testing was arrived at by multiplying the length into the breadth and the thickness at the edges (all the plates being bright), and as there was no appreciable difference between the dimensions of the various plates, the areas were shown as the same. Nowhere in the paper is it stated that the weights were all the same. These, as carefully ascertained by weighing, varied from 27·65 to 29·91 ounces.

In what way by the arrangement of the plates in Series II. I "assumed what" I "set out to prove" MR. FARQUHARSON is not good enough to explain. The arrangement of the plates when connected was similar to what occurs in actual practice, where steel combustion chambers are closely stayed to iron shells and iron tubes put into steel tube plates, &c. When, however, he says that I accomplished "the novel feat of making a galvanic couple of three plates, all different," I join issue with him again. I did not say that the plates, when connected, constituted a galvanic *couple*, but that they constituted *what is called* a galvanic *group*, the term not being my own. The results of this series are, says MR. FARQUHARSON, "impossible" (*i.e.* untrue), because the Bessemer steel No. 1 is "reduced in superficial area (*sic*) 4·7 square inches by a loss in weight of 2·36 ounces, which is absurd." Absurd indeed, but whose is the absurdity? The plate did *not* lose, nor is it shown as loosing, 2·36 ounces in weight, and 4·7 square inches in "superficial area." It lost, as shown in Table II., 18·055 ounces in weight, and the *area of its exposed surface* was, through corrosion, reduced by 4·7 square inches. I do not complain that MR. FARQUHARSON should not have taken the trouble to read my paper, but that he should, without having looked at them, declare the figures which it contains to be "impossible," is hardly honest criticism.

To follow MR. FARQUHARSON further is very much like flogging a dead horse, but whilst neglecting—in view of what has been said of the mode of criticism adopted—all general declamation, it will be well to meet distinct charges.

The first, as regards Series III., is that I am not surprised to find that the iron plate B 1, which was coupled to a steel plate, lost less than the insulated iron plate B 5. As, however, at page 23, I state that whilst it is difficult to altogether account for this difference, the insulated plate appears to have been dirtier and less homogeneous, this must be set down as another of MR. FARQUHARSON's misstatements. It is noteworthy that whilst MR. FARQUHARSON implies that this greater loss of the coupled iron is such as he would have expected, it ought, according to his 1882 paper, to have been such as he would *not* have expected, seeing that the coupled iron plates therein referred to lost nearly twice as much as the insulated irons;—which, with other figures given, was made the basis of the theory, that by means of galvanic action, steel injuriously affects iron to which it is electrically connected.

The second charge is that my method of testing the effects of mill scale was to couple a partially scale-covered steel plate to a bright iron plate, and that, thus having found work for the scale to do on the steel, I estimated the effects of the scale on the iron. This is yet another misrepresentation. I was comparatively little concerned with the effect (if effect there be) of scale upon *iron*, and I certainly never attempted to estimate the effects upon iron of scale upon attached steel. I was, however, very desirous of making test of the alleged injurious effect of scale upon steel, and with this view included three partially scale-covered steel plates in Series III., one, as stated by Mr. Farquharson, attached to bright iron, whilst, as carefully *not* stated, one was attached to a partially scale-covered iron plate, and one was insulated.

Mr. Farquharson goes on to say that the slight grooving which occured near the joints of the coupled plates was the only result to be expected from a combination of metals differing but slightly from one another, electrically, as did my test plates. This it is difficult to understand when in opposition we quote Mr. Farquharson. The plates in my experiments were of B B Staffordshire iron and Siemens steel, and those metals, says Mr. Farquharson, differ so slightly, electrically, that nothing but a slight grooving in either metal could be expected as the result of their combination. In the experiments described by Mr. Farquharson, the plates were also of B B Staffordshire iron and Siemens steel, and they differed electrically so much that as the result of their combination the irons lost five times as much as the steels. It is interesting to note in contrast to these remarkable results, that in Mr. Andrews' experiments on "galvanic corrosion," the combined steel plates lost 39 $^0/_0$ more than the combined irons.

I am not like Mr. Farquharson, an authority on electro-chemistry, and personally will not therefore attempt to deal with his enunciation of its laws. The passage in which this occurs however appeared to me to be so extraordinary that I submitted it to a friend who favours me with the following remarks:—

"I recommend readers to take the last sentence of the "penultimate paragraph of Mr. Farquharson's remarks first, and "if they believe that the action varies as the square of the distance, "as he says it does, they may then agree with him in all the other "statements he makes. This is a statement quite new to me. As he "puts it the action is greater when the distance apart is greater. "Say, if one of the plates had been placed in New York Harbour "and the other off the Irish Coast, instead of having been, perhaps, "only one inch apart, then the rate at which the reduction of "weight would have gone on, according to Mr. Farquharson's "'well-known law," would have greatly exceeded the rate of "production of iron and steel in the whole world. Even granting "him the benefit of a correction to the extent of admitting that "he means just the reverse of what he has written, still I say then, "that it is a novel principle in electrolytic action that he is now "putting forward, and one for which there is no foundation.

"The corrosion dealt with in the paper is the result of "secondary action in electrolysis, and it must therefore be "principally proportionate to the amount of the primary electrolytic "action. That depends upon the amount of electricity passing, "and that again depends on the resistance in the circuit and on "difference of potential.

"Where the geometrical relation comes in which Mr. "Farquharson says is 'a well-known law of electro-chemical "action,' it would be very interesting to know; and if Mr. "Farquharson will write a paper about it he will be surprised to "find that he has been for a long time the fortunate possessor of "knowledge of great importance, but a profound secret to all the "rest of the world, and all the time undervaluing his own "knowledge and calling it "a well-known law."

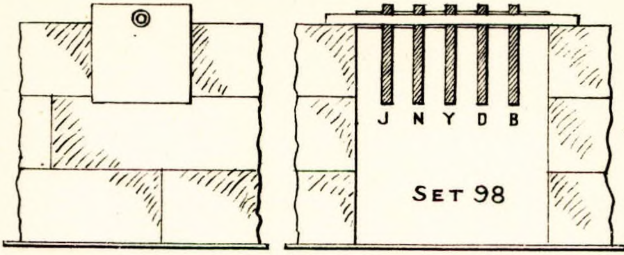
One word more and I shall have done with Mr. Farquharson. As after $3\frac{1}{4}$ years' immersion so little of the scale was detached from the partially scale-covered plates of Series III. of my experiments, and as some of the scale remained on the No. 2 steel of Series II. after nearly 7 years' immersion in the sea, I must decline to accept his statement that "scale is not water-proof," and that its protective effect is solely due "to the polarization of the atoms "of the liquid, whereby the oxygen constituents are turned away "from the surface of the steel."

I would add that, having been a member of the First Admiralty Boiler Committee, the treatment that I have received at the hands of Mr. Farquharson—an ex-Admiralty Official—has not surprised me. The labours of that Committee resulted in the saving of hundreds of thousands of pounds to the Nation, but the Admiralty Constructive Staff have had none but ill words to say of it. Reference has been made by Mr. A. F. Taylor to the contradictions in the evidence of Admiralty Officials, and I am strongly tempted here to mention some of my own experience on this point. They started—whilst that Committee was still sitting—experiments in the "Camel" and "Trusty" tugs, which had the same object as those which were being conducted by the Committee, and the results obtained have gone the round of the civilized world as proving the superiority of steel over iron in withstanding corrosion.

Yet, when the Committee, who had been kept in ignorance of this proceeding, chanced to come upon the report of the results, they found that these had been reported by the Dockyard Officials, and acknowledged by a high Admiralty Official as being very far from favourable to steel. It was, therefore, not surprising to me to find that the second Boiler Committee, which consisted of Admiralty Officials only, produced in a few months results completely the reverse of those obtained by the First Committee after 4 years' labour.

To conclude, I would observe how much more important it is to shipowners, to use in the construction of their ships, and especially in those parts most liable to corrosion,—which, in consequence of long voyages, small crews, &c., are necessarily more or less neglected,—the metal best able to withstand corrosion, than it is to the Navy, the ships of which have but an occasional few day's steaming, and crews three or fourfold those in the Merchant Service.

FIG I



Bricks.

Bottom of Water-Butt.

FIG 2.

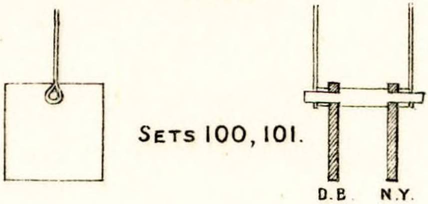
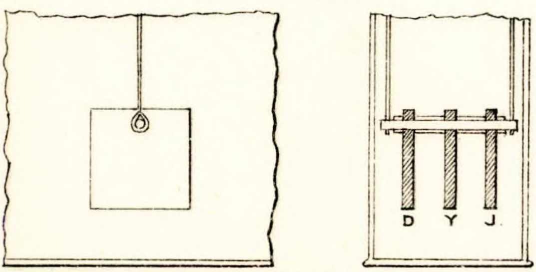


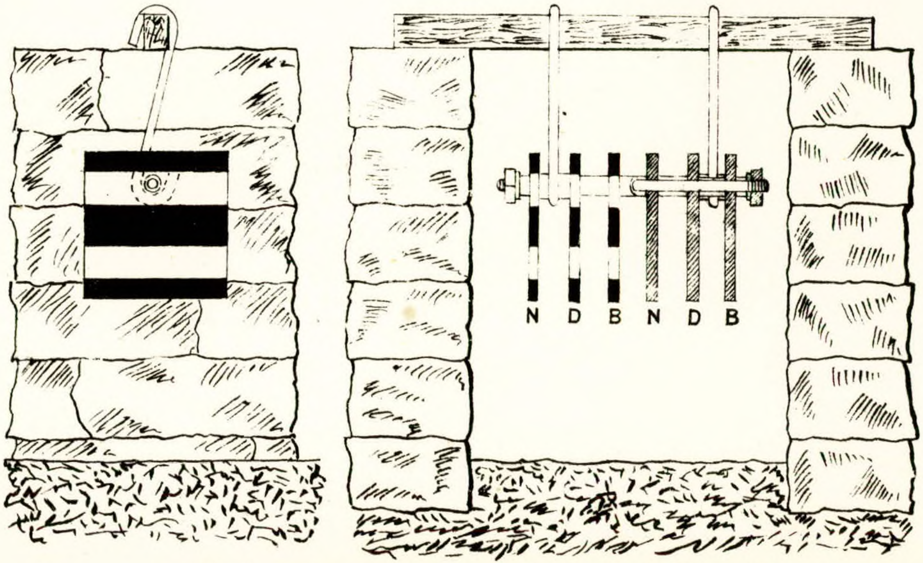
FIG 3.

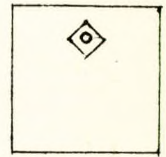


SET 101. *Tank.*

Scale, $1\frac{1}{2}$ *inch—1 foot.*

FIG. 4.

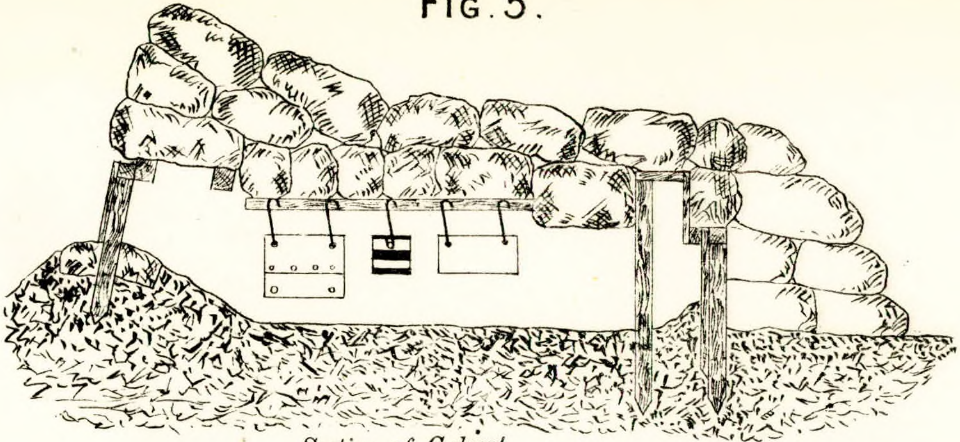




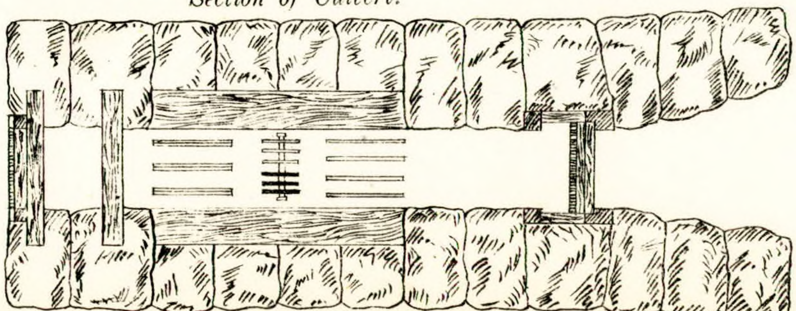
Scale, $1\frac{1}{2}$ inch—1 foot.

Black parts represent the surfaces protected by paint.

FIG. 5.



Section of Culvert.



PLAN OF CULVERT.

Scale, $\frac{3}{8}$ inch—1 foot.

FIG 6

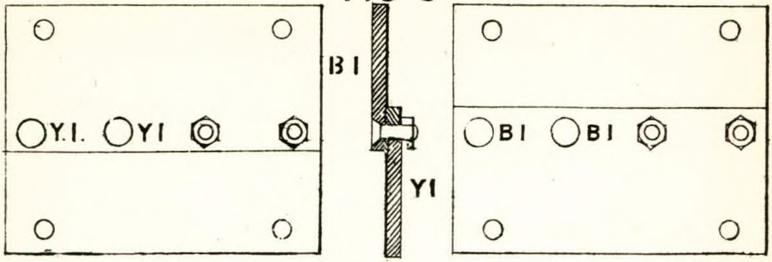


FIG 7.

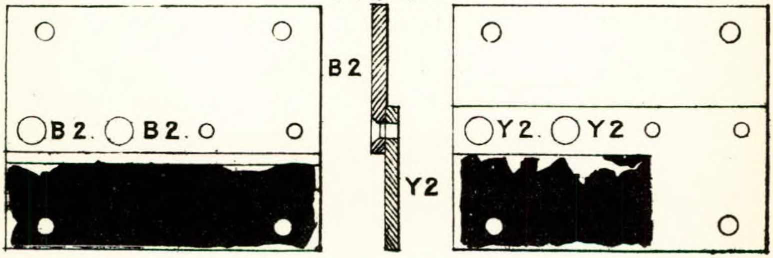


FIG 8.

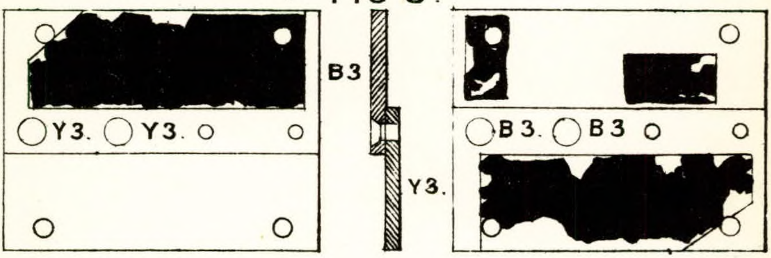
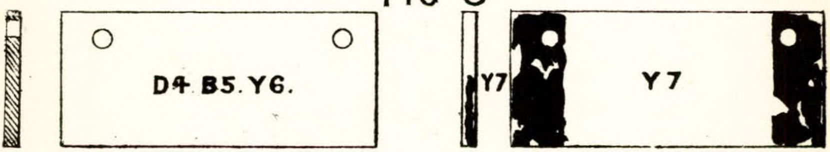


FIG 9



Scale, 1½ inch—1 foot.

Black parts represent the surfaces covered with Scale.

THE LANGTHORNE ROOMS,

BROADWAY, STRATFORD,

May 27th, 1890.

PREFACE.

A Meeting of the Institute was held this evening, presided over by Mr. G. W. Manuel (President), when a Paper of a preliminary character on the subject of Ventilation was read by Mr. D. G. Hoey (Honorary Member).

A further Paper is in preparation, dealing with a systematic and detailed arrangement of ventilation suitable for every department of Steamships. This Paper will be ready, in ordinary course, for reading during the second half of the current session.

In order that the discussions on this as well as on the other subjects brought before us from time to time, may be productive of the greatest possible benefit and embrace the greatest area, it is desirable that Members unable to be present should contribute their Remarks in writing to be read at the Meetings, if possible, or forwarded as soon as possible afterwards.

JAS. ADAMSON,

Honorary Secretary.