

38,000° C., and inconceivably attenuated as this interplanetary atmosphere would be, the moon would yet come into contact with 600 kilogrammes of it in each minute of time. On a body like the earth, surrounded by an atmosphere, the inevitable result of this unceasing collision with the interplanetary atmosphere would be the stripping away of the terrestrial atmosphere layer by layer. Arriving at results of a similar unacceptable character from the consideration of the action of a diffuse interplanetary gas on the other members of the solar system, M. Hirn decides that matter exists only in a sporadic state in space; only in the state of distinct bodies—stars, satellites, meteorites, and the like. It exists in a state of extreme diffusion only in nebulae, but elsewhere space is perfectly empty, or, at least, whatever remains cannot suffice to explain the relations of stars to stars.

COMETS 1888 *e* AND *f* (BARNARD, SEPTEMBER 2 AND OCTOBER 30).—The following ephemerides for these objects are in continuation of those given in NATURE of April 4, p. 546, and are for Berlin midnight:—

Comet 1888 <i>e</i> .				Comet 1888 <i>f</i> .				
R.A.	Decl.			R.A.	Decl.			
h. m. s.	°	'	"	h. m. s.	°	'	"	
April 30 ...	23 25 51	1	28.1	N. ...	9 31 10	37	39.4	N.
May 4 ...	23 23 34	1	41.6	...	9 33 48	37	35.8	
8 ...	23 20 54	1	54.1	...	9 36 36	37	30.4	
12 ...	23 17 50	2	5.5	...	9 39 38	37	23.7	
16 ...	23 14 18	2	15.7	...	9 42 50	37	15.8	
20 ...	23 10 15	2	24.5	...	9 46 12	37	6.7	
24 ...	23 5 37	2	31.6	N. ...	9 49 43	36	56.8	N.

α URSAE MAJORIS.—Mr. Burnham reports from the Lick Observatory that he has discovered this star to be a close double. He gives the following measures of the companion:—

	P =	D =	Mag.
1889.142 ...	327.0	0.96	11
1889.151 ...	325.9	0.83	11

Mr. Burnham was not able to see the companion with the 12-inch telescope, and concludes that it is too difficult for such an aperture, the difference in magnitude between the two components being so great.

THE WHITE SPOT ON SATURN'S RING.—M. Terby, writing to the *Astronomische Nachrichten*, reports that he has not been able to see the white spot again which he observed on March 6 and 12 (NATURE, vol. xxxix. p. 497). MM. Knorre, Knopf, Lamp, Struve, and Schiaparelli have likewise failed to detect it. On the other hand, Prof. McLeod, of Montreal, and Mr. Brooks, of Smith Observatory, Geneva, U.S.A., both state that they have seen it; and the latter reports it variable. If it be a real spot, and not a mere effect of contrast with the shadow of the planet, it evidently would only occasionally be seen in the place where it was first discovered, but would be observed from time to time in other parts of the ring, for it would be carried round with it in its rotation.

ASTRONOMICAL PHENOMENA FOR THE WEEK 1889 APRIL 28—MAY 4.

(FOR the reckoning of time the civil day, commencing at Greenwich mean midnight, counting the hours on to 24, is here employed.)

At Greenwich on April 28

Sun rises, 4h. 39m.; souths, 11h. 57m. 20.7s.; sets, 19h. 16m.: right asc. on meridian, 2h. 23.9m.; decl. 14° 18' N. Sidereal Time at Sunset, 9h. 44m.

Moon (New on April 30, 2h.) rises, 4h. 36m.; souths, 10h. 54m.; sets, 17h. 25m.: right asc. on meridian, 1h. 20.3m.; decl. 3° 3' N.

Planet.	Rises.			Souths.			Sets.			Right asc. and declination on meridian.		
	h.	m.	s.	h.	m.	s.	h.	m.	s.	h.	m.	s.
Mercury..	4	46	...	12	12	...	19	38	...	2	38.6	15 42 N.
Venus....	4	9	...	12	7	...	20	5	...	2	33.2	20 42 N.
Mars .....	5	8	...	12	51	...	20	34	...	3	17.9	18 30 N.
Jupiter...	0	15	...	4	11	...	8	7	...	18	35.9	22 55 S.
Saturn....	10	59	...	18	38	...	2	17*	...	9	5.7	17 51 N.
Uranus...	17	15	...	22	43	...	4	11*	...	13	11.7	6 54 S.
Neptune..	5	44	...	13	30	...	21	16	...	3	57.3	18 49 N.

\* Indicates that the setting is that of the following morning.

April.	h.		
29 ...	23	...	Venus in conjunction with and 10° 15' north of the Moon.
30 ...	12	...	Mercury in conjunction with and 5° 8' north of the Moon.
May.			
1 ...	2	...	Venus in inferior conjunction with the Sun.
1 ...	3	...	Mars in conjunction with and 4° 21' north of the Moon.
1 ...	21	...	Mercury at least distance from the Sun.

Variable Stars.

Star.	R.A.		Decl.	h. m.	
	h. m.	s.		h. m.	s.
U Cephei ...	0 52.5	...	81 17 N.	May 1,	2 12 m
U Monocerotis ...	7 25.5	...	9 33 S.	...	3, m
δ Libræ ...	14 55.1	...	8 5 S.	Apr. 30,	0 17 m
U Ophiuchi...	17 10.9	...	1 20 N.	May 1,	1 44 m
β Lyræ...	18 46.0	...	33 14 N.	...	1, 21 52 m
U Aquilæ ...	19 23.4	...	7 16 S.	...	4, 0 0 M
η Aquilæ ...	19 46.8	...	0 43 N.	...	1, 20 0 M
S Sagittæ ...	19 51.0	...	16 20 N.	...	3, 22 0 m
R Sagittæ ...	20 9.0	...	16 23 N.	...	3, m
T Vulpeculæ ...	20 46.8	...	27 50 N.	...	3, 2 0 m
δ Cephei ...	22 25.1	...	57 51 N.	Apr. 28,	4 0 m

M signifies maximum; m minimum.

Meteor-Showers.

R.A. Decl.

Near ζ Ursæ Majoris ...	206	...	57° N.	...	Slow; bright.
,, α Serpentis ...	234	...	10 N.	...	Swift.
,, υ Herculis ...	239	...	46 N.	...	May 1. Swift; short.
,, η Aquarii ...	337	...	2 S.	...	Swift; very long.

THE CORROSION AND FOULING OF STEEL AND IRON SHIPS.<sup>1</sup>

THE difficulty of obtaining adequate experimental data, and the fact that nearly everyone who has worked at the subject has had a composition of his own to bring before the public, has so hampered and restrained the free discussion and interchange of ideas on this most important question, that at the present time we have made but scant progress beyond the point reached twenty years ago, and my object in bringing this paper before you is more to excite you to discussion, and to show you the known facts of the case, than to tell you of any very new or startling discoveries.

Corrosion generally precedes fouling on exposed metal surfaces, and it is therefore this portion of the subject that will be considered first, together with the means which have been taken to prevent it and to protect the plates of our vessels from decay.

In a paper which I had the honour to bring before you two years ago, I pointed out that in all processes of rusting carbonic acid gas and moisture played an important part, the iron uniting with the carbonic acid and oxygen of the water to form ferrous carbonate whilst the hydrogen was set free, and that the ferrous carbonate then took up oxygen dissolved in the water, or present in the atmosphere as the case may be, and was decomposed into ferric oxide (rust) and carbonic acid, which being liberated in actual contact with the moist surface of the iron carried on the process of "rusting."

This view of the case was confirmed by a paper read by Prof. Crum Brown before the Iron and Steel Institute, at Edinburgh, last autumn, and is generally accepted as the true explanation of the corrosion taking place on iron or steel surfaces exposed to moist air or fresh water; but the rusting of the metal in sea water has by many chemists been ascribed to a more complex action, in which the salt present plays an important part by first forming oxychloride of iron.

This preliminary stage of corrosion in sea water is, I am inclined to think, a myth. When iron filings or turnings are exposed to the action of sea water, hydrogen gas is evolved, and ferrous oxide and carbonate are formed, and this changes, as in air or fresh water, into ferric oxide, by taking up dissolved oxygen present in the water. At no time have I been able to

<sup>1</sup> A Paper read at the thirtieth session of the Institution of Naval Architects, by Prof. V. B. Lewes, F.C.S., F.I.C., Royal Naval College Associate, on April 12, 1889.



detect the presence of oxychloride, and from the fact that a few drops of alkali added to the sea water stop the corrosion, I am of opinion that the simple rusting of iron in sea water is due to the same cause as in fresh—*i. e.*, the decomposition of the water by the iron in presence of carbonic acid.

The saline constituents of sea water, however, do undoubtedly play an important part in a more active form of corrosion, by helping to excite galvanic action between the iron in the plates and any foreign metal or impurities present, an action which is also materially aided by want of homogeneity in the metal, by particles of rust, by mill scale, by wrought and cast iron or steel in contact with each other; or even by the different amount of work, such as hammering or bending, undergone by different parts of the same plate; and in all of these cases the galvanic action set up causes rapid oxidation of the iron at the expense of the oxygen of the water, hydrogen being evolved.

We may therefore consider that on the skin of a ship two processes of rusting are going on, the simple corrosion on exposed surfaces of the metal, due to the presence of moisture, carbonic acid and free oxygen, which forms a fairly uniform coating of rust on the metal, and the more local corrosion due to galvanic action, which results in pitting and uneven eating away of the plates.

As I pointed out in a previous paper, rust cones are due to the most local form of galvanic action, caused by the presence of a spec of deposited copper, lead, or other foreign metal, or even a small particle of rust, or mill scale, left on the surface of the iron, and covered by the compositions used as protectives and antifoulers; as soon as the sea water penetrates to these, galvanic action is set up, water is decomposed, rust formed, and the escaping hydrogen pushes up the composition, forming a blister, the hydrogen leaks out, the water leaks in, the action becoming more and more rapid, and the blister gradually filling with the result of the action—rust. The blister bursts, but the cone of rust has by this time set fairly hard, and continues to grow from the base, the layers of rust being perfectly visible in a well-formed cone, and when the rust cone is detached, the pitting of the metal at the base of the cone is, as a rule, found to be of considerable depth.

The speck of foreign matter which has caused this destructive action generally clings to the surface of the iron, and, being at the bottom of the pitting, escapes detection and removal, and when the vessel, newly coated with fresh compositions, again goes to sea, the corrosion will again probably be set up in the same spot.

The corrosion of the plates in the interior of a vessel is a subject quite equal in importance to the external action of sea water and dissolved gases on the metal; and from the fact that certain portions of the interior plates, from their position, escape the frequent examination and attention bestowed upon the exterior, it becomes a still greater source of danger.

Corrosion, like all other forms of chemical action, is much accelerated by increase of temperature; and in the bottom of a ship, near the furnace-room and boilers, this has a considerable effect in increasing the rapidity of rusting. Also in the coal bunkers, the mere contact of moist coal with the iron plates sets up galvanic action, carbon being electro-negative to iron, and the coal dust which sifts down into the double bottom lends its aid to the destruction of the plates; whilst, if the coal contains any "pyrites," which is nearly always the case, these double sulphides of iron and copper are gradually oxidised into soluble sulphates of the metals, and these, washing down into the bilge water, would at once cause most serious corrosion, should they come in contact with any bare portion of the plates. Repairs to any portion of the inside plates will loosen rust and mill scale, which, finding its way into the bottom, tends to set up galvanic action; whilst the scale of oxide of copper from copper and brass fittings and pipes is another great cause of danger, as the bilge water would gradually convert it into soluble salts, which will deposit their copper upon the iron wherever a crack or abrasion enables them to come in contact with it; and finally, leakages from stores and cargo are in many cases of a character highly injurious to iron.

In addition to all these sources of danger, we must remember that the interior of the vessel is the part most liable to abrasion from shifting and moving of cargo, coals, &c.

The protection of the outsides of the bottoms of our ships from the destructive agencies of sea water and dissolved gases may be said to have been attempted in two ways, by metallic and by non-metallic coatings.

So far, all attempts at metallic coatings have proved failures, and, as far as it is possible to judge, there is but small likelihood of their ever being made to succeed, because if zinc is used in order to protect the iron of the ship there must be galvanic action, and this action must take place evenly all over the surface of the iron plates, which means that the sheathing must be in uniform metallic contact with the iron, in which case the wasting of the sheathing would be so rapid that it would have to be renewed frequently, which, even leaving out the question of cost, is in many cases impossible.

Zinc is practically the only metal which could be used for this purpose, in order to place the plates of the ship in an electro-negative condition, and it is, therefore, to zinc that inventors have turned from time to time, the chief novelties introduced being the method of attachment. As far back as the year 1835, I believe Mr. Peacock tried zinc plates on the bottom of H.M.S. *Medea*, and in 1867 Mr. T. B. Daft again brought the subject forward; Sir Nathaniel Barnaby, Mr. McIntyre, and others, also suggesting various plans of attachment, whilst as late as last year Mr. C. F. Henwood read a paper at the United Service Institute strongly advocating zinc sheathing as attached by his system.

Where the galvanic contact has been but small there the sheathing has had a certain life, but has afforded but little protection to the iron, and has gradually decayed away in a very uneven fashion; whilst in those cases where galvanic contact has been successfully made the ship has on several occasions returned from her voyage minus a considerable portion of the sheathing.

Another drawback to the use of zinc sheathing is one which was found when it was used to coat wooden ships, and that is that zinc when in sheets, like every other metal, is by no means homogeneous, and that for this reason the action of sea water upon it, leaving out of consideration galvanic action, is very unevenly carried on, the sheathing showing a strong tendency to be eaten away in patches, whilst the metal itself undergoes some physical change, and rapidly becomes brittle.

Attempts have been made to galvanize the iron before the building of a ship; but Mr. Mallet showed as early as 1843 that this coating was useless when exposed to sea water, as in from two to three months the whole of the zinc was converted into chloride and oxide, and that, when, therefore, galvanising is used, care must be taken to protect the thin coating of zinc. This does not, of course, apply to fresh water, in which galvanised iron would answer very well, the rapid action being due to the salts in the sea water; but even in this case the galvanising would have to be done after the plates had been riveted together, as any breaking of the surface would set up rapid wasting of the zinc, and it could, therefore, only be used on small craft.

Copper, tin and lead have been proposed for coating ships, but these metals are electro-negative to iron, and would rapidly destroy the hull, should any abrasion of the coating or damage to the insulating material take place.

The non-metallic coatings which are intended to do away with corrosion have been almost endless. At the present moment there are upwards of thirty in the market; whilst the patent list of the last fifty years contains an enormous number which were practically still-born.

They may be divided for convenience into—

- (a) Oil paints.
- (b) Pitch, asphalt, tar, or waxes.
- (c) Varnishes, consisting of resins and gums dissolved in volatile solvents.
- (d) Varnishes, containing substances to give them body.
- (e) Coatings of cement.

And, before going into these in detail, it is necessary to consider the condition of the surfaces to which they will have to be applied, and the effect this will have upon them.

Air has the power of holding water vapour in suspension, the amount so held being regulated by the temperature; the higher the temperature the more can the air hold as vapour, whilst any cooling of the air saturated at the particular temperature causes a deposition of the surplus moisture. When a ship is scraped down to the bare iron in the dry dock, we have a huge surface of metal which varies in temperature much more rapidly than the surrounding air, and cools much more rapidly than the stone walls of the dock; as it cools, so it chills the layer of air in immediate contact with it, and causes a deposition of the surplus moisture on its surface—a phenomenon known as the "sweating



of iron"—and on to this moist surface the protective composition has to be painted. If now a rapidly-drying varnish is put on, the rapid evaporation of the volatile solvent causes again another sudden fall of temperature—evaporation being always accompanied by loss of heat—and this fall of temperature again causes a deposition of moisture, this time on the surface of the protective, so that the coating is sandwiched between two layers of moisture, both of them probably acting deleteriously upon the resin or gum in the varnish, whilst the moisture on the iron also prevents adherence of the varnish to the metal. If, instead of a quick-drying varnish, the old-fashioned red lead and linseed oil protector had been used, the second deposition would not have taken place, but the sweating of the iron would have prevented cohesion, and, when dry, any rubbing of the coating would bring it off in strips.

The condition of the outer skin of a ship, when she is being coated with her protective composition, is one of the prime factors in the discrepancies found in the way in which compositions act. It being a very usual thing for a composition to give most satisfactory results on several occasions, and then, apparently under exactly similar circumstances, to utterly break down, and to refuse even to keep on. Too much stress cannot be laid upon the condition of the plates at the time of coating, and it is absolutely essential either to have a perfectly dry ship or else a composition which is not affected by water.

When an old ship is broken up, you will often see on the backs of the plates the numbers which had been painted on them with white lead and linseed oil before the ship was built, and, under the paint, the iron in a perfect state of preservation, the secret being that the paint was put on while the plates were hot and dry.

Boiled linseed oil, mixed with red or white lead, is amongst the oldest of the protective compositions in use, but of late years has been but little employed, since it was proved by M. Jouvin, of the French Navy, and also in this country, that compounds of lead, when exposed by the wasting of the vehicle to the action of sea water, are converted into chloride of lead, and this is rapidly acted on by the iron, depositing metallic lead and forming chloride of iron, the deposited lead carrying on the corrosion of the iron by rapid galvanic action. The drying of boiled linseed oil is due to the fact that it has in it a certain quantity of an organic compound of lead, and the drying properties are given to it by boiling it with litharge (oxide of lead), so that, even when red or white lead is not mixed with it, still lead compounds are present, and this action will go on to a lesser extent. When the boiled oil dries, it does so by absorbing oxygen from the air, and becomes converted into a sort of resin, the acid properties of which also have a bad effect upon iron, so that protectives containing boiled oil are open to objection. Within the last two months a good example of the action of sea water on the bottom of an iron ship, coated with red lead, has been afforded by H.M.S. *Nile*, which, after being painted over with coats of red lead, was allowed to remain for some months in Milford Haven, with the result that her bottom is very seriously corroded, and, on examination of specimens of rust taken from her, the crystals of metallic lead are in many cases easily identified.

If red lead is used, it can only form a ground-work for an anti-fouling composition which has to protect the red lead as well as the iron of the ship from the action of sea water, and when the anti-fouling composition and the vehicle perish, then serious corrosion must ensue.

The second class of protectives, consisting of tar and tar products, such as pitch, black varnish, and also asphalt and mineral waxes, are amongst the best protectives, the waxes especially not being affected by the sweating of the plates, and forming admirable coatings for the plates. Certain precautions, however, must be taken in the case of tar and tar products, both of which are liable to contain small quantities of acid and of ammonia salts; but if care be taken to eliminate these, and if it could be managed to apply this class of protectives hot to warm plates, the question of protection would be practically solved, bituminous and asphaltic substances forming an enamel on the surface of the iron which is free from the objections to be raised against all other protectives, that is, that being microscopically porous they are pervious to sea water.

The third class of protectives consists of varnishes formed by dissolving gums or resins in volatile solvents, such as spirit, turpentine, naphtha, fusel oil, &c., and such varnishes are open to several objections—in the first place, they are acted upon by moisture, which causes a deposition of the resins or gums as a non-coherent powder and destroys tenacity of the varnish. The

amount of action which moisture has on such a spirit-varnish depends to a considerable extent upon the proportion of resin or gum to spirit, when the solvent is present in large quantities, and the resin in comparatively small; then the moisture has apparently little action; but it must be remembered that the drying of such protectives means the rapid evaporation of the solvent and concentration of the resin or gum, whilst the rapid volatilization which is going on cools the hull of the ship, and causes deposition of moisture on the drying varnish with most disastrous results.

Another point which must be borne in mind is that no such varnish is impervious to gases and liquids. We are apt to think of a coating of varnish as being perfectly homogeneous; but, on examining it through a microscope, it is seen to be full of minute capillary tubes, which become gradually enlarged by the action of water, and finally result in the destruction of the varnish, whilst moisture and dissolved gases find their way to the metal, and carry on corrosion. The application of several coats of varnish tends to diminish this evil, as in many cases the holes in the first coat will not correspond with the holes in the second, and so each succeeding coat will tend to make the protective more and more impervious. In using such varnishes, they must only be applied in favourable weather, and must be allowed to thoroughly harden before being brought in contact with the water.

In the fourth class we have varnishes of this kind to which body has been given by the addition of foreign constituents, generally mineral oxides; and this class is far preferable to the last, if the solvent used is not too rapid in its evaporation, and if care has been taken to select substances which do not themselves act injuriously upon iron or upon the gums or resins which are to bind them together, and are also free from any impurities which could do so.

At present the favourite substance used to give colour and body to such varnishes is the red oxide of iron, the colour of which effectually cloaks any rusting which may be going on under it. In using the red oxide for this purpose, care should be taken that it contains no free sulphuric acid or soluble sulphates, as these are common impurities, and are extremely injurious, tending to greatly increase the rate of corrosion. The finest coloured oxides are, as a rule, the worst offenders in this respect, as they are made by heating green vitriol (sulphate of iron), and in most cases the whole of the sulphuric acid is not driven off as the heat necessary impairs the colour; this acid is often neutralized by washing the oxide with dilute soda solution, but very little trouble, as a rule, is taken to wash it free from the resulting sulphate of soda, which is left in the oxide.

A sample of exceptionally good colour intended for using in protective compositions was sent me a few weeks ago for analysis, and proved to contain no less than 15·3 per cent. of sulphate of soda.

The best form of oxide of iron to use for this purpose is obtained by calcining a good specimen of hæmatite iron ore at a high temperature. When prepared in this way, it contains no sulphates, but from 8 to 40 per cent. of clay; if the percentage does not, however, exceed 12 to 18 per cent. it is perfectly harmless.

Composition manufacturers can easily test their red oxides for themselves, to see if it contains soluble sulphates, by warming a little of it with pure water, filtering through blotting paper, and adding to the clear solution a few drops of hydrochloric acid, and a little solution of chloride of barium (easily obtained at any druggist's). If a white sediment forms in the solution, the sample should be rejected.

In a previous paper<sup>1</sup> on the corrosion and protection of iron and steel ships, I pointed out that when such a varnish perished, the oxide of iron being left in contact with the iron plates, increased the corrosion going on at the surface of the metal, all oxides being electro-negative to the metals from which they are produced, and on that occasion I advocated the use of finely divided metallic zinc, which can be obtained as an impalpable powder, in place of the oxide of iron, pointing out that such a composition would last as long as any varnish of this class, and that, when the varnish perished, as it must do after long exposure to sea water, then the metallic zinc would, on coming in contact with the iron, set up galvanic action; but that, instead of being electro-negative, as in the case of oxide of iron, and causing corrosion of the plates, it would be electro-positive, and in consequence would protect them, being itself slowly oxidized, and so would give a fresh period of protection.

<sup>1</sup> Transactions of the Institution of Naval Architects, vol. xxviii.



I hoped at the time that I had made it perfectly clear that the zinc would in no way act until both the anti-fouling and protective varnish had perished, and had become spongy and porous, and that the idea was a prolongation of the period of protection, the great point which has now to be aimed at; but the remarks made afterwards in several journals which were kind enough to notice my paper showed me that they had mistaken my intention, and supposed that the zinc was put in to at once create galvanic action, and predicted that if by any chance it did act, the hydrogen generated would blow the composition into blisters, and defeat its own purpose. I need hardly point out that nothing was farther from my intention, as zinc in fine powder will be acted on more rapidly than the dense metal in plates, and I have already pointed out that this is destroyed too rapidly by galvanic action to render it of practical use as a protective *per se*.

As to the hydrogen blowing off the composition, no gas could be generated until both the anti-fouling and the protective coatings had been perished and rendered perfectly porous by the action of the sea water, a condition which would have permitted the free escape of the generated hydrogen, which, it must be remembered, will permeate through openings which other gases cannot pass through.

One of the largest firms of composition manufacturers had enough curiosity to try the effect of zinc *versus* oxide of iron, and painted a patch of it upon a ship coated with his compositions, and after a long voyage she returned with her protectives in perfectly good order, and had it not been for the patch containing zinc having had its position fixed by careful measurements, its whereabouts could not have been discovered. This is exactly what one would have expected; as long as the varnish remains intact oxide of iron, zinc, or, indeed, any substance which will not damage the varnish, does perfectly well; but had the vessel been allowed to continue until the varnishes had perished, then I venture to say that the patch containing the zinc would have shown better protection than those parts containing the oxide of iron. My ideas have undergone considerable modification during the past two years, but I still consider the views I put forward in my last paper were perfectly sound, and I am every day more and more convinced that the great object the composition-maker has to aim at is the prolongation of the life and effectiveness of compositions, and not the multiplication of short-lived devices, however admirable in their action.

In the fifth class of protectives we have cement coatings; but these, together with such schemes as the covering the hull of the vessels with vitreous glazes, glass, &c., have of late years, as far as I know, entirely been abandoned. The action of cement on iron, however, must later on be discussed in its important bearing on the protection of the interior portions of the hull, for which it is largely employed, its weight and the difficulty of attachment rendering it unfitted for outside work.

In selecting a protective composition for the bottom of a vessel, one of the second or fourth class should be chosen, attention being given to the points I have indicated, which are that in the bituminous and asphaltic compositions all the original acids must be eliminated, and that in the varnishes of the fourth group quickly evaporating solvents should be avoided, and, if possible, zinc substituted for oxide of iron.

The vessel should have her plates as dry as possible during the application of the protective, and, if feasible, days on which the air is fairly dry should be chosen. The protective should not be too thick, as, if it is, it does not readily fill into inequalities in the plates; and, if in this way any air is inclosed, change of temperature will cause it to expand or contract, thus causing a blister to form, which will fill with sea water and set up rapid corrosion. The composition must either be elastic or else have the same rate of expansion and contraction as the iron; for, if not, the change of temperature will cause cracking and tearing of the composition with disastrous results. The vessel, if she has to be scraped down to the bare metal, must be scrubbed free from all traces of rust, and where a well-adhering coating of composition exists, it should be painted over and not disturbed. In the case of a new ship, she must be pickled with dilute acid, to get rid of every trace of mill scale, and then washed down with some slightly alkaline liquid to neutralize every trace of acidity, the alkali in turn being removed by clean water. Under these conditions, and given a composition with good adhering properties, but little apprehension need be felt as to the ravages of corrosion on the metal of a ship's bottom, the chief risk being from abrasion and other mechanical injury to the composition, coupled with improper constituents in the anti-fouling compositions. The protection of the interior portion of the vessels, where

the plates are exposed to the corroding action of bilge water, rendered more active by a high temperature, leakage from cargo, acids and sulphates from wet coals, and the presence of such electro-negative factors as coal dust, scale, and rust, is a matter of quite as great importance as the exterior protection; whilst the great chance of mechanical abrasion during coaling and shifting of cargo, as well as the difficulty of getting at the lower portions of the hold to examine the condition of the plates, renders it a question of the gravest consideration. The corrosion found in the portions underneath the engine-seats, the bunkers, and the water-ballast chambers, especially near the engine-room, is often very serious, and needs most careful watching, which, from the position of these parts of the vessel, it is very hard to bestow upon it.

It must also be remembered that the bilge water in a vessel is in constant motion, and that the air in these parts of the vessel may be expected to be exceptionally rich in carbonic acid gas, which, as I have before shown, is the most important factor in corrosion. Under these conditions any abraded portion would probably be continually washed over, and then exposed to the foul air, a condition of things most conducive to rapid rusting. There are three main classes of protectives for the interior of a ship—

- (1) Cements.
- (2) Bituminous coatings.
- (3) Paints.

The first of these, the cement coatings, have many good points to recommend them, but they also have many serious drawbacks.

The rigidity, firmness of adherence and endurance, are all of them points of the greatest importance, and there is no doubt but that the silicates present in the cement in time, not only bind the cement into a mass of wonderful hardness, but also bind that cement to the iron. A point to which I should like to draw your attention, however, is that a thin coating of Portland cement is highly porous, and that it can be permeated by liquids and gases. Suppose, now, that some copper scale from the interior fittings had fallen into the bottom of the vessel, and had been converted into soluble salts of copper by the saline bilge water, this solution would soak through the capillary orifices in the cement, until it came in contact with the iron below, when the copper would be deposited on the iron, and rapid galvanic action set up, the cement being loosened, and to a certain extent lifted, by the formation of rust, whilst corrosion would gradually extend under the cement, giving on the outside of the coating but little sign of damage taking place below it.

Also the hardness and rigidity of the cement gives it a tendency to crack away from the metal when any strain is thrown upon the plates, or during any expansion or contraction of the metal; whilst any repairs on the outside of the ship, such as making a boring to test the thickness of plate, replacement of rivets, &c., would undoubtedly cause a loosening of the cement coating within, and, wherever a loosening takes place, the space between the cement and the plate will quickly be found to become a starting-point for corrosion, which quickly spreads and loosens the cement, and will only be discovered by chance.

It is for this reason that I consider bituminous or asphaltic varnishes, freed from any trace of acid, and applied hot, or sound tough paint, preferable to cement; as, although they are not so hard, yet if serious corrosion should be set up, it is easily discovered and stopped before much damage results, whilst, being impervious to moisture, deleterious solutions, either from the coal bunkers or cargo, would be prevented from acting upon the skin of the ship.

In approaching the subject of fouling, one is impressed with the apparent hopelessness of obtaining any reliable information from the successes or failures registered by the bottoms of the vessels, in the Service, or in the Mercantile Marine. Hundreds of ships may be examined, and their condition and the nature of the compositions used upon them registered, and just as one begins to feel that the key to the mystery is within one's grasp, a whole series of results so abnormal suddenly comes to light that it seems impossible to reconcile them with one's previous experience. A ship may sail half a dozen times to the same waters, coated with the same composition—on four occasions she will come home clean and in good condition, whilst on the other two voyages she may accumulate an amount of weed and animal life sufficient to knock down her speed from nine knots to five. Moreover, if the compositions with which she was coated be examined, and scrapings taken from her on her return, no cause will present itself that



can in any way explain the great difference in her condition. After several years' close observation, however, certain factors begin to make themselves apparent. Ships at sea from March to August show a worse average than those afloat from August to March; one also begins to realize that the amount of fouling increases enormously if the ship has been long at anchor—ships which have been lying at the mouths of rivers, although quite clean in the brackish water, foul much more rapidly on going to sea than the vessels which have been cruising, or even at anchor for the same time in salt water; and finally, certain ports and certain seas seem to exercise a deleterious effect, both as regards corrosion and fouling, which is not to be found elsewhere.

Turning back to the naval history of the past, we find that fouling is no new trouble born with the advent of our present iron monsters; but that it has been the one trouble that the combined engineering and scientific skill of many centuries has been unable to overcome.

With our wooden ships, metallic copper sheathing, if it were of the best kind, answered the purpose fairly well; but then the copper wasted so fast the inferior kinds and alloys were substituted to prevent the rapid loss, and, with the slowing down of the destruction of the copper, at once the trouble of fouling returned.

When iron ships began to replace the wooden ones, as was only natural, attempts were made to utilize the metal which had before given relief; but it was quickly found that the effect of the galvanic action set up by the copper was fatal to the iron plates of the ship, and attempts were then made to sheathe the ship with copper plates in such a way that they should be insulated from the iron of the vessel, a condition almost impossible to attain and attended with great risk, should any accidental injury to the insulation take place.<sup>1</sup> Early in the history of iron shipbuilding the idea was started of using coatings of paint, so prepared as to fulfil the same functions as the copper plates had done; but from 1840, when the first paint of this kind was patented, down to the present day, when there are upwards of thirty-two different compositions in the market, very little progress has been made in their manufacture, and the best of their compounds cannot be relied upon for keeping a ship's bottom even fairly free from fouling for periods extending beyond nine months, and I am personally convinced that the reason of this is to be found in the fact that a start was originally made in the wrong direction.

The idea which originally led to the present class of anti-fouling compositions was that the copper salts formed by the action of the sea water on the metallic sheathing owed a considerable portion of their value as anti-foulers to the poisonous action they exerted upon marine animal and vegetable growths; but, when an observer comes to study the natural history of these lower forms of animal life and vegetation, it is gradually forced upon one that it is only in the early stages of their growth—the germ period—that metallic poisons can affect them. Seaweeds do not take in the constituents they require for their growth by means of their roots, as is, to a certain extent, the case with ordinary plants, but absorb them by means of their pores from the water itself, the root only serving to attach them to the solid they choose for their resting-place; it is also well known that when once a marine plant which has passed the first stages of existence is dislodged or torn from its support, it cannot reattach itself to anything else, whilst most of the mineral poisons have little or no effect upon their life and growth.

In the same way we find that, with the animal life found on a ship's bottom, the under side is used to cling on with only, and not as an extractor of nourishment, and that, therefore, after the seeds and germs have once obtained a foothold on the side of the vessel, no amount of poison which can be put into a composition will have any effect upon them. Metallic poisons undoubtedly do exert an influence upon the germs in their earliest stages; but after that they are perfectly useless as anti-foulers, and only imperil the plates of the vessel.

The germs of both kinds of growth are of necessity more abundant in the surface water near shore than in deep water, and therefore the period when the ship is in port is the time when the germs are most likely to make good their attachment, after which their further development is, unless other methods of getting rid of them are employed, merely a matter of time.

On examining the conditions under which a vessel is placed when coated with a composition which relies for its anti-fouling powers on metallic poisons only, we at once see the reasons which must make such a coating of little or no avail. In the composition we have drastic mineral poisons, probably salts of

copper, mercury, or arsenic, which have been worked into a paint by admixture with varnishes of varying composition, and each particle of poison is protected from the action of the sea water by being entirely coated by this vehicle: that this must be so is evident, or the composition would not have sufficient cohesive power to stick on the ship. As a rule, care is taken to select fairly good varnishes, which will resist the action of sea water for, perhaps, two or three months, before they get sufficiently disintegrated to allow the sea water to dissolve any of the poison; whilst, even with the accidental or intentional use of inferior varnishes, three or four weeks will pass before any solution can take place, and any poison be liberated to attack the germs. A ship is dry docked, cleaned, and, her anti-fouling composition having been put on, she goes probably into the basin to take in cargo. Here she is at rest, and, with no skin friction or other disturbing causes to prevent it, a slimy deposit of dirt from the water takes place, and this, as a rule, is rich in the ova and germs of all kinds of growth, whilst the poisons in her coating are locked up in their restraining varnish, and are rendered inactive at the only period during which they could be of any use. After a more or less protracted period, the ship puts to sea, and, the perishing of the varnish being aided by the friction of the water, the poisonous salts begin to dissolve or wash out of the composition; but the germs have already got a foothold, and with a vessel sweeping at a rate of, say 10 to 12 knots through the water, the amount of poison which can come in contact with their breathing and absorbing organs is evidently so infinitesimally minute that it would be impossible to imagine it having any effect whatever upon their growth. If the poison is soluble, it is at once washed away as it dissolves; if it is insoluble, then it is also washed away, but there is just a chance that a grain or two may become entangled in the organs of some of the forms of life, and cause them discomfort. As the surface varnish perishes, the impact of the water during the rapid passage of the vessel through the water quickly dissolves out or washes out the poisonous salts, and leaves a perished and porous, but still cohesive, coating of resinous matter, which forms an admirable lodgment for anything which can cling to it; and by the time the vessel lays-to in foreign waters, teeming with every kind of life, the poison which would now again have been of some use is probably all washed away, and a fresh crop of germs are acquired, to be developed on the homeward voyage, and a "bad ship" is reported by the person who looks after her docking. It is evident that a poison, even if it had the power of killing animal and vegetable life in all stages, could only act with the vessel at rest, unless it were of so actively corrosive a nature as to burn off the roots and attachments of the life rooted to it, and if it did this, what, may I ask, would become of the protective composition and the plates of the vessel? And I think it is also evident that any poison so used must be under conditions in which it is very unlikely to be in a position to act when it might do good.

The lamentable failure of composition after composition of this kind has gradually reduced them in number to some ten or twelve at the present time, and in most cases it is low price alone which keeps them in the market.

The practical proof, given by experience, that poisons alone are unable to secure a clean bottom, soon led many inquirers to the conviction that it was the exfoliation in the case of copper which had acted in giving fairly good results, and in many compositions the attempt has been made to provide a coating which shall slowly wash off, and, by losing its original surface, shall at the same time clear away germs and partly developed growths, and so expose a continually renewed surface, in this way keeping the bottom of the vessel free from life. There is no doubt that, when this is successfully done, a most valuable composition will result, but the practical difficulties which beset this class of anti-foulers must not be overlooked. In order to secure success, the composition must waste at a fairly uniform rate, when the ship is at rest, and also when she is rushing through the water; and this is the more important in the case of Service vessels, as in many cases they spend a large percentage of their existence at anchor, or in the basins of our big dockyards. If a composition is made to waste so rapidly that it will keep a vessel clean for months in a basin, then you have a good composition for that purpose; but send the vessel to sea, and under conditions where you have a higher temperature, and the enormous friction caused by her passage through the water exerting its influence upon the composition, and you will find that the coating, which did its work well for six months at rest in the basin, will, in the course of one month under these altered conditions, be all washed

<sup>1</sup> Some copper sheathed vessels still exist, and its revival has been lately warmly advocated in America.



away, and fouling will be set up. Noting this result, the manufacturer renders his composition more insoluble—less wasting—and so obtains a coating which, when the vessel is in motion, scales just fast enough to prevent fouling, and good results at once follow; the composition is then put on the same or other vessels, and they take a spell of rest in the basin, and, bereft of the aid of the higher temperatures and the friction of the water, the composition ceases to waste fast enough, and bad results at once have to be recorded.

There is no doubt that this is the true explanation of the wide discrepancies which are found between the compositions in the Navy and in the Mercantile Marine: take any of the big lines, their steamers are running at a fairly uniform rate of speed, and the periods of inaction are as short as the desire not to waste the charge on the capital they represent can make them, and under these conditions, by varying the constituents in the varnishes used for anti-fouling purposes, it is fairly easy, given the necessary data, to so constitute a composition as to secure admirable results; but when you come to apply this same coating to an ironclad running at various speeds, and as often at rest as in motion, then you at once find that the composition you before imagined to be all that could be desired fails just as lamentably as the tribe of anti-foulers which preceded it. It is not so very long ago that I had the honour to serve on an Admiralty Committee under the able guidance of Admiral Colomb, and, after inspecting many vessels in the Mercantile Marine, and watching all the dockings of Service vessels over a considerable space of time, we were forced to the conviction that it was only in very rare cases that the condition of the bottoms of Her Majesty's ships at all approached the freedom from fouling to be found in the ships belonging to the big companies, with the result that some of the most successful of the compositions in the Mercantile Marine were brought into use in the Navy, and I believe the reports of the dockings since they have been adopted will amply prove the existence of the difficulties I have mentioned.

Another factor which is often overlooked, and which tends to give misleading results, is the action of brackish water, which, in many cases, seems to exert a special action in keeping the bottom of a vessel clean, the fresh water having a tendency to disagree with certain forms of marine growth, whilst the salt water is apparently equally unpalatable to the fresh-water forms of fouling.

In most of the compositions now in use, attempts are made to combine strongly poisonous substances with exfoliating and wasting coatings, and this is done by either using metallic soaps, the basis of which is, as a rule, copper, or else by charging a perishable and easily washed-off varnish with poisonous salts, consisting, as usual, of compounds of either copper, mercury, or arsenic, and in some cases all three.

As I have before pointed out, I do not think the presence of these substances exerts any deterrent action upon the fouling, save perhaps when the vessel is at rest; but they exert undoubtedly an important influence upon the rate of exfoliation, as when the perishing of the varnish exposes them they dissolve, or are washed out, and in this way tend to disintegrate and clear away the surface more rapidly—an important and decidedly useful function, but one which might be more cheaply performed by substances other than high-priced metallic poisons.

The use of metallic poisons of the character indicated throws an increased burden upon the protective composition, as, should the latter become abraded by friction of chain cables, barges alongside, or any other cause, the iron of the vessel will be attacked by the metallic salts, either present in the soluble form in the anti-fouling composition, or rendered so by the solvent action of the saline constituents of the sea water, the action of the metallic salts being to rapidly dissolve portions of the iron, and to deposit the metal which they contain upon the surface of the plates, and these deposits, exciting energetic galvanic action, cause corrosion and pitting to go on with alarming rapidity. Both mercury and copper salts are offenders in this way, but copper is by far the most objectionable, from the fact that the salts formed by the action of the sea water upon the compounds used in the compositions are far more soluble than the corresponding salts of mercury, and are therefore liable to be present in much larger quantity, and so exert comparatively a much more injurious action on the plates.

As an illustration of this, two equal portions of sea water were saturated, the one with copper chloride, the other with mercuric chloride, and into each a piece of steel, planed upon one side, and of about equal weight and size, was placed, and left for four days. At the end of this period the two plates

were removed, and, after being cleaned and dried, were again weighed, when it was found that the one exposed to the copper-saturated sea water had lost 22.2 per cent. in weight, while the plate exposed to the mercurial solution had only lost 3.6 per cent., this being due to the much larger amount of the copper salt soluble in the sea water.

On now placing these plates in clean sea water, corrosion went on in each case with extreme rapidity, and after being exposed for a month, they had both wasted to about the same extent—that is to say, when once deposited on the iron, mercury is practically as injurious as copper.

I am quite aware that this experiment is not at all likely to be carried out in practice, and none can have a greater conviction of the inutility of small laboratory experiments than I have, as they lack all the factors of mass of material and atmospheric influence which play so important a part in a question like the present; but such an experiment gives one a definite and fairly correct idea of the relative rate of action of the two poisons upon the plates.

All the time the ship is in motion, the wash of the sea water will prevent the metallic poisons doing the plates or the marine growths much harm, but there is one phase of this question which I think has been overlooked. I need not point out that in certain ports there is a fashion in compositions, and that most of the homes of the Mercantile Marine have some pet local composition which is largely used at the particular port. If, now, many ships are laying in a basin, taking in and discharging cargo, and if the prevalent compositions contain copper, it is evident that a certain quantity will go into solution in the water, which often does not undergo frequent or rapid change, and under these conditions every ship in the basin will be exposed to the same danger, and wherever an abrasion has taken place in the protectives, there copper will be deposited on the iron, causing corrosion and destruction of the plates; and it must be remembered that when the vessel is next docked and coated no amount of scraping will remove the fine particles of copper deposited in the pitted and corroded portions of the plate, and so finely divided as to be invisible to the eye, but that they will remain and carry on the destructive work under the new coatings of protective.

It is, I think, a well-recognized fact that, when a vessel coated with a copper compound has become corroded from failure of her protective, or from abrasion, even an entire change of composition does little or no good in stemming the tide of corrosion, until after some considerable period has elapsed, a result which is due to the same cause; and, inasmuch as copper compositions are a source of danger, not only to the ships coated with them, but to any others which may be at rest in the same basin, I do strongly urge upon the manufacturers to abandon the use of these deleterious compounds, and to use others equally efficacious and free from the grave objections I have enumerated.

At the present time, 15 out of 32 principal compositions rely upon copper in some form or other as the basis of their anti-fouling composition, and in one which has enjoyed considerable favour finely divided metallic copper itself is used, and should vessel coated with it, after the varnishes had commenced to disintegrate, be moored alongside an iron ship by a chain cable, or even by a wet hawser, a big galvanic couple would be formed at the expense of serious damage to any exposed iron.

In the history of anti-fouling many attempts have been made to obtain highly glazed and glass like-surfaces which it was hoped would withstand the action of sea water, and afford no lodgment to marine growths; but even glass itself is slowly acted upon by sea water, and, when once roughened on the surface, will foul, whilst the rigidity of such coatings, and the straining and cracking consequent on unequal expansion and contraction of the plates and their coating, offers a serious obstacle to any such scheme.

In concluding this long paper, I wish to point out that in the present phase of the anti-fouling question, and until some new principle for preventing marine growth has been advanced and successfully adopted, satisfactory results can only be insured by an intelligent use of the existing compositions.

The protective composition is the important composition, and care must be taken to obtain the best in the market, as, if the protection is good, the plates remain uninjured even if fouling take place. The anti-fouling composition to be used with it must either be elastic, or have the same rate of contraction and expansion as the protective, and must—at any rate in the Navy—be chosen to suit the work to be done, such as contain copper compounds being carefully rejected, whilst preference should be given to those which rely on exfoliation rather than mineral poisons.



If a vessel is to remain at rest for a considerable period, an anti-fouling composition which exfoliates rapidly, and which also contains poisons known to act on germ life, must be used, the amount of such poison depending on the seasons and the waters in which the ship is to be ; whilst if a vessel is to be continually running, then a slowly exfoliating composition must be employed, and a very small percentage of poison is all that is required, as skin friction and the comparative absence of the germs and spores in deep water will do the rest.

Our ships represent an enormous capital, and any trouble or care which will prolong their existence is well worth taking and will be amply repaid, and at the present time a heavily corroded and foul vessel means either ignorance or negligence on the part of those who have the responsibility of deciding on the compositions to be used ; and, finally, it must be clearly borne in mind that there is no anti-fouling composition which ever has been made, or probably ever will be made, that will answer for all cases, and that, until this is clearly recognized, the present unsatisfactory condition of the question will exist.

SOCIETIES AND ACADEMIES.

LONDON.

Royal Society, March 28.—“The Diurnal Variation of Terrestrial Magnetism.” By Arthur Schuster, F.R.S., Professor of Physics ; with an Appendix by H. Lamb, F.R.S., Professor of Mathematics, Owens College, Manchester.

In the year 1839, Gauss published his celebrated memoir on “Terrestrial Magnetism,” in which the potential on the earth’s surface was calculated to twenty-four terms of a series of surface harmonics. It was proved in this memoir that if the horizontal components of magnetic force were known all over the earth the surface potential could be derived without the help of the vertical forces, and it is well known now how these latter can be used to separate the terms of the potential which depend on internal from those which depend on external sources.

The use of harmonic analysis to separate internal from external causes has never been put to a practical test, but it seems to me to be specially well adapted to inquiries on the causes of the periodic oscillations of the magnetic needle.

If the magnetic effects can be fairly represented by a single term in the series of harmonics as far as the horizontal forces are concerned, there should be no doubt as to the location of the disturbing cause, for the vertical force should be in the opposite direction if the origin is outside from what it should be if the origin is inside the earth.

In any case, the differences between the two results will be of the same order of magnitude as the vertical force itself. If it were then a question simply of deciding whether the cause is outside or inside, without taking into account a possible combination of both causes, the result should not be doubtful even if we have only an approximate knowledge of the vertical forces.

Two years ago I showed that the leading features of the horizontal components for diurnal variation could be approximately represented by the surface harmonic of the second degree and first type, and that the vertical variation agreed in direction and phase with the calculation on the assumption that the seat of the force is outside the earth. The agreement seemed to me to be sufficiently good to justify the conclusion that the greater part of the variation is due to causes outside the earth’s surface. Nevertheless, it seemed advisable to enter more fully into the matter, as in the first approximate treatment of the subject a number of important questions had to be left untouched. I now publish the results of an investigation which has been carried out as far as the observations at my disposal have allowed me to do. My original conclusions have been fully confirmed, and some further information has been obtained, which I believe to be of importance.

I have made use of the observations taken at Bombay, Lisbon, Greenwich, and St. Petersburg. The horizontal components of the diurnal variation during the year 1870 were in the first place reduced to the same system of co-ordinates and to the same units. If we remember that experience has shown the diurnal variation to be very nearly the same for places in the same latitude, except near the magnetic pole, and also that it is symmetrical north and south of the equator, we may for a given time of day assume the horizontal components known over eight circles of latitude, four of which are north and four south of the equator.

From the horizontal components, the potential was calculated in terms of a series of surface harmonics. It was found that in

order to represent both the summer and the winter effect with sufficient accuracy thirty-eight terms were necessary. In this calculation the vertical forces were not made use of at all.

From the potential, as calculated from the horizontal components, we can deduce the vertical force, either on the assumption that the variation is due to an outside cause, or that it is due to an inside cause ; and compare the vertical forces thus found with the vertical forces as actually observed.

If we put both into the form

$$r_n \cos n(t - t_n),$$

we can obtain an idea of the agreement as regards amplitude and phase for each harmonic term. The following tables give the results for  $n = 1$  and  $n = 2$ —that is, for the diurnal and the semi-diurnal variation :—

TABLE I.

Observed and calculated Values of the Coefficients  $t_1$  and  $t_2$  of Vertical Force, when expressed in the form  $r_1 \cos(t - t_1) + r_2 \cos 2(t - t_2)$ , on the supposition that the Disturbing Force is *inside* the Earth.

	$t_1$			$t_2$		
	Calc.	Obs.	Diff.	Calc.	Obs.	Diff.
	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Bombay.....	23 02	11 13	+11 49	9 55	4 23	+ 5 32
Lisbon .....	22 35	10 40	+11 55	11 42	5 50	+ 5 52
Greenwich.....	22 06	8 42	-11 54	11 32	5 56	+ 5 36
St. Petersburg, 1870	21 16	3 10	- 5 54	10 48	7 05	+ 3 43
” 1878	...	7 05	- 9 49	...	6 12	+ 4 36

TABLE II.

Observed and calculated Values of the Coefficients  $t$  and  $t_2$  when expressed in the form  $r_1 \cos(t - t_1) + r_2 \cos 2(t - t_2)$ , on the supposition that the Disturbing Force is *outside* the Earth.

	$t_1$			$t_2$		
	Calc.	Obs.	Diff.	Calc.	Obs.	Diff.
	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Bombay.....	11 10	11 13	- 0 03	3 47	4 23	- 0 36
Lisbon .....	13 37	10 40	- 0 03	5 46	5 50	- 0 04
Greenwich.....	10 03	8 42	+ 1 21	5 38	5 56	- 0 18
St. Petersburg, 1870	8 52	3 10	+ 5 42	4 38	7 05	- 2 27
” 1878	...	7 05	- 1 47	...	6 12	- 1 34

In Table I. the comparison of the observed phases is made with the values calculated on the assumption that the disturbing force is inside the earth. In Table II. the same comparison is made on the alternative hypothesis. There is complete disagreement in Table I. between the observed and calculated values, and nearly complete agreement in Table II. It is seen how both at Lisbon and Bombay the time of maximum displacement agrees within three minutes of time for the diurnal variation, and at Lisbon within four minutes of time also for the semi-diurnal variation. Considering that Lisbon is the most important station, not only on account of its geographical position, but also because the observed vertical forces apply to the same year as the calculated ones, the result is strikingly in favour of the outside force. The results for Greenwich argue in the same direction. As regards St. Petersburg, the results for 1870 neither agree with one nor with the other hypothesis. The observations for 1870 are, however, doubtful, but the results for 1878 agree well with the hypothesis of an outside disturbing force.

The observed amplitudes are found in all cases to be considerably smaller than the calculated ones.

If we then take it as proved that the primary cause of this variation comes to us from outside the earth’s surface, we are led to consider that a varying magnetic potential must cause induced currents within the earth, if that body is a sufficiently good conductor. These induced currents might be the cause of the apparent reduction in amplitude. As my colleague, Prof. Lamb, has given considerable attention to the problem of currents in a conducting sphere, I consulted him, and he