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ADMIRAL H. BOYS, Vice-Chairman of the Council, in the Chair.

ON THE MARINER'S COMPASS IN MODERN VESSELS OF WAR.

By Staff-Commander E. W. CREAK, R.N., F.R.S., Superintendent of Compasses at the Admiralty.

It is now seventeen years since the late Captain Sir F. Evans gave his last lecture in this Institution, on the magnetism of iron ships and the treatment of their compasses. It is true that during that period the improvement of the mariner's compass as an instrument of navigation and the means of correcting its errors have been the subject of various papers, but there remains much to be said on the increasing difficulties with which the compass on board modern ships of war is surrounded, and how those difficulties have to be met and overcome.

The Council of this Institution have done me the honour of inviting me to read a paper on this subject, and I have therefore prepared the following remarks commencing from the period of 1872, and in continuation of the paper before referred to. There will, consequently, be no need to enter into the historical portion of the subject, as it has already been so fully treated of in several papers written in England, and also in that excellent introduction to the French translation of the Admiralty Manual of 1870, entitled "Exposé Historique," by Lieutenant Collet of the French Navy.

In addressing an audience of my countrymen I need hardly make an effort to arouse a special interest in the subject of the compass in ships-of-war. We should know now—if not from our own conception of what is needful to the national safety—at any rate from the writings and speeches of numerous high authorities, both political and naval, that we must have a large and powerful navy, one part of it consisting of vessels possessing considerable powers of resistance to the effects of modern projectiles combined with high speed; the other part, a more numerous family of small lightly constructed craft of still greater speed and handiness.

This consideration of high speed points to the necessity of providing our ships with compasses of the greatest accuracy with which to navigate them, capable of withstanding severe vibrations of the hull caused by their powerful engines, and shocks from firing heavy guns, while the requirements of a modern war vessel as regards dis-

tribution of the iron and steel armour seem to vie with the previous considerations in rendering the task more and more one of care and judicious treatment. Let us therefore inquire into the various causes of disturbance, mechanical as well as magnetical, and ascertain how far success has been attained in making the compass, in the midst of its numerous enemies, the instrument of precision we would fain have it.

Referring to the paper of 1872, it will be found that after an examination of the magnetic history of a large number of iron vessels of the Fleet combined with the results obtained by the Liverpool Compass Committee, certain definite conclusions were arrived at of which the following are the principal:—

"1. The magnetism of iron ships is distributed according to precise and well determined laws.

"2. That a definite magnetic character is impressed on every iron ship whilst on the building-slip, which is never afterwards entirely lost.

"3. That in an iron-built ship and in that part of her within which the navigating or standard compass is generally placed, the polar force is that from the magnetism of the whole body of the ship, and is nearly uniform; that we cannot escape from the action of that force by any care in the selection of a place for the compass.

"4. That the definite magnetic character of an iron ship, so far as relates to the polar forces developed in her during construction, is shown by the connection which exists between the direction of the ship's original magnetism and the direction of her head when on the building-slip; for the original semicircular deviation consists principally in an attraction of the north point of the compass-needle to the part of the ship that was south (or nearly so) in building.

"5. That a great reduction takes place in the magnetism of an iron ship on first changing her position after launching, and that her magnetism is then unstable for a short period. Then, after a few months' service, perhaps within a year for the average of ships, the time probably depending on the nature of the iron employed in the construction, the magnetism of the ship acquires a very stable character.

"6. That in iron-built ships, as at present constructed, the ship's polar force is generally so great as to make it necessary to employ magnets to equalize the directive force on different azimuths of the ship's head, even at the most carefully selected position."

Of these the two first conclusions have been fully confirmed by observation up to the present time. Of Nos. 3 and 4 it may be said that they are only so far true, "that we cannot escape from the action of that force (the polar force of the ship) by any care in the selection of a place for the compass;" but however carefully the position of the standard compass may be selected in modern ships, it is very seldom that the polar force at that position "is that from the magnetism of the whole body of the ship." Not many years ago it was a matter of simple calculation to ascertain approximately the direction in which a ship had been built, if the deviation on two adjacent

cardinal points of the compass were known, showing that the compass was affected by the whole body of the ship. Now, however, from the largely increased use of iron and steel in the shape of superstructures in turret-ships, conning-towers, iron masts, and deck cabins, the deviations observed at a standard position proceed from the hull largely dominated by that of the nearest iron body. For example, the turret-ship "Hecato" was built with her head in a northerly direction, and, according to conclusions 3 and 4, the standard compass needle should have been attracted towards the stern. It was nevertheless attracted towards the bow by a force greatly in excess of the earth's directive force. Again, in the "Dreadnought," built head S.W., the attraction should have been towards the port bow; whereas it was found acting strongly towards the stern, and, as in the former case, by a force greatly in excess of that of the earth. Conclusion 5 may be considered as confirmed by the experience of later years to a great extent, but really before a ship is commissioned she undergoes such lengthened trials under steam at high speed, followed by gun trials, that she may be expected to have assumed a fairly stable magnetic condition, and subsequent changes will occur very slowly, forming no source of anxiety to the navigator.

The following conclusions are the results of a comparatively recent investigation of the deviations of the compass at the standard positions of a number of vessels of different types, which had during their commission traversed large ranges of magnetic latitude during the years 1871-83, and amply confirmed by subsequent results up to the present date.¹ The list includes six armour-plated vessels, four of iron cased with wood, three iron troopships, three iron and steel cased with wood, and seven composite-built vessels. The deviations were not only analyzed according to the usual methods by which the several values of the semicircular and quadrantal components are ascertained, but the semicircular deviations were subjected to a further analysis, showing how much was due to hard and soft iron, or to iron of a character intermediate between what is known, magnetically speaking, as "hard" and "soft" iron. Always remembering that the observations were made at standard positions carefully selected as the best available in each ship, the following conclusions were arrived at:—

"1. A large proportion of the semicircular deviation is due to permanent magnetism in hard iron."

"2. A large proportion of the semicircular deviation may be reduced to zero, or corrected for all magnetic latitudes, by fixing a hard steel bar magnet or magnets in the compass pillar in opposition to, and of equal force to, the forces producing that deviation."

"3. A very small proportion of the semicircular deviation is due to sub-permanent magnetism, which diminishes slowly by lapse of time."

"4. The sub-permanent magnetism produces deviation in the same direction as the permanent magnetism in hard iron, except when temporarily disturbed, (1) by the ship's remaining in a constant position

¹ See "Phil. Trans. Roy. Soc.," 1883, Part II, p. 616, *et seq.*

with respect to the magnetic meridian for several days, (2) by concussions, (3) or by both combined, when the disturbance is intensified."

"5. To ascertain the full values of the changes in the sub-permanent magnetism, observations should be taken immediately on removal of the inducing cause."

"6. In the usual place of the standard compass, the deviation caused by transient vertical induction in soft iron is small, and of the same value (nearly) for ships of similar construction."

"7. The preceding conclusions point to the conditions which should govern the selection of a suitable position for the standard compass with regard to surrounding iron in the ship."

Now the establishment of conclusions 1 and 2 was very important, for it showed that the principal part of the magnetism of armoured ships like the ordinary iron ship was nearly all permanent, and could be corrected once for all by permanent magnets, instead of "the amount of the induced and permanent magnetism" being "nearly equal," as was supposed in 1872—conditions which would have necessitated either the acceptance of a constantly changing deviation as the ship proceeded from high to low magnetic dip in one hemisphere, and *vice versa*, or the constant alteration of the correcting magnets as well as the application of a large Flinders' bar. One instance of the latter complicated state of things in the case of a Sir William Thomson's compass, placed, for convenience of handling the ship, forward, abaft the director-room of the "Agamemnon," may serve to illustrate. When that vessel proceeded from Colombo to the Mediterranean, although 4 feet of Flinders' bar were fixed to the binnacle, the magnets required to be constantly changed to keep the compass errors within moderate limits. Here the changing part of the semicircular deviation due to vertical induction in vertical soft iron, varying as the tangent of the dip, was largely in excess of that due to hard iron. On the other hand, the "Impérieuse" has been to the Cape and then to Hong Kong with less change than many an old wooden ship.

Conclusions 3, 4, and 5 may be discussed together, as they all refer to the sub-permanent magnetism of the ships. But first let us pause to consider for a moment the exact definition of sub-permanent magnetism as used here. As already stated, a large portion of the semicircular deviation at the standard positions of our ships has been found to be due to permanent magnetism in hard iron, a small portion of it and the quadrantal deviation being due to the soft iron of the ship taking up and parting with its magnetism very rapidly. Intermediate between this strictly hard and soft iron, and, fortunately, not evident in large quantities, there is found in every ship iron showing for a time the characteristics of hard iron, in causing polar deviations in the compass. It is, however, constantly liable to lose this polarity, either by lapse of time after the removal of the inducing cause, or its polarity may be reduced to zero, or totally reversed instantly by shocks inflicted on the general structure of the ship. The amount of deviation produced by iron of this nature has been found to vary for each ship, and to range from 1° to 6° or 7° ; a great deal depending upon the proximity to the compass of the surrounding iron.

Now, no suitable corrector has as yet been found for deviations of this kind, and the only course open is that of constant observation and careful notation of the results for immediate and future use.

As vessels of war are specially under consideration, I would lay stress on the effects of firing heavy guns with the ship's head in one direction. Sometimes the violent shocks which the ship receives alter considerably the direction of the pull of the sub-permanent magnetism of the ship on the compass. The change gradually decreases in amount, occupying from a month or six weeks to a few days in returning to its normal condition. Considerable success in obviating these changes has been obtained by firing with the ship's head in various directions. For example, when simultaneous broadsides of five 13-ton guns were fired from the "Bellerophon" off Plymouth in 1886, with the ship's head in opposite directions, there was no change of deviation. Other instances might be quoted in support of this.

On conclusion 6, I would remark that up to the present time, the deviation caused by transient vortical induction in vertical soft iron continues to be of moderate amounts at standard positions in most of our ships—a very desirable result, considering that the use of correctors should be avoided when possible.

In dismissing that part of the subject relating to semicircular deviation, it may be said that, if sufficient care is exercised in preparing a place for the standard compass, experience shows that in modern war-ships the semicircular deviation is generally either of moderate amount, or of such a character that it can be corrected for all latitudes. Much may be done in a similar direction for the steering compasses, which are not very near thick vertical armour.

The vessels which have been thus treated of, have always been considered to be upright, or on "even beam," as it has been aptly termed, and there are still certain difficulties to be overcome before we can navigate them safely by the compass. I allude more particularly to the diminution of the mean directive force acting on the compasses at the protected positions on board our modern armour-plated and armour-decked ships, the large values of the quadrantal deviation, the great increase of their heeling errors, and the evil effects of swinging ships other than very slowly in one direction, either to starboard or to port.

Before, however, considering these difficulties, I think my reasons for thus accentuating them so strongly should be given, especially as at standard positions we are able to fairly sustain the conditions of twenty years ago; and no untoward result to navigation has happened during that time, depending in any way upon low directive force, or quadrantal deviation. I believe I am fully supported by many leading Officers of the day in the opinion, that compasses successfully placed in conning-towers and other protected places, so as to be nearly correct in showing the direction of the ship's head, and as a consequence the arc of the horizon through which the ship's head may be turned, are of the greatest importance. Compasses in our well-placed standard positions with closely corrected auxiliary compasses on chart-houses and bridges, from which all-round views

may be had, are all very well for taking the ship to the scene of action or for concerted manœuvres of the fleet without an enemy in sight; but I do not think I detract from British pluck when I say that in face of an enemy within range well provided with quick-firing and machine-guns, the Officer who went to observe at these exposed positions would, besides probably finding the compass *hors de combat*, seriously endanger a valuable life far more useful elsewhere.

On the Diminution of the Mean Directive Force to North acting on the Compass Needle.

It has been thought by many persons that as long as a position could be found in a ship where the deviations were moderate, or could be nearly corrected, such conditions were satisfactory for a compass used in navigating the ship. This idea is most illusory and even dangerous in its consequences, as it is easy to conceive a position where there may be no deviation, and yet the directive force is so low that the compass is not only very sluggish in action, but is liable to the effects of every temporary change in the magnetism in the surrounding iron, and all its mechanical defects are rendered doubly apparent. The following table gives the values of the mean horizontal directive force to north, or λ according to the notation of the Admiralty Manual, on board two of our modern belted cruisers, considering the earth's horizontal force = 1.0. In six of our battle ships the λ at their standard positions varied from 0.800 to 0.855, which may be taken as common values for that class of ship.

Ship's name.	Standard.	Bridge.	Conning-tower.	Fore torpedo-flat.	Steam steering aft.
"Orlando".....	0.762	0.616	0.212	0.660	0.720
"Undaunted".....	0.822	0.618	0.243	..	..

It will be seen by these figures that whilst as a rule 0.8 of the earth's directive force remains intact at the standard positions, only a little over 0.6 is found at the bridge compasses of the "Orlando" and "Undaunted." These latter compasses were placed on the fore bridge for convenience of steering as well as for taking bearings when the ship is going in and out of harbour, and other pilotage waters. They are secured in positions 6 feet above the conning-tower which acts as a gigantic Flinders' bar below it. Descending to the conning-tower, where the compasses are placed in the most advantageous position near the centre, the mean directive force is found to be only 0.212 and 0.243 respectively, or a diminution of rather more than three-fourths as compared with a position on shore. Thus a conning-tower with a plating of 12" thick and two-thirds of that thickness

very soft iron as in the two ships mentioned, is about as bad a place as possible for a compass even when nearly corrected.

On the Quadrantal Deviation.

As long as the quadrantal deviation at any compass is not more than 8° , it may be considered as within manageable limits either for correction by soft iron or to be left for tabular correction. At standard positions in eight typical battle-ships, the quadrantal deviation varied between 5° and $8^{\circ} 30'$; but it is when the protected positions are examined, that the difficulties arise, for then we have generally a combination of limited space and large values of this deviation.

Table of Quadrantal Deviation, or Coefficient D.

Ship's name.	Bridge.	Conning-tower.	Fore torpedo-flat.	After steam steering.
"Orlando"	+4° 54'	+16° 9'	+18° 56'	+25° 38'
"Undaunted"	+4 7	+16 0	..	..
"Collingwood"	..	..	..	+20 30
"Dreadnought"	..	..	..	+21 0

The figures in the table show what is commonly found in protected positions, and they convey the certain information that compasses with such errors, combined with low directive force, are of little use unless closely corrected. How this is to be done will be fully considered towards the close. The attempt was made to correct the 10-inch Thomson compass at the armour-cross of the "Agamemnon," only 12-inch spheres being used on account of the cramped space available, but large and most inconvenient quadrantal deviations of 16° remained uncorrected, and the result was an undesirable compass for manœuvring purposes. Great efforts were made to correct a Thomson compass outside the conning-tower of the "Polyphemus," but they were unsuccessful, and the remaining deviations are constantly changing from the compass being so close to the iron. The only means to obtain anything like successful working, is to place the compass near the centre of the tower, for experiment has shown how futile it is to place it near the sides. Two instances when the compass was placed very near the sides of the tower will suffice to illustrate this: (1.) The "Curlew," lying N. by W. On visiting the tower the movable top was lowered to its full extent, the compass, a 6-inch Thomson, pointed to S.E., the top raised 2 inches, it settled at N.E., raised to 4 inches it showed N. by W.; in fact it was hard to make the compass point in any northerly direction at all. The correcting spheres too, became so strongly magnetized by induction from the tower that they had to be re-

moved as mischievously increasing the errors. (2.) In another tower in the "Conqueror," merely raising the small shutters to look out, altered the Thomson compass inside three points. It is therefore incumbent upon Officers in these ships to see that the movable top of the towers should only be raised to one determined height, if the compass inside and that above it, are to be of use.

On the Heeling Error.

As long as iron and armour-plated vessels were liable to heel under sail, the uncorrected heeling error was often a source of trouble, if not of danger to the navigator; especially if the ship were first on one tack and then on the other. With the sail-less ships of to-day, these conditions no longer exist, but the uncorrected heeling error has still a disturbing effect on the compass when the ship rolls, sometimes producing considerable oscillation of the card, or if that be apparently steady, an uncertainty in its pointing. As regards standard compass positions, the heeling coefficients have much the same values as in ships of twenty years ago, seldom exceeding $1\frac{1}{2}^{\circ}$, often much less, and quite within the limits of easy correction. As with the two other coefficients λ and D , with which the heeling error is closely connected, it is when we approach the conning-towers and other protected places, that abnormal results follow. I do not think I can place the subject more clearly before you, than by giving the details of experiments made last year, when the belted cruiser "Orlando" was actually inclined, and the results of a subsequent series of observations made during her voyage to King George's Sound. This vessel, lying with her head magnetic south in Keyham Basin, was inclined 5° to star-board, and 5° to port, the ship's head by all compasses being noted for each degree as the vessel heeled over. The usual observations of vertical force were also made when the ship was upright. The calculated results from the force observations, and those from actual heel are shown in the table. Their agreement is not as close in all cases as I had hoped, but I do not think the late Mr. Archibald Smith, who gave the formula, expected it to be put to so severe a test. It is nevertheless a boon to possess so ready a means of obtaining approximate values without inclining the ship—a formidable task for every ship of the Navy.

The Navigating Officer of the "Orlando" was furnished with the usual instruments for observing the horizontal and vertical forces, and he sent into office observations for Colombo and King George's Sound. These have now been discussed with the following resulting table of heeling coefficients, in which those from actually inclining the ship are noted in italics:—

	Standard.	Bridge.	Conning-tower.	Fore torpedo-flat.	After steam steering-wheel.
Devonport..... {	+1° 42'	+3° 28'	-0° 32'	-1° 15'	-1° 11'
	+1 10	+2 50	-0 36	-1 36	-0 40
Colombo.....	-0 36	-0 5	-1 47	-0 44	-0 38
King George's Sound.	-1 14	-3 14	-6 17	-1 30	-1 13

To take one example—the above figures show that at the bridge compass when the ship heeled over 10°, on a north or south point, the heeling error would be about three points to the high side in England, and about three points to low side in Australia—a change of six points if not kept frequently corrected by magnets at different positions during the voyage.

The next table shows the relative portions of soft and hard iron in the vertical force of the ship, which is the principal element in producing the heeling error, k representing soft iron, and R , hard iron; and the vertical force in England being taken as 1·0. It may be corrected for all latitudes by a permanent magnet placed vertically under the compass; k should, according to the law that “like cures like,” be corrected by a vertical soft iron bar. It is, however, more convenient to use a permanent magnet vertically *below* the compass, and alter its distance therefrom as necessary.

	k .	R .
Standard	+0·136	+0·039
Bridge.....	+0·419	+0·019
Conning-tower	-0·557	-0·318
Fore torpedo-flat	-0·474	-0·414
Steam steering aft ..	-0·545	-0·387

Note.—The sign + denotes a downward force, the sign — an upward.

At the bridge compass raised 6 feet above the conning-tower the heeling coefficient is shown to be abnormally large and changeable in character from its being almost entirely due to vertical induction in soft iron, the value of k being +0·419, of R only +0·019, which, added to the constantly changing deviation from the horizontal forces, makes the position one to be carefully avoided, except for steering purposes. It is true that as long as the vessel remained in one magnetic latitude, a compass in such a position might be kept with errors of a moderate amount, but the “Orlando” is a vessel intended for possible rapid changes of magnetic latitude, and it would therefore prove a very uncertain compass to trust to. There was, however, a standard position in this ship as usual, where the compass appears to have remained constant in its deviation beyond expectation.

Inside the conning-tower no heeling error of large amount was observed until the vessel reached south dip, and at King George's Sound, it assumed the unprecedented value, as far as I am aware, of about five points for 10 degrees of heel.

At the other protected positions below, the heeling errors proved more constant than at the standard, and capable of easy correction by a magnet.

Taking a general view of the results in the table, it may be remarked, that thick armour plating appears to be the chief cause of difficulty when dealing with a compass, as magnetically speaking it is almost entirely composed of soft iron, seriously reducing the directive force on the needle whilst producing large deviations of a constantly changing character.

On Electric Lighting of Vessels.

When everything has been done by carefully placing the compass, removing all the iron possible from its vicinity, and applying the necessary correctors, there still remains another source of danger to its successful working to be guarded against, which has arisen from the introduction of the electric light on board ship. Fortunately, experiment has now shown that with a well-designed installation, all trouble may be avoided, but I think it would be a want in the present paper if the results of experiments, and the sources of danger which have been discovered, were left untold.

The two causes of disturbance are the dynamo and single wire leads. Thus, experiments on board the "Euphrates" showed that the polarity of an Edison machine affected a compass at a distance of over 40 feet, and instances of disturbance from the dynamo in other vessels have been observed. Of the effects of single wires, an experiment on board the "Royalist" may be cited. One wire was lead under the standard compass at a distance of 13 feet, the return wire was separated only 5 feet from it. With a current of about 100 ampères, a deflection of 8° was observed in the compass, which proved an excellent galvanometer, the deflection increasing and decreasing for every variation of the current without oscillation. In our present state of knowledge, the prudent course appears to be to avoid the use of dynamos of large external field, to keep these machines at least 35 feet from the compass, and to take care, as far as possible, that both poles of the machine be at equal distances from the compass. It has been thought that iron bulkheads and decks would so alter the direction of the external lines of magnetic force of the machine that they would act as screens. This suggestion has not been borne out by experience and suitable magnetic screens have yet to be devised.

As regards the wires, the use of single wires with hull as return is to be deprecated, and the lead and return wires should be kept close together and carefully insulated.

I have used the expression "our present state of knowledge" in order to avoid any appearance of wishing to give a law for a matter

connected with electricity, a branch of science which moves onward at so rapid a pace.

On the Effects of Swinging Iron Ships only in one Direction.

I am not aware of a better means of illustrating the effects of swinging iron ships otherwise than very slowly in one direction, than that of bringing before you some of the results of a series of observations made on board the "Inflexible" in 1882. The compasses used were the Admiralty standard in one position, and a Sir W. Thomson's compass in another; the observations being made by the azimuth instrument of each compass, so that no errors due to comparing one compass with the other could creep in. It was generally found, that when the ship was swung opposite ways, to starboard and to port, on the same day, there was often a difference of at least 2° in the deviation for each direction of the ship's head at both positions. As much as 4° between the swinging to starboard and to port was found at a compass, when the surrounding iron was near and unsymmetrically distributed. The series of deviation tables from the "Inflexible" are very instructive, and form a valuable record of scientific and practical interest. The ship appears to have been swung in the usual manner as regards time, but it is evident that a vessel with such thickly-armoured decks and sides, and iron so close to the various compasses, must either be swung very slowly and steadied on each point, so as to allow the iron not strictly "soft" to take up the proper amount of magnetism due to the direction of the ship's head, or she must be swung opposite ways, and a mean result taken for the correct deviation. It should be borne in mind that the case of the "Inflexible" is one amongst many others, and the lesson to be learnt is applicable to all iron vessels of the present day.

The Disturbance of the Compass on approach to certain Shores.

The mariner's compass has yet another enemy to contend with in the magnetic disturbance caused by proximity to land. This reported disturbing effect is not now brought forward as a novelty, in fact it is an old story often told and discredited by many whose opinions were well worthy of consideration. Well authenticated reports of recent years show that both those who doubted and those who reported were both partly right and partly wrong. The facts are these: it is seldom, if ever, that the visible land disturbs the compasses of a ship, as her distance from the shore would almost in every case entirely keep her out of its magnetic influence. It is the submerged land near the ship's bottom which, possessed of magnetic properties, sometimes of attraction, sometimes of repulsion, produces the observed effects on the north point of the compass.

Now, I have brought this part of the subject forward, in order to place a clearly proved fact on a proper basis, and not with the view of alarming the seaman. We have now a list of localities, situated in different parts of the world, where the disturbance of the compass has

been noted by trustworthy observers, and I would raise a note of warning to navigators, prone to shave corners on a dark night, guiding their ships solely by the compass, that the rocks they approach with ample water over for the ship to float and be safe, may be so strongly magnetic as to deflect the compass, carrying the ship into serious danger if not destruction.

Observations tend to show that magnetic rocks in the northern hemisphere attract the north end of the needle, and therefore a ship nearing the land in moderate depths of water, say under twenty fathoms, on northerly courses, would be drawn nearer and nearer to them. In the southern hemisphere the converse appears to hold good, the north end of the needle being generally repelled, and a ship steering on southerly courses might be liable to close the land without her Officers knowing anything about it. There is no need here to enlarge upon the results of an iron ship's merely touching the ground, much less striking on a rocky bottom. Two well-established examples of disturbing localities will help to illustrate the foregoing remarks, which are the outcome of considerable inquiry.

The first is the case of our surveying vessel "Meda" at Cossack in North Australia. Here, with the visible land three miles off, the "Meda," running on a transit of two objects on shore, in 8 fathoms of water, had her compass steadily deflected 30° for a quarter of an hour during which she sailed over a mile.

The next instance is that furnished by observations of the variation of the compass on the East Coast of Madagascar. The normal lines of the variation for several miles of the coast from St. Mary's Isle southward should vary from about 11° W. to 12° W., but instead of this the French men-of-war, which are frequently running up and down this part of the coast, find that the variation near the shore at St. Mary's Isle is only 6° or 7° W. and 12° W. at $80'$ south, the north end of the compass being repelled by the magnetic properties of the bottom. These results are analogous with those of observations on shore in Madagascar, New Zealand, and other places.

On the Magnetic Character of Torpedo-boats.

As torpedo-boats are an entirely novel form of fighting vessel, introduced since the paper of 1872, a few remarks on their magnetic character may be acceptable.

It may be said at once, that with the standard positions there is every reason to be as fully satisfied as with those of any other iron vessel. The semicircular deviation seldom exceeds 12° or 14° , the quadrantal is generally $+4^\circ$, and the mean directive force is satisfactory. The compass, therefore, is easily corrected by magnets and soft iron; the small remaining deviations of about 2° being fairly permanent in spite of the constant vibrations to which the boats' hulls are subjected. The steering compasses have generally to be placed near the sides of the turrets with semicircular deviations of some 30° or 40° , the maximum of quadrantal deviation being sometimes 8° or 10° , at others 3° or 4° ; but this is a subject which is

receiving attention, with a view to placing the compasses in more satisfactory positions.

Modern Systems of Correcting the Deviations of the Compass.

Very little has been said as yet on the question of correcting the errors of the compass, but the readers of the Journal of this Institution will remember how fully Sir William Thomson described the manner in which he had applied Sir G. Airy's system of correctors to his patent compass, as well as the Flinders' bar.¹ Subsequently to this, in the Journal for 1882, there is a paper by myself, "On Compass Correction in Iron Ships." I, therefore, propose to confine my remarks to the latest phase of the question.

It is commonly remarked, that either a compass is sluggish and will not move, or that it is excellent and moves directly the ship's head moves. Now the ideal compass on board ship is one in which the card refuses to move at all, and steadily and strongly points to magnetic north while the ship and compass bowl turn round it as required by those in command. It should have no work to do in the shape of turning to starboard or port, to bow or stern, in obedience to the magnetic forces existing in the ship, and the directive force of the earth should be interfered with as little as possible. How far the compasses on board our iron and armour-plated vessels fall short of this ideal is shown by their deviations, which, at best, are but reduced to a small amount for a given time and place, whilst constancy of deviation may be said, as yet, to be unattainable.

The reason is obvious: the correctors we use are constant in their action, whilst a portion of the magnetic forces they are intended to oppose is for the most part variable in amount and direction. With well-placed compasses there should be no difficulty in reducing the deviations to a minimum amount of 2° or 3° , subject to changes from firing heavy guns and running for some time on one course; it is when we come to conning-towers and other protected places that trouble arises, first in making the correction and afterwards maintaining it. Our difficulties lie in the correction of large quadrantal deviations ranging from 12° to 30° , and increasing the low directive force. The polar deviations must be left to the care of the magnets, but let us inquire what can be done for the quadrantal.

Beginning with the best form of Sir W. Thomson's compass—the 10"—and supposing that the "Orlando," as a typical ship which we know so well, is provided with them on the bridge, in the conning-tower, and the two protected stations below, what happens? At the same time bear in mind that Sir W. Thomson lays special stress on the close correction of his compasses, for he naturally wishes them to be like the ideal compass just mentioned and inexorably point to the north.

At the bridge compass the quadrantal deviation is only about 5° , and can be readily corrected by a pair of 7" spheres, which also help to correct about $44'$ of heeling error for every degree of heel on

¹ See papers of February, 1878, and May, 1880.

the north and south points till the first 5° of heel are reached, but gradually decreasing in their power as correctors as the ship inclines further. Inside the conning-tower, the quadrantal deviation is a little over 16° , requiring a pair of $18''$ spheres to correct it. These spheres add about $1\frac{3}{4}^\circ$ of heeling error for every degree of heel.

On the fore torpedo-flats the quadrantal deviation is 19° , requiring correcting spheres of $20''$ diameter, and adding largely to the heeling error which might otherwise be kept nearly correct in all latitudes by a permanent magnet.

At the after steam steering wheel the 26° of quadrantal deviation must have at least $24''$ spheres, again adding largely to the otherwise moderate heeling error.

Again, the effect of spheres is to reduce the directive force on north and south courses, and to increase it on east and west, their general effect being to slightly increase the mean directive force to north on the compass, to correct the quadrantal deviation, and to introduce heeling errors sometimes of a beneficial order, but in some cases producing adverse complications.

In positions below such as we have considered, and specially in conning-towers, the great size of the spheres required for accurate correction makes their use almost prohibitive, and in many ships there is no room even for the moderate sizes. Moreover, we have seen that the directive force is so low that one instinctively inquires why cannot these large deviations be corrected by some system which requires small space, say, within a circle of 20 inches, and at the same time sensibly increases the directive force which is so sorely needed?

By reducing the size of the compass somewhat, I have reason to believe these objects may be attained, and the compass card may be given needles of great directive force, which, instead of being a hindrance to correction, are a benefit.

In order to possess clear views of the quadrantal corrector I am about to describe, a short explanation of the principles upon which it is based seems necessary.

The well-known example of soft iron rods, placed in a horizontal plane passing through the needles of a compass, will help towards this

FIG. 1.

FIG. 2.

FIG. 3.

SPHERICAL QUADRANTAL CORRECTORS FIXED TO BINNACLE
TO CORRECT VALUES OF D IN ORLANDO.

- k* CLAMPING SCREW.
h SCREW FOR D MACHINERY.
k CLAMPING SCREW FOR SETTING THE QUADRANTAL CORRECTOR FOR OBLIQUE DEVIATIONS $\pm E$.
k INDEX FOR THE CORRECTION OF $\pm E$.
c SOFT IRON CORRECTING ROD OF UPPER SET OF RODS.
c' SOFT IRON CORRECTING ROD OF LOWER SET OF RODS.

Figs. 4, 5, 6, 7, 8, 9 are not drawn to scale.

Fig. 4.

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

PLAN OF RODS FOR
CORRECTING QUAD-
RANTAL DEVIATION.

THE CURVE A E C F B H D G, WHICH SHOWS OCTANTAL
DEVIATIONS FROM AN ELLIPTICAL CURVE SERVES TO
CONNECT BESIDES THE QUADRANTAL DEVIATION
ALSO THE OCTANTAL ERROR.

purpose. Thus, in Fig. 1, the equal rods *increase* the directive force but produce no deviation. In Fig. 2 the equal rods *decrease* the directive force but produce no deviation. In Fig. 3 the transverse rod is much longer than the longitudinal, and the deviation of the compass is caused as well as loss of directive force. It is soft iron, represented by rods of the type Fig. 3, which produces the low directive force combined with large quadrantal deviation on board ship. Therefore, reasoning from the effects of the rods in Figs. 1 and 3, we have only to place round the compass soft iron rods of the type Fig. 1, but of different lengths, so as to counteract the forces of the unequal and detrimental iron of the type Fig. 3. This solution of the difficulty of correction has been most cleverly worked out by the Chevalier Peichl of the Austro-Hungarian Navy, and a compass with corrector, invented and patented by that Officer (see Plate), lies before you on the table; but as the system of soft iron rods is concealed by the woodwork, reference must be had to the diagrams for explanation. I may remark here that this corrector has been adopted for five years in the Austro-Hungarian Navy with great success.

Using the notation of the Admiralty Manual which is now common to the world, the parts of the quadrantal deviation are known as coefficients D and E . The following is a translation of the inventor's description of the instrument:—

"The quadrantal corrector forms the principal part of the instrument in question. The action of this corrector is easily derived from the following considerations: an arrangement of perfectly soft iron rods, and of equal dimensions, disposed radially round a compass at equal distances from the card (Fig. 4), can produce no other effect than that of increasing the directive force, for then it is only a multiplier of intensity. But if, on the contrary, these rods were no longer equal in such a manner that their interior ends form an ellipse (Fig. 5), of which the major axis is parallel to the keel, that different arrangement will produce a multiplier of intensity which at the same time will be capable of compensating a given value of the positive quadrantal deviation, since it produces a negative D . In the positions of this arrangement shown by Figs. 6, 7, and 8, the effects are $+D$, $+E$, $-E$; and in the intermediate positions, the relative portions of D and E will result. Now the quadrantal corrector consists of two sets or systems of soft iron rods placed one above the other, and movable in opposite directions round the compass bowl. Fig. 9 represents their position when the index is at zero. One sees by that that they produce $+E$ and $-E$, and that consequently their total effect in that position is *nil*. By turning them in the direction indicated by the arrows, the position will be reached when the major axes of the two ellipses are parallel to the keel. This is the position of their maximum effect, and it is marked on the index as 1.0. The value of this maximum effect depends upon the details in the construction of the instrument, that is to say, on the length of the bars, and the distance of their interior ends from the card respectively with the form of the ellipse."

The action of this corrector is due especially to the induction of

the compass needles in the soft iron rods. This necessitates an adjustment of the corrector on change of latitude, for which an index and scale are provided for all latitudes, and is of a very simple nature.

"This quadrantal corrector produces an increase of directive force for every direction of the ship's head."

I have experimented with this instrument in the conning-tower of the "Medusa," and I found I could correct 30° of quadrantal deviation for all latitudes, and for the coasts of the United Kingdom about 44° . These advantages, coupled with the increase of directive force on all azimuths, and the small space occupied, have led me to hope that this instrument will meet a deficiency in our present compass equipment. Before concluding the description of this corrector, I may point out another valuable property connected with it. As the ship proceeds to parts of the world such as Quebec and the St. Lawrence, where the horizontal force of the earth is smaller than in England, so the directive force of the instrument increases, making the compass point with greater energy than with any other system.

In a paper read last month at the Institute of Naval Architects, Mr. W. W. Rundell, who may be styled one of the fathers in compass matters, discussed the question of correcting certain compass errors caused by iron unsymmetrically placed near a compass. His arguments tend to show that these errors are such as would be produced by one horizontal and one vertical bar of soft iron unsymmetrically placed, and that the corrector should be an inclined bar of soft iron, the position of which is to be found from an analysis of the observed deviations. I am testing his propositions experimentally, but am not yet in a position to give an opinion upon them.

General Observations.

Every now and then it is reported that the mariner's compass which has served the navigator on the ocean and the traveller in the trackless forest so faithfully for hundreds of years is about to be superseded by an instrument which shall always show the true north. The idea is captivating, and its realization would be a boon when we call to mind what has been said of the compass in ships of war. Such an instrument therefore must be independent of all magnetic influences. It is true that in 1852 Léon Foucault showed that the gyroscope takes up a direction parallel to the earth's axis. Foucault writes: "Then without the help of any astronomical observations the rotation of a body at the surface of the earth suffices to indicate the plane of the meridian." Sir W. Thomson, at a meeting of the British Association in 1883, also described a form of gyroscope, which, when rapidly rotated, showed distinctly the direction of the true meridian.

The question as to the motor of such an instrument, which should at once be automatic and continuous, has not yet been answered; and I think we shall for the present do wisely in treating the compass fairly, knowing full well that the earth's magnetic force is ever present to direct it.

The words "Mariner's Compass" cover a great variety of means for utilizing the one great principle of the earth's directive force, in the shape of a large number of compasses patented and otherwise. Finality has not been reached by any one of them, nor is it likely to be. Still we must always feel grateful to inventors for the many valuable aids they have provided for safe navigation; but those who have to report on inventions, and have the good of the Service at heart combined with due economy, must always be on their guard, remembering that they have to deal with individuals often pleasant, persuasive, persistent, and perceptive of everything but possible faults in their inventions. Amongst the many patents, I will only mention Sir W. Thomson's compass, the valuable qualities of which under certain conditions are so well known and require no special notice here.

There is another compass to which I would draw attention, and that is the liquid compass, which, if properly constructed, is one of the most generally useful instruments of navigation yet made. In torpedo-boats, and some of the latest types of fast cruiser steaming under forced draught, the liquid compass has acted well when every other compass failed to a serious extent or was practically unserviceable. It has been in general use in the United States Navy for many years, and in their official book of "Notes on Chronometers, Compasses," &c., the following occurs: "It may then fairly be concluded that the United States Navy is possessed of a compass unsurpassed in its essential qualities by those in other services whether naval or mercantile."

It is used universally in the Austrian and German Navies, and also as a standard compass in the Italian Navy, I, therefore, say without hesitation, apart from such witnesses to its value, that we must hold fast to such a friend in need as it has lately proved, doing all that is possible to perfect it as a part of the necessary equipment.

As to the placing and correction of compasses in our vessels of whatever type, the departments at the Admiralty are working heartily together. The Controller of the Navy, at the request of the Hydrographer, has lately issued revised instructions to meet the requirements of the day, with a view to providing as suitable places for all compasses as the fighting necessities of a war-ship will permit. With the sources of error thus eliminated as far as may be, the work of providing suitable compasses and correctors is a constant subject of earnest enquiry in the department to which I have the honour to belong, and the strength or weakness of the several compass positions is fully proved.

It is not necessary to ascertain the magnetic character of every ship as has been done in the "Orlando" and "Undaunted," as a number of ships of one class or type are generally built, and the full knowledge of one or at most two of each type furnishes all the most useful and necessary data for the rest.

The care thus bestowed is none too much, although it is sometimes asserted that correctors can do anything—and, lest a good way should come to be evil spoken of, I will quote a few lines from a work pub-

lished by the United States Bureau of Navigation after they had made a searching inquiry into the subject of compass errors, and their treatment in iron and steel ships:—

“From all that precedes, it will readily be inferred that to place a compass where the magnetism of the ship will least affect it, is essential both to the safety of the vessel, and to the good behaviour of the instrument itself.” Again, “Compensation of large deviations by means of magnets is at best but a remedy for an ailment; better not sow the seeds of the disease.”

I should add that this inquiry was accompanied by experimental tests of the truth of Archibald Smith's mathematical theory of the deviations of the compass.

There is yet another point upon which I would make a few short remarks, that is on the constant changing of the correcting magnets of the standard or navigating compass, by which the ship's course should be shaped, even if not so conveniently at hand as the badly placed auxiliary compass. The word “standard,” as here used, refers to a position, not to any particular form of compass.

If the changes of the semicircular deviation range from zero to 4° or 5° , I think it much more advantageous to leave them alone, and trust to frequent observation for ascertaining the deviation, entering each observation in a compass journal for future reference. Should the semicircular deviation change largely and permanently, it would, no doubt, be right to correct it, taking care to swing the ship immediately after to ascertain remaining deviations.

These recommendations do not refer to manœuvring compasses, which it is most convenient to keep as nearly as possible correct, Commanding Officers giving opportunities for making the corrections as required.

As to the compass journal, it is largely used in the navigation of the many noble vessels of the mercantile navy, and a constant changing of magnets is generally deprecated by their eminently practical commanders.

Touching the question of education in matters relating to the compass, every means has been adopted for imparting sound information to Officers. At the Royal Naval College, Greenwich, the seniors find able instruction of a most practical kind. At the College in Portsmouth Dockyard, every Sub-Lieutenant goes through a most useful course, illustrated by models and practical adjustments in an iron gunboat at Spithead. They are also supplied with a pamphlet of instructions in compasses and their treatment in iron ships, issued by order of the Admiralty.

After all that has been said, true science teaches us a never-to-be-forgotten lesson. Observe the deviation when possible, note it in a book, and learn its changes under every circumstance as you do the rate of a chronometer. Then on some thick dirty night, the reward will come in the shape of a reasonable confidence that you can steer the required course without delay and detriment to the service upon which the ship may be ordered.

The CHAIRMAN: I may take this opportunity of saying that I have received a note from Sir William Thomson, addressed to the Chairman, regretting not being able to be present to-day. I am sure you will all join in that regret.

Admiral Sir ERASMUS OMMANEY, F.R.S.: I am very glad to find that we have this subject brought before us again after such a long interval, for it is now seventeen years since Sir Frederick Evans delivered a most instructive address here regarding the magnetization of iron ships and its effect on the steering compasses. During this interval a wonderful alteration has been progressing in the construction and in the metal of iron ships, likewise in the improvement of steering compasses; we are therefore grateful to Captain Creak (the able successor to Sir F. Evans) for the instructive paper we have now heard, containing so much scientific and practical information of great value. I will not attempt to criticize this paper, coming from such an eminent expert as Captain Creak, than whom there is no higher authority in our kingdom on this important question. In my opinion the author of this paper has put the whole matter before us, as it now stands, most completely. I regret to observe so few naval Officers present. Let us hope this paper will be read elsewhere, very extensively, beyond this room. The influence and effect of magnetism, which operates so mysteriously and invisibly over the surface of the earth, renders it more incumbent for the mariner of the present day to study more attentively this branch of science and the properties of this secret agent which possesses an individuality in every metallic ship which traverses the wide oceans, in order to secure accuracy for its navigation. I am sure we are all much indebted to Captain Creak for producing this very instructive paper.

Captain WHARTON (Hydrographer to the Navy): Captain Creak's very able and lucid paper so fully covers the ground and opens up so many questions that there is not much left for me to say. I may remark in starting that I heartily agree with all that he has said, although I do not pretend to be such an authority on the subject as he is. I think he very prominently brought to everybody's mind the enormous difficulties that there now are in correcting compasses on board our men-of-war. For some years there have been difficulties, but it is not too much to say that they increase every day. There is no doubt that in war-time the compass you will want is a compass that you can depend upon in a conning-tower, and these are just the compasses I am sorry to say that at the present moment are not at all reliable. The admirable invention of Sir William Thomson fails there, because in these protected positions, as Captain Creak showed, you have not room to place a compass with large spheres. Those enormous spheres not only take the whole space in these limited towers, but to a certain extent they introduce error. Captain Creak referred to the invention of Chevalier Peichl, whose compass has been introduced into the Austro-Hungarian Navy for the last five years. I believe it has been under the consideration of the Admiralty nearly as long as that, but recent improvements of Mr. Peichl's have led Captain Creak to make further experiments, the results of which are so encouraging that we are getting some more of them over to try in our ships and test their efficacy thoroughly. If it answers as we hope, it will go very far towards solving that most important question of getting the compass to work in these extremely awkward positions with large masses of iron near it, and at the same time it will take up less space. I only hope our anticipations may be justified. I may mention in connection with the difficulty of fixing the position of a ship that I have been for some time most anxious whenever there is an opportunity to inculcate the use of the station pointer. I am happy to say these instruments are now being issued to all ships, and I hope with a little practice we shall come to recognize the extreme value of that system, which in time of war, in action, and also in time of peace, in ships where there are so many obstructions to clear view from the compass, enables you to fix the position extremely accurately from either a protected position or a position where, by inclining your head a little, you can see the object which in a modern ship of war you cannot possibly get from many of the compasses. Captain Creak has brought forward the question of the disturbance of the compass on approaching shore. For a long time it was thought not possible that the compass could really be disturbed. By well-known magnetic laws the sphere of influence of any disturbing forces is so small that it was felt quite impossible that the compass passing a point of land should ever be disturbed by the

magnetic character of the rock. But in some extraordinary manner it has been overlooked that while a ship is a long distance horizontally from land, she may be passing very closely vertically over it in shallow water, and it has only been recently recognized that this is the true explanation, and that there really is a danger in certain places, the majority of which are quite unknown, in passing over shallow water, of the compass being seriously deflected. I believe now that it is known it will be borne in mind. I can only conclude by saying that I hope that our motto will always be "Onward." Finality is by no means reached. We have a very difficult task in deciding what is the best form of invention to take up. It is very slow work indeed experimenting, but I feel very safe with Captain Creak at the head of the Department looking after it. I know that he has not only a very open mind, but he has the fullest knowledge of the subject, and I have every hope in time that we shall arrive at a more satisfactory condition of the compass in awkward positions than I am afraid exists at the present moment.

Captain MAYES: I wish to bear testimony to the great value of the paper read by Captain Creak. It shows the difficulty there always has been to correct the deviation of the compass in positions where the space is limited in iron ships. It is too technical a subject to go into very much, but I will just mention a few things that I have noticed. Captain Creak spoke of permanent and sub-permanent magnetism. In the very earliest days, Sir George Airy, Astronomer Royal, spoke of a part of the magnetism of an iron ship as "permanent." He afterwards thought proper to change the term to "sub-permanent." From that time to this there has always been a doubt in the minds of many people as to which is "sub-permanent" and which is "permanent" magnetism. I cannot help thinking if we use the word permanent only, instead of permanent and sub-permanent, we should be able to express all that is required, recollecting that the magnetism of a ship is, like most sublunary things, permanent only for a time. The correction of the heeling error is unsatisfactory, and the formula given by Mr. Archibald Smith does not appear to be correct. I have always found a difficulty in dealing with it, and I do not think that difficulty is quite got over yet. With regard to the electric light, when first it was introduced into the Service, electricians were very confident that the iron about the dynamo would conduct away and shield the compass from all disturbing influences. But they seemed to forget that we are dealing with magnetic force and not electric force. Magnetic force may be transposed but cannot be cut off by iron. The only way I can see out of the difficulty is to intervene between the compasses and the dynamo a bar of iron so magnetized by a wire carrying a current when the dynamo is running, as to set up a counteracting magnetic field. There is no way of insulating it that I can see. The effect of swinging the ship to port and starboard was known many years ago. It was first spoken of by the Liverpool Compass Committee. The "Defence" was swung in 1865 both ways, showing a maximum difference of 3° , the maximum being on the north and south points. I have never seen an explanation of this disturbance of the needle which has quite satisfied me. With regard to the disturbing effect of land upon compasses, that has been known since the early part of the century; but as the Hydrographer says, it was generally forgotten that land was very near the ship sometimes when it was spoken of as being miles away. When men spoke of land, they thought of dry land, not of the wet land under the ship's bottom. With regard to torpedo-boats, some have been swung after various intervals of time, and I have been much struck with the very great permanence of the deviation of their standard compasses. The compass in the conning-tower presents insuperable difficulties for want of space wherein to apply the necessary correctors, even to the smallest compass. Captain Creak has alluded to a recent paper by Mr. Rundell. I may state with reference thereto, that no iron bar can be placed about a compass in such a manner that its deviation cannot be expressed by Archibald Smith's formula. The last part of Captain Creak's paper is perhaps the most important, that relating to the education of naval Officers on the subject. I am very pleased to hear that it is going on so well, but it has been going on several years now, and I think it is quite time that we got something out of it. This will never be the case until the Admiralty insist upon naval Officers putting to practical use the education which it has cost so much to impart. If it were once made clear that Officers are expected to adjust the

compasses of and swing their ships, even if the duty were not immediately made compulsory, it would be one step towards abolishing the present inefficient system. I do not know that I have anything else to say upon the paper, excepting that I think Captain Creak has done good service in reading it.

Admiral COLOMB: There were one or two points that struck me in the reading of the paper. I rather thought the lecturer explained better than I could, and it seemed satisfactory to my mind, the difference in apparent deviation when the ship is swung the opposite way, that it was the time required for the magnetism of the ship to, as it were, re-assert itself. I have never understood it before, but it does seem to me to be a satisfactory explanation. I would ask him in his reply whether that is what has been called Gauss's error. I would like also if he would answer another question. Some time ago there was a strong correspondence—I must say, that with my slight knowledge, to be a rather senseless correspondence—in the mercantile marine papers, and I think in the "Nautical Magazine" also, referring to deviation of the compass in fog. May it not be that in approaching the land in a fog the shallow water had affected the compass, and that the idea arose in that way? Unquestionably all that has been said, speaking practically, about the necessity for getting some reliable compass in those parts of the ship where alone in action the command is to be—conning-towers, or whatever they may be—is exceedingly important. One is delighted to think that we may be getting hold of something of that sort in this Austrian compass, but I have always felt myself, in all these cases of the protected command of the ship, that the point is to get everything out of that place, and to have nothing but the Officer commanding, with the staff which it is necessary for him to have, to have no instruments whatever of any kind inside those places. I do not know whether anything has been done in the direction of reflection, but I cannot help thinking that we might use the principle to some extent. You might move the compass to a suitable distance and merely have the face of it reflected by a series of looking-glasses into the place where you want to see it. To my mind the trouble is analogous to what we have had in conveying the words of command, and the telegraph signals working them from the conning-tower, and I have always aimed, as long as I had power in that way, at getting apparatus away from that place, allowing the Captain's voice simply, without tubes or anything of the sort, to communicate downwards to the spot where the telegraphs and tubes and everything else were, so that he should not be troubled about anything except giving his orders. In the same way if he had merely the reflection of the compass before him I think it would be all he would probably require. My own predilections, as far as they go, have been, I must say, in favour of shifting magnets rather than fixed ones for correcting deviation. I have always thought very highly of Sir William Thomson's plan, but I am not sure I ever went so far as to think you should dispense with the standard compass and recording the magnetic changes in the condition of the ship, but I certainly have found much benefit in having a compass where you could continually correct it on the spur of the moment. For instance, when I was in the Steam Reserve at Portsmouth I had to take ships to sea, knowing nothing of their deviation, and to be at sea for eight or ten hours, liable, as happened to me once or twice, to get into fog, not knowing where you were or what you could do, with a compass that you could not trust. The plan I adopted was this. My Staff Commander laid down a series of transits as we were going out—altering the ship's head, taking the transits and correcting a Thomson's compass by them, after which we could fairly trust it. At any rate we were in a better condition from having a compass that we could correct, however roughly, than in being caught in a fog at sea without a compass that you could trust at all. I have been extremely pleased with the lecture, and I only wish that I had been more competent to follow it accurately.

Captain A. C. PARR: As the instruction of Officers at the Naval College at Greenwich has been referred to, I, as one who has been going through a course there, should like to bear testimony to the extreme interest which I have felt in doing so. Before I went there I understood nothing about the compass, and my instruction with regard to any corrections has been absolutely *nil*. As to being able to understand or get any benefit from the Admiralty Manual, I am afraid I did not succeed like Admiral Colomb in tracking the murderer to earth at all. I simply

could not understand it. But now I must say, having gone through a course of instruction at the Naval College, I have been able to follow this lecture with very great pleasure, and to thank the lecturer for it, and to feel the benefit which I have received from that course. I am also very glad indeed that the Sub-Lieutenants are receiving instruction in the compass, for I think there is the proper end to begin at. If the midshipmen know something about it, as they go on they will be able to develop and to obtain very useful information. How long the course of instruction at the College has been going on I do not know, but certainly we have many capable Officers already instructed, who would be perfectly competent to carry out any observations that might be required, and I have no doubt that we shall very soon see the results which one gentleman who has spoken hopes may soon be visible. I will conclude by thanking the lecturer for his paper.

Captain CURTIS: I might suggest to these young gentlemen, the midshipmen, that they should get a small magnet and experiment with it. One of the prettiest effects of magnetism is to take the kitchen poker, and just hold it in a line north and south, at an angle of 67° , give it a blow or two with a mallet or hammer; one end of it will become the north pole and the other the south, and you then reverse the poker and give it another blow, and you reverse the poles. I am sure that such an experiment would set any midshipman or schoolboy wondering at the effects of magnetism and excite his curiosity for more knowledge. I might also suggest, permanent magnetism is due to the hammering of iron in the manufacture of a ship, and also when she is twisting and turning about; the firing off the guns, we suggest is that sub-permanent magnetism is produced. A ship is always altering the magnetism; when she is in the north and south line she increases it by induced magnetism of the earth, when she reverses her head she reverses the current, consequently the compasses are always liable to be corrected, "in fact magnetism is not a constant."

Sir ERASMUS OMMANNEY: Might I ask whether any amount of deviation has been detected in the magnetic character of a ship during its lifetime?

Admiral LINDSEY BRINE: As I did not hear the whole of the lecture, what I am going to say may have already been touched upon. The first point I notice is where the lecturer spoke of heeling error. I do not know whether Captain Creak means this, but he says that when a ship heels over the error is as much as 10° .

Captain CREAK: It is sometimes as much as 30° .

Admiral BRINE: I observe that in the paper you say it goes up sometimes three points on one side and three points on another. Now as regards this other very important point about the disturbance of the compass on approaching the land. You say in the case of one of your surveying vessels that running on a certain course you found the compass was "steadily deflected 30° for a quarter of an hour, during which she sailed over a mile." I suppose that would depend very much upon the nature of the ground over which she was going. Is it known what was the nature of the bottom at the point where that ship sailed over? Was it volcanic or some rock of a known character other than volcanic? I would also ask the value of the vertical attraction as compared with horizontal attraction when a ship is going over land nearer the bottom. I have never understood that to any extent the vertical attraction affects the compass in a horizontal direction. I suppose that this subject has been worked out. If you would be kind enough to answer the question it might be useful.

Captain BEALL (Board of Trade): As my experience is connected entirely with the mercantile marine, I fear I shall not be able to add much to the value of the discussion, but there are two or three points in the paper I should like to remark upon. Captain Mayes spoke just now about the term "sub-permanent magnetism." That is a point I really do not quite understand in the paper. The officers of the

¹ "Some Curiosities of Magnetism," lecture at the London Institution, February 11, 1889, by Sheldford Bidwell, F.R.S. A rod of iron which has been magnetized by the action of the magnetic field is found generally to retain some of its magnetism when withdrawn from the field. This "*residual magnetism*," as it is called, is held much more tenaciously by hard steel or iron than by metals which have been softened by careful annealing.

mercantile marine, and, indeed, nearly all writers on the subject, regard sub-permanent magnetism as referring to the permanent magnetism of an iron ship as distinguished from the permanent magnetism of a permanent magnet, or magnetized steel bar, and consequently they would correct that magnetism with a permanent magnet. Captain Creak appears to apply the term "sub-permanent magnetism" to something between permanent magnetism and transient induced magnetism, or what is commonly known by the term "retentive" or "retained" magnetism. I might explain myself more clearly, perhaps, by referring to two or three extracts I have here. This is from "Towson's Practical Information on the Deviation of the Compass, for the use of Masters and Mates," a work that was really prepared as a textbook for the Board of Trade examinations. His remarks: "From what has been said it will be apparent that the term 'permanent' is not accurate when applied to the magnetism of an iron ship. Dr. Scoresby perceived this, and proposed to designate as 'retentive magnetism' the portion of the magnetism acquired on the building slip, which was retained after launching, and which he considered was retained only for a period, and under certain circumstances might be lost altogether, or even reversed. But experience has shown that this is a misapprehension, for although a ship does not retain the whole of the magnetism acquired on the building slip, yet it is certain that in all our iron ships some portion of the magnetism so acquired remains permanent. And we agree with the Astronomer Royal, Sir George B. Airy, in calling this residual magnetism 'sub-permanent magnetism.'" On the other hand, to put it briefly and clearly, the term is now applied in the following sense in the Navy. This is taken from "The Course of Instruction for Acting Sub-Lieutenants," published by the Admiralty: "Perfectly soft iron as here defined is rare, and the soft iron in ships requires a certain time to fully acquire and lose the induced magnetism. When this time is very perceptible—amounting often to many days—the magnetism induced is called sub-permanent." It is evident, therefore, that in the Royal Navy "sub-permanent" refers to induced magnetism, and in the mercantile marine, and indeed by nearly all writers on the subject, to the permanent magnetism of the ship. I think it is rather unfortunate that the term "sub-permanent," which is so well known, should now be applied to two different, in fact, opposite, things. I may say it was rather confusing to me, although I am not new at the subject. Therefore, I am sure it must be so to a great many of those who have but little knowledge of the subject. There is one more point I should like to remark upon, and that is in regard to the following sentence:—Captain Creak says: "At the bridge compass the quadrantal deviation is only about 5°, and can be readily corrected by a pair of 7" spheres, which also help to correct about 4' of heeling error for every degree of heel on the north and south points till the first 5° of heel are reached, but gradually decreasing in their power as correctors as the ship inclines further." Now, I do not quite see this, but probably I may not understand the remarks in the sense intended. It appears to me that their power as correctors, instead of decreasing after the ship heels 5°, is really increased till she has heeled over, say, 25° or 30°. Put it this way. Suppose you compensate a quadrantal +D of 5° by spheres, in the ordinary way. You then put the ship's head north and heel her over; you would then find when she has heeled over 5° that these spheres would compensate about 2° of heeling error; at 10° heel, about 4° of heeling error; at 15° heel, about 6°; at 20° heel, about 8°; and when at 25° heel, about 10°. It appears, therefore, to me that it is a continually increasing power as the vessel goes over instead of decreasing. I do not know that I have anything further to add, but I should like to be allowed to express my thanks to Captain Creak for his very able and interesting paper.

Colonel BAXLIS: Would you forgive me for rising to ask a question? I feel that this lecture is more than usually important, it is one of universal interest. I have derived a great deal of information from this admirable lecture. There is one point which struck me before coming into this room. It is only perhaps a rudimentary question, and therefore will be most easily answered by the lecturer, and as the Journal goes far and wide throughout the world I think probably what has struck me has struck others also, and they would like to have the answer. I know something of the variation of the compass and the adjustment of the compass, and so on, and it often occurred to me whether it would be possible to get some material which

will so isolate the ship's compass that it will not be subject to other magnetic properties or influences of external matter. The lecturer has stated that the introduction of the electric light on board ship has been a source of danger to the successful working of the ship's compass, and that experiment has fortunately now shown that with a well-designed installation all trouble may be avoided. It occurred to me, before I read this paper or came down here, that some better method of isolating the ship's compass might yet be discovered. If it had been, it no doubt would have been brought into use, but is there any likelihood of some mode being discovered by which you shall be able to isolate the ship's compass that it shall not be liable to be affected by external magnetic properties, and only the natural magnetic direction prevail? I think that it would be useful to myself and it may be to others that my question, though simple to him, should be answered by so experienced a lecturer.

Captain CURTIS: You can isolate electric wires by gutta-percha, but unless you can get transparent gutta-percha to see the compass through, I do not see how you can isolate it.¹

The CHAIRMAN: Before asking the lecturer to answer the questions that have been put, I intended making a few remarks, but the wind has been taken out of my sails, for I think they have all been touched upon in the discussion. The first one simply was as to the possibility of having a reliable compass in a conning-tower or in a protected position to steer the ship by. In a ship of war the important point is the consideration of what may happen in action. The man at the wheel may be told to steer a course, but that is no use unless the compass is free from vibration from the concussion of gun-fire. He can see nothing from inside the conning-tower, even if there is no obscurity from smoke. Therefore he is solely dependent upon the compass. I quite concur that it is improbable that the Commanding Officer, under the fire of machine-guns and quick-firing guns, will be able to get at any other compass outside the conning-tower, if he does the chances are he will not get back again, and most probably he will find the compass destroyed. I dare say some of us here as midshipmen were very much puzzled in shaping a course between the variations to be allowed to the right and deviations to the left, &c., and when we had to pass examinations for Lieutenants, it was a stumbling block to a great many of us. It is a comfort to the younger members of our Service that it is quite possible nowadays that this may be removed, and we may have a tolerably permanent corrected compass to steer by. No doubt on the compass question the sea service of all countries is very much indebted to the inventive genius of Sir William Thomson. I am sorry he is not here to-day, because we should very much like to have heard him on this subject. The compass, as it appears to me, is the same as any other scientific instrument, there can be no finality in it, and we must go on improving. As time goes on, new discoveries are made in magnetism, and new inventions in construction, as in almost every other subject. Then we must remember this, that different compasses are required for different positions in a ship, and that one that would be suitable in the conning-tower probably would not be suitable outside. In the conning-tower, what with the iron walls surrounding it and the magnets required for compensation, it is a wonder to me that you can get the compass card to move at all. The directive force of it must be very high indeed to overcome all these difficulties. I think after all, the main point comes to this, that the whole question of compass designing and compass construction must be a matter for open competition. The inventive talent of the country must be called upon to combine with the experience of the sailor, and asked to advance. There are many marine instrument makers in England, and in compass construction competition is as important as in any other trade in the country.

¹ At present no substance is known to isolate magnetism. Vibration or jarring has a remarkable effect in removing the "residual" magnetism of "soft iron."

I think it redounds to the credit of the Officers navigating our men-of-war that not more accidents occur through the error of the compasses.

I believe many merchant ships get embayed by shaping their course too fine from point to point at night, and run ashore, by the errors of the compass.

Staff Commander CREAK: I must first return my sincere thanks to the Hydrographer for his very kind remarks with regard to me in the matter we have discussed. As he has not made any special remarks except in support of my views, I have nothing to answer. I also thank Captain Mayes for his kind support. Admiral Colomb asked me one or two questions. One was about Gaussin's error; whether this difference of deviation resulting from swinging in opposite directions was due to Gaussin's error. It bears something of that character, but I really think it arises from the cause stated in the paper, though I am not quite satisfied with what I have said about it. A certain amount of iron in the ship parts with its magnetism instantly, the same as when you roll a soft iron sphere rapidly on a table, and no trace of magnetism is carried round with it; but there is another kind of iron in the ship which is not quite so soft, and takes some little time to part with its magnetism. I think that is really the cause of the deviation being different when swinging different ways. Then with regard to fog. The Captain of a merchant ship with whom I was once talking complained that he was constantly being troubled with the effect of fogs on his compass in the Baltic. I asked him to try it systematically, and to send me the result when he came back. He was to go to some place in the Baltic and lay alongside the quay; when there to note whether the compass altered after fog had come on, and then I should believe in it. He never could tell me such was the case. I found it simply arose from this fact: when they were steering up amongst the various islands in the Baltic, as long as it was clear weather, although the man at the helm often let the vessel fall off her course, the land being always in sight, the Captain could haul up a point or so, as required. After the fog came on the helmsman steered no better, whilst the Captain's corrective for the bad steering was no longer available, and the fog was blamed. I believe that is the sole cause. We know that the most delicately constructed instruments at Kew are in no way affected by the fog. Reflection applied to the compass is another question. I do not see how it is to be done. I think if you come to think of the smoke with which we should be surrounded in action, we should hardly see any reflection. Steam especially has a very bad effect upon all reflectors. They have often been proposed, but I can see no way to the use of reflectors. I quite agree with what Admiral Colomb said about the frequent corrections of the manoeuvring compass, and the auxiliary compasses used for steering might be corrected as often as desired, and Commanding Officers should give an opportunity for it to be done. I know in some ships the complaint is made, "Why is the compass not correct?" and the answer has been, "You have not given me the opportunity of correcting it." The magnetism of the iron of a ship is liable to changes, and the deviation of the compass must change in obedience to them; therefore there must be constant correction. Captain Parr has made some well-deserved remarks about the instruction at Greenwich. I am glad to hear he is satisfied with it, and I dare say he will be ready for the next examination when it comes on. I must also thank Admiral Ommanney for his kind remarks about this paper. Respecting the change of magnetism of a ship, I must say that there is a definite character impressed upon her in building which is never lost. Admiral Brize asks about the heeling error. Perhaps I have not made myself perfectly clear on that question. What I mean is if you take the heeling error of $1^{\circ} 10'$ obtained for the standard compass of the "Orlando," by actual inclination of the ship for 1° either to starboard or port on north and south courses, then, if that ship were inclined 10° , there would be $11^{\circ} 40'$ of heeling error.

Admiral BRIZE: That would be constant all through.

Captain CREAK: No, it would alter as the cosine of the azimuth of the ship's head, and would be zero at E. Take N.E., the intermediate point, for example, you would have to multiply the $11^{\circ} 40'$ by 0.7, and you would get as result a heeling error of about $8^{\circ} 10'$ on that point. I may say with regard to the remarkable disturbance of the compass at Cossack, Australia, that unfortunately the "Meda" did not return there, and therefore as full an examination of the spot was not made as was desirable, though the best was done in the time available. The whole of that part of Australia is very highly magnetic. There are ferruginous rocks in several parts of Australia; in fact one may observe the red lines passing through the sandstone rocks, many of them very highly magnetic. With regard

to the vertical force of these rocks where the compass is concerned, the only thing to be feared is a possible horizontal component to their total deflecting power. Captain Beall made some remarks about sub-permanent magnetism. The word "retentive" I have never taken to. "Retentive" means something that is kept, not parted with; but "retentive magnetism" in the way we see it described in the books is anything but retentive in the natural meaning of the word.

Captain BEALL: I say you call "permanent" what we call "retentive."

Captain CREAK: I am only speaking of the word "retentive." Now with regard to the word "sub-permanent" I think that is another matter, in which we must move a little with the times. When the Astronomer Royal adopted the word "sub-permanent" it was his opinion that the whole of the magnetism of the ship was more or less sub-permanent and not permanent. By the investigations I have shown in the early part of the paper almost the whole of the magnetism of our men-of-war is permanent, so why call it sub-permanent? I speak of sub-permanent magnetism which has the character of permanent magnetism in a measure, but is subject to constant change either from running on one course or from the blows of firing guns and various other causes. With regard to the heeling error caused by spheres, I have made experiments with $8\frac{1}{2}$ -inch spheres attached to a Thomson binnacle, and found that if you incline that binnacle, for the first 5° of inclination there is a heeling error of $55'$ for each degree of heel; for the first $10'$ about $50'$, and if you incline it to 30° you will find it is $20'$ for the last 5° of heel. I conclude, therefore, that whilst the heeling error is a constant quantity and goes on increasing equally for every degree of heel till 30° is reached, the effect of the globes as correctors is a diminishing quantity.

Captain BEALL: I understood Captain Creak to mean that, supposing for the sake of clearness the heeling error were a constant quantity, say 4° , then, if the vessel heeled over more than 5° , the spheres would not be so powerful, or in other words would not compensate the supposed constant error of 4° . But perhaps I may have misunderstood Captain Creak, and he means to convey that they decrease in power proportionately to the heel of the ship, but even then it would appear from the figures given in my remarks, which were obtained from actual experiment, that the decrease would in some cases be very small, if any. I found that spheres (about $4''$) which corrected a $+D$ from athwartship iron alone, also just corrected the heeling error caused by the same iron up to 25° of heel; and no doubt would do so beyond that.

Captain CREAK: What I mean exactly is this, that the globes do not do as much work at the extreme heel of 30° or 40° as they do during the first 5° . Then, with regard to the point mentioned by Colonel Baylis, asking whether some insulating substance cannot be interposed to eliminate the magnetic effect of the ship on the compass; that has been tried by several people. Some have tried it by using soft iron and various other substances, but we know perfectly well it cannot be done. The directive power upon the compass is the earth, and we have already interposed between the compass and the earth a very big magnet and a lot of small magnets in the shape of a ship, and her fittings, as well as armour-plating of soft iron, which adds to the difficulty. I know of no substance which can be interposed between the compass and the ship which does not isolate it from the directive force of the earth. I am very glad to hear that our Chairman believes that there is no finality in the question of compasses, and that anybody, no matter who he may be, who will bring forward some improvement, should be courteously entertained and his proposals fully gone into, and, if good, adopted. I should not like to sit down without making one remark with regard to the Constructive Department of the Admiralty, and acknowledge the ready manner in which the Director of Naval Construction and his whole staff meet me in every way, by affording me every facility for carrying out experiments or desirable improvements in the disposition of the compasses in our ships. I have also to return my thanks for the kind attention with which my paper has been received.

The CHAIRMAN: I meant to have referred to the question of the reflector for compasses, raised by Admiral Colomb. I have had some experience with reflectors with reference to gun-fire, and found they were always dim on board ship and generally out of order. They have never been able to stand the shock of gun-fire.

I remember on one occasion at Shoeburyness the disappearing gun was being fired with reflecting sights. The captain of the gun looked up over head into the reflector which was above the parapet. The gun was fired and everybody looked out towards the target, 1,500 yards off, but instead of the shot striking the water near the target, we found the gun had been pointed about 45° to the left, and the shot had gone through the roof of a shed in that direction owing to the reflector having got disturbed. It now devolves upon me to return our thanks to the lecturer for his admirable lecture which had led to a very interesting discussion.

P.S.—I can bear testimony as to the efficiency of the liquid compass for boat service; forty years ago one liquid boat compass was supplied to the flag-ship on the West Coast of Africa. Boat cruising after slaves was carried on to a considerable extent mostly out of sight of land. This liquid compass was the only one that was of any use when rowing hard or in a sea-way, all others would vibrate three or four points off the course each way.—H. B.