pendix" is given; and here the author takes occasion to describe much earlier stages of the skull in typical birds, viz. in the Crows. The primordial parts of the facial arches are carefully compared, beginning at the lowest Fishes, and ascending to the Mammalia; the pattern and *habit* of growth of the facial structures in the higher classes is shown to be adumbrated by the condition of these parts in the Lamprey (*Petromyzon*). The essential independence of the two arches in front of the mouth is asserted, and their low type of development is shown in the non-segmentation of the parts that should answer to the free *post*-stomal rays, the mandible, and the hyoid arch.

A survey is also made of the system of secondary bones—bones which have no preexistent hyaline cartilage as their basis; and these are shown to pass insensibly into dermal plates: the only distinction that can be made, viz. into *dermal, subcutaneous,* and *aponeurotic bones,* is there explained to be merely *useful,* but not to have anything embryologically essential in it.

March 16, 1865.

Major-General SABINE, President, in the Chair.

Pursuant to notice given at the last Meeting, Dr. Watson proposed, and Dr. Sharpey seconded, the Right Honourable Lord Justice Turner for election and immediate ballot.

The ballot having been taken, Lord Justice Turner was declared duly elected a Fellow of the Society.

The following communication was read:—

"On the Magnetic Character of the Armour-Plated Ships of the Royal Navy, and on the effect on the Compass of particular arrangements of Iron in a Ship." By FREDERICK JOHN EVANS, Staff-Commander R.N., F.R.S., Superintendent of the Compass Department H.M. Navy, and ARCHIBALD SMITH, M.A., F.R.S., Corresponding Member of the Scientific Committee of the Imperial Russian Navy. Received March 9, 1865.

(Abstract.)

This paper contains a reduction and discussion of all the observations of deviation and of horizontal and vertical force made in the armour-plated ships of the Royal Navy, and also in certain iron-built ships of the Royal Navy and of the mercantile marine. It may be considered as a continuation of a paper on the Deviation of the Compass in iron-built ships of the Royal Navy, by Staff Commander Evans, published in the Phil. Trans. for 1860, p. 337.

The reduction gives the numerical values of the several parts of the

deviation, viz. the "constant," the "semicircular," and the "quadrantal" of λ, or the proportion of the mean force to north on board to the force to north on shore—of μ, the proportion of the vertical force on board to that on shore, of χ the heeling coefficient to windward; also of the several constituent parts of these coefficients.

The following are the principal conclusions derived from these values:

The introduction of armour plating, and the great increase in the amount and thickness of iron used in the construction of modern ships of war, have greatly increased the amount of the deviations previously considered, and have given importance to two sources of error not previously considered, viz. the diminution of the directive force, and the heeling error. To determine these, observations of horizontal and vertical force are necessary, and they are now part of the regular series of observations made by the Superintendent of the Compass Department in the iron-built ships of the Royal Navy.

For the formulæ by which the reductions are made, and which are derived from Poisson's General Equations, reference is made to the 'Admiralty Manual for ascertaining and applying the deviations of the compass caused by the iron in a ship,' 2nd edition, London, 1863, edited by the authors. This work has been translated into French by M. Darondeau, into Russian by Captain Belavenetz, of the Russian Navy, and into German by Dr. Schaub, the Director of the Hydrographical Department of the Austrian Navy.

The observations confirm the conclusion formerly obtained, that the semicircular deviation in an iron-built ship is chiefly due to the attraction of the north point of the compass to the part of the ship which was *south* in building, modified in armour-plated ships by the direction of the ship while being plated.

The observations also show the rapid changes which take place in the semicircular deviation soon after launching, and the considerable changes which take place for about a year afterwards, and the great permanence of the semicircular deviation after that time.

Observations are yet wanting from which the separation of the principal part of the semicircular deviation B into its two constituents can be derived with much certainty. The following can only be looked on as approximate.

	B in England.	Part of B from soft iron.	Part of B from hard iron.
Warrior	$-24\frac{1}{4}^\circ$	$+12^\circ$	$-36\frac{1}{4}^\circ$
Black Prince	$+23$	$+23$	0
Defence	$+25\frac{3}{4}$	$+14\frac{1}{4}$	$+11\frac{1}{2}$

The great difference in the values of the last part in the 'Warrior' and 'Black Prince' depend on this, that the 'Warrior' was built head north, the 'Black Prince' head south.

In the iron-built armour-plated ships the quadrantal deviation becomes very large, very much exceeding what has been found in other ships. This, however, is not to be attributed in all cases to the armour-plating, as is shown by the small values of the quadrantal deviation in the wood-built armour-plated ships ; and theory as well as observation shows that, in the case of a compass in a central position, the armour-plating rather tends to diminish the quadrantal deviation. The different amount in the different ships is completely accounted for by the position of the bulkheads and armour-plating, rifle-towers, &c.

Thus in the following cases, in which the position of the armour-plating relatively to the compass is such as to increase the quadrantal deviation, the values are,—

	Warrior.	Black Prince.	Achilles.	Defence.	Resistance.
Standard compass	8° 27′	7° 38′	....	7° 0′	6° 17′
Steering compass	11 56	10 32	....	10 16	8 28
Main-deck compass	11 43	13 6	12 13	14 35	14 0

In the following cases of iron-built ships, the armour-plating is so placed as to have little effect on the quadrantal deviation.

	Achilles.	Hector.	Valiant.
Standard compass	6° 58′	5° 24′	4° 54′
Steering compass	8 51	8 24	6 52
Main-deck compass	....	9 47	8 05

In the following wood-built armour-plated ships, the armour-plating being carried all round, and the compasses near the centre of the vessel, the effect is to diminish the quadrantal deviation.

	Royal Oak.	Prince Consort.	Caledonia.	Ocean.
Standard compass......	3° 09′	2° 18′	2° 57′	2° 31′
Steering compass	1 47	....	....	....
Main-deck compass.....	1 28	....	....	....

In one of the turret ships, where the compass was out of the midship line, E, the other part of the quadrantal deviation, attained a large amount, being 4° for one compass, and 9° for the other. In all the cases of compasses in the midship line, E is small.

The diminution of the directive force in these ships is also remarkable. In the main-deck compasses of some of the iron-built armour-plated ships the mean directive force hardly exceeds $\frac{7}{10}$ of that on shore.

The most remarkable feature, both in the quadrantal deviation and in

the diminution of the directive force, is the constant and regular diminution of both effects with the lapse of time, showing apparently a change in the molecular structure of the iron, by which it becomes less susceptible of induced magnetism. This change has not yet been connected with any observations on the strength of the iron.

The amount of heeling error in these ships is very considerable, averaging about 1° for every degree of heel. In those which have been built head north it is greater. Thus in the 'Warrior,' which was built head north, it is at the standard compass aft 1° 49′ for every degree of heel. This error may be corrected by means of a vertical magnet. In the wood-built armour-plated ships, from the armour-plating causing the vertical force to act upwards, the heeling error is very small, and generally to leeward. Thus it is, for each degree of heel for the standard compass, in the following ships—

Royal Oak............	7′ to windward.
Prince Consort......	8′ to leeward.
Ocean	15′ to leeward.

The method of obtaining the heeling error by observations of horizontal and vertical force, in addition to observations of deviation, is practically used in this paper for the first time. The formulæ for the purpose were given for the first time in the 'Admiralty Manual.'

Among the practical conclusions drawn by the authors, the most important are, that the best position for the ship to be built in is head south; that armour-plated ships should be plated with the head in the opposite direction to that of building; that there should be as little iron as possible within a cone traced out by a line passing through the compass, and making an angle of 54° 45′ $\left(\cos^{-1}\frac{1}{\sqrt{3}}\right)$ with the vertical; and that in the construction of iron-built and iron-plated ships, regard should be had to providing a suitable place for the standard compass.

The separation of the constituent parts of the various coefficients is not only of great scientific interest, as giving the causes of the different amounts of these parts in different ships, but some of these quantities are so nearly the same in ships of the same class, that when a sufficient number have been observed, we are able, by means of observations of deviation and horizontal and vertical force, made without swinging a ship, and even when she is on the stocks or in dock, to construct by anticipation a table of deviations and of the heeling error. This method was applied in certain of the cases given in the Tables when there was not an opportunity of swinging the ship. This method may be expected to be of much use when the selection of a place for the standard compass comes to be considered part of the duty of the naval constructor.

The second part of the paper treats of the effect on the compass of masses of iron of various shapes, bearing some analogy to shapes for

which the problem of the distribution of induced magnetism can be exactly solved. It is known that when a uniform mass of iron is magnetized by induction in a uniform field of force, the effect of the whole magnetism induced throughout the mass is precisely the same as that of a certain distribution of free magnetism on the surface (including, in the case of a hollow shell, a distribution on the inner surface), the amount and law of this distribution depending on a coefficient κ, which is zero for non-magnetic bodies, and infinite for a body infinitely susceptible of induction. Very few observations of the value of this coefficient have been made. The only observations of which the authors are aware, made for this special purpose, are those by Weber (Götting. Trans. vol. vi. p. 20), Thalen (Nov. Act. Soc. Reg. Upsal. 1861), and by the authors. Weber finds for hard steel $\kappa=4\cdot934$, for soft steel $\kappa=5\cdot61$, for soft iron $\kappa=36$. Thalen finds for soft iron κ varying from 27·24 to 44·23, the mean being 36·75. The authors find, for a rod of iron probably not very different from the iron used in the construction of iron ships, $\kappa=12$ when the iron is not struck between reversals, but when hammered sharply it rose to upwards of 80. The effect of rods or plates magnetized longitudinally is nearly proportional to κ; but when a mass is magnetized at right angles to its surface the case is very different, and the free magnetism is almost independent of κ. Thus in the case of a plate magnetized at right angles to its surface, in the case of a sphere, and in the case of a cylinder magnetized at right angles to its axis, the free magnetism is proportional to

$$\frac{4\pi\kappa}{1+4\pi\kappa},\quad \frac{\frac{4}{3}\pi\kappa}{1+\frac{4}{3}\pi\kappa}\quad \text{and}\quad \frac{2\pi\kappa}{1+2\pi\kappa}\ \text{respectively,}$$

which are so nearly independent of the value of κ, that the effect of a sphere of the hardest steel magnetized by induction is within 4 per cent. of the effect of a similar sphere of the softest iron, and the effect of the latter within 1 per cent. of what it would be if the iron were infinitely susceptible of induction. Hence the magnetism of thin masses of iron depends very much on the quality, and also on whether the iron is hammered or not. The magnetism of thick masses of iron is almost wholly independent of these circumstances.

One of the most interesting applications of the formulæ is the comparative effects of solid and hollow spheres, and bodies of analogous shapes.

The proportion of the effect of a solid sphere to that of a spherical shell of thickness t (in terms of the radius of the sphere) is as $t+\dfrac{3}{8\pi\kappa}:t$.

In the case of soft iron this is about

$$t+\frac{1}{300}:t,$$

so that when the thickness of the iron considerably exceeds $\frac{1}{300}$ of the radius of the sphere, the effect of the spherical shell is sensibly the same as that of a solid sphere of the same external diameter. Mr. Barlow found

that when $t=\frac{1}{150}$, the above proportion was as 3 : 2, which gives for κ a value $=35$, agreeing closely with the values found by Weber and Thalen. In the case of iron of the quality experimented on by the authors, this ratio would be

$$t+\frac{1}{100}:t.$$

Hence in the case of a tank $\frac{1}{10}$th of an inch thick and 4 feet in diameter, t would be about $\frac{1}{250}$, and the effect about $\frac{1}{3\cdot5}$ that of a solid mass of iron of the same size. These results, which, however, are not new, as they are involved in Poisson's paper of 1824, explain the mistakes into which various magneticians have fallen as to the magnetism residing entirely on the surface, and as to the effect of a body such as a tank depending on its surface, not on its mass.

The same formulæ show that to correct a quadrantal deviation of 6° 10′ by two cannon-balls placed one on each side of the compass, the distance of the centre of each ball from the centre of the compass should be three radii of the balls. If the distance is greater or less, the quadrantal deviation corrected will vary inversely as the cube of the distance.

The investigation also shows that the effect of a sphere of iron, if its centre be within the cone of 54° 45′, will be prejudicial both by diminishing the directive force, and by increasing the heeling error to windward. When without that cone it will be beneficial in both respects. Hence, as far as possible, no iron should be within this cone.

Masses of iron which may be compared to a sphere, and near the level of the compass, but in the fore or aft quadrant, are beneficial in increasing the directive force, but prejudicial in increasing the quadrantal deviation. If they are on the port or starboard quadrant, they are doubly beneficial, by increasing the directive force and diminishing the deviation.

Bodies which may be compared to infinite vertical cylinders, such as iron masts placed before or abaft the compass, are prejudicial by increasing the quadrantal deviation, and they do not increase the directive force.

March 23, 1865.

Major-General SABINE, President, in the Chair.

Pursuant to notice given at the last Meeting, Count Strzelecki proposed, and the Master of the Mint seconded, the Right Honourable the Earl of Donoughmore for election and immediate ballot.

The ballot having been taken, the Earl of Donoughmore was declared duly elected.

The following communications were read :—