ART. XI.—TERRESTRIAL MAGNETISM.—BY MARTIN MURPHY, *C. E.*

I merely wish to make a few remarks on certain points which have occurred to me in reading what Arago, Hansteen, Humboldt, Sabine, Faraday, Thomson and others, have said on the subject of terrestrial magnetism. The magnetic power of our globe is manifested on the terrestrial surface in three cases of phenomena, one of which exhibits itself in the varying intensity of the force, and the two others in the varying direction of the inclination and in the horizontal deviation from the terrestrial meridian of the spot. Their combined action may therefore be graphically represented by three systems of lines or those of equal force, equal inclination and equal declination. The distances apart and relative positions of these moving, oscilating and advancing curves, do not always remain the same.

If we take a steel bar which has been magnetized, its centres of power are located near each extremity, while near the middle is a neutral ground, over which the influence of neither end predominates. If fine iron filings be sprinkled around the magnet, they will form into curved lines emenating from each other, and tending towards an union.

These centres are called poles. The magnetism in one is opposite in kind and nearly equal in degree to that in the other; there is a mutual attraction between these opposite magnetisms and this tendency to rush across neutral ground, and by combining yield up every distinctive feature of the magnet is successsully opposed by the hardness of the steel bar.

These lines are called the lines of magnetic force, and the area over which their influence is felt is known as the magnetic field. If a compass needle suspended by a silk thread, and free to move in any plane, be brought into the field, it will assume a direction parallel to the lines of force, as at e e′ e″ e‴

The strength of the field and hence the force that tends to give the needle steadiness and direction, varies greatly at different points; at e it is powerful, at e‴ it is feeble.

If two magnets similar to that at the figure be brought into proximity so that the poles of the same touch, they will repel each other; if, on the other hand, the north pole of one be approached to the south pole of the other, both bars, as if instinct with life, will fly in contact and cling one unto the other, and this intense affinity of opposite magnetisms is a general characteristic.

The Magnetic Property is Molecular.—Apart altogether from the question as how we are to represent the action of a magnet upon other magnets, there arises another distinct question as to where the course of the action resides. A very old experiment at once throws considerable light on this point. If we break a bar magnet into two pieces, it will be found that each of these is itself a magnet, its axis being in much the same direction as that of the original magnet, and its poles in corresponding positions.

The same holds if we break the bar into any number of pieces, and, quite generally, if we remove any piece however small from a magnet, this piece will be found to be magnetic, the direction of its axis usually bearing a distinct and easily recognizable relation to the direction of the axis of the whole magnet. We are driven to the conclusion, therefore, that the magnetic quality of a body is related to its ultimate structure, and not simply to its mass as a whole, or to its surface alone, and this conclusion is not to be invalidated by the fact that we can in general, as will afterwards appear, represent the action of the magnet at external points by means of a proper distribution of centres of attractive and repulsive forces upon its surface merely. *We shall again refer to this property of the magnet.*

Temporary magnetism of soft iron and steel in the magnetic field.—Bodies which possess permanent magnetic properties not depending on the circumstances in which they are placed we shall call "permanent magnets." The law of the action of one permanent magnet on another, as we have seen, is that like poles repel and unlike poles attract each other. The action of a permanent magnet on pieces of soft iron is, at first sight, different, for either pole attracts them alike.

THE EARTH A MAGNET.—The earth has magnetic features entirely analagous to those of the bar marget. If we examine the figure which I place before you we find the parallels of latitude and meridians of longitude appear at regular curves. But from a focus at N. radiate a series of curves, which take sinuous forms and finally converge towards another focus at the antipodes. These foci are the magnetic poles of the earth toward which the compass needle ever points, not directly but parallel to the lines of force. It will be seen that these magnetic poles are far removed from the geographical poles.

These three features of the earth's magnetic action which are chiefly attended to by observers are then—the inclination, the declination and the intensity.

The inclination is the angle at which the dipping needle is inclined to the horizon. The declination is the angle at which the horizontal needle is inclined to the north and south line. The intensity is the magnitude of the force with which the needle seeks the position of rest.

Now if we travelled over the whole surface of our earth and carefully determined the declination, the inclination and the intensity of the magnetic action at every point, we should be able to map down on a chart of the earth the relations thus presented to our notice, we should—speaking generally—have the following peculiarities to deal with :

First, as to the declination, we should find that in certain regions the magnet's northern end was to the west of north, whilst in certain other regions the reverse was the case. If we marked in the boundary line between these regions, it is obvious that we should have traced a line along which the needle would lie due north and south. This is what is termed the line of no declination. On charts of the earth's magnetic relations the position of this line for the middle of the present century is usually indicated. In some maps a set of lines used to be added along each of which the magnetic needle had a definite declination. These lines are now omitted on account of their complexity.

Secondly, as to the inclination, we should find as we travelled over the earth's surface that the dipping needle tends to vertical at two nearly opposite points—one close to the Arctic, and he other to the Antarctic circle. These are called the northern and southern inclination poles, and must not be confounded with the intensity poles presently to be mentioned. As we leave either inclination pole, the dipping needle leaves its vertical position and gradually approaches the horizontal direction, until, along a curve lying midway between the two poles, the needle becomes exactly horizontal. This curve is called the magnetic inclination equator.

Lastly, as to the intensity. If we noticed in every part of the earth's surface the number of times the needle vibrated through its position of rest in a given interval, we should find that along a curve lying near to, but not absolutely coincident with the inclination equator, the intensity has a minimum value. This curve is called the intensity equator. Leaving it towards the north or south, we should find the intensity gradually increasing. We should not, however, find this increase guiding us to an intensity pole either north or south, but we should recognize two magnetic intensity poles in each hemisphere.

Now, in considering the various relations here presented, it is important that we should decide which property of the magnetic needle should be adopted as our guide or receive our chief attention.

General Sabine considers that intensity is the primary quality of the magnet in all such inquiries as we are at present concerned with. Professor Proctor considers that if we were to select one or the other of these elements as our special guide it must clearly be the inclination, because he says the declination has comparatively narrow limits of range, which the inclination varies from 0 to 90.

If a properly balanced magnet could be suspended or supported so as to be free to take up any position, it would be found at London at the present time, that it would finally rest in a position making an angle of about 67 degrees, with the horizontal; also that the vertical plane passing through the magnet would make an angle of about 18 degrees with that of the meridian, the magnetic deviation being to the west of the true astronomical or geographical north and to the east of south. Such is the dip and declination given at the Royal Observatory for the first of the present year. I am not aware of any record being kept at Halifax, N. S. I cannot speak with any degree of reliability respecting the dipping needle here. The declination was about 20.50 degrees west of north, and I am informed by the officers of the Crown Land Department that there is an annual variation of about three minutes per year.

If a magnetic needle be pivoted so as to confine its motion to the horizontal plane as an ordinary compass needle, the north end of such a needle when at rest will deviate in the azimuth to the west of true north by the amount of this magnetic declination or variation of the compass, which varies with locality. For any place situate on one of the magnetic lines on the map or chart the value of the magnetic declination will be exactly that of the line, and for places situate between the two lines proportion will be made between the values of the adjacent lines. Such values are generally made to apply to the year for which the map or chart has been issued. The values shewn by the lines on the English chart or map are for the year 1889, but to obtain values for any other epoch it must be understood that the magnetic declination over the area included in that map diminishes yearly by about seven minutes of an arc. Thus mean values for any place and for any time within a few years may be found.

Values of magnetic declination obtained in the way described will, it is presumed, serve for all purposes of mine surveying. It may, however, be further mentioned that the needle is subject also to diurnal variation, its north end being drawn most to the west at about two hours p. m., and most to the east during the night or early morning, occupying its mean position about 10 hours a. m., and 6 hours p. m. The diurnal variation is greater in summer than in winter, but the needle seldom deviates from its mean position more than from five to ten minutes of an arc, excepting during what are called " magnetic storms." During the year 1888 there were very few occasations of much change recorded at London, so we seem to be passing through a quiet period.

The English map produced has been tested by comparing results obtained at Greenwich, Kew, Stoneyhurst and Falmouth, as well as other recent determinations for Newcastle, Scarborough, Whitehaven, Cardiff and Falmouth. This comparison gave the compilers the means of correcting as necessary the maps brought up from Sabine and Evans in the way mentioned. There are of course practically local peculiarities or irregularities which cannot be considered in such a map.

The whole of Europe, excepting a small part of Russia, has now a western declination, while at the close of the seventeenth century the needle first pointed due north in London, in 1657, and in Paris in 1669,—there being thus a difference of twelve years, notwithstanding the small distance between these places. Hunsteen and Erman shew the remarkable double curvature of the lines of declination in the region of Northern Asia. On the 13th of September, 1492, Columbus found a line of no variation 3° west of the meridian of the island of Flores, one of the Azores. Gilbert says that in 1600 the declination was still null in the region of the Azores, just as it had been found by the discoverer of the New World. Columbus attached great importance to the zone in which the compass showed no variation. In the beginning of the present century, at an elevation of 11,936 feet above the level of the sea, Humboldt made an astronomical determination of the point (7° 1′ south lat. 48° 40′ west longitude from Paris), where, in the interior of the new continent, the chain of the Andes is intersected by the magnetic equator between Quito and Lima. The more recent observations of Sabine have shewn that the node near the island of St. Thomas moved 4° from east to west between 1825 and 1837. In London the needle pointed to the east of north before the year 1657, when it pointed due north. From that time the westerly declination gradually increased until the beginning of the present century, when the westerly motion was observed to flag. In 1819 the greatest westerly declination was reached. At this time the needle pointed $24\frac{2}{3}$ degrees to the west of north. Since then the needle has been slowly travelling eastwards, and the westerly declination is now only some 17° west of north.

In Paris the needle pointed due North in 1663, it ceased to move westwards in 1817, and the greatest westerly declination attained was only $22\frac{1}{2}$ degrees.

On the western side of the Atlantic a line of no variation, as it is called, is marked on the Admiralty chart, which I place before you. It leaves Dutch Guiana, crosses the meridian of 60 west from Greenwich, crosses the islands of St. Lucia and Porto Rico of the Antilles, runs East of San Domingo and San Salvador, of the Bahama Islands, touches the coast of South Carolina at Long Bay, crosses the western shores of Lake Erie and the narrows between Lake Huron and Lake Michigan, follows the eastern shores of Lake Superior and touches Hudson Bay at West Pens, and after running through western waters of Hudson Bay passes through Pistol Bay and Farther Hope Island in Chesterfield Inlet.

From these facts of observation, Professor Proctor seemed to favor the theory that at some time near the year 1657 the northern magnetic pole must have been on the meridian of Greenwich, or that the magnetic pole must have been directly between England and the real pole of the earth, or somewhere beyond the real pole; and as before 1657 the declination was easterly, whereas afterwards it was westerly, hence the magnetic pole must have travelled from east to west round the north pole of the earth, and he further says that from these observations we can learn something about the rate at which the magnetic pole is travelling. For he says:—

"Supposing the magnetic needle in the meridian of London in 1657, and Ross's estimate of the place of the magnetic pole to be approximately correct, giving (in round figures) 95° west of Greenwich for the longitude of the magnetic pole in 1883, we get a period of revolution of

$$\begin{aligned}&\tfrac{360}{15} \times (1883\text{–}1657) \text{ years.}\\ &= \tfrac{72}{19} \times 176 \text{ years} = 667 \text{ years about.}\end{aligned}$$

"And combining Ross's estimate with Paris epoch we get a period of

$$\begin{aligned}&\tfrac{72}{19} \times (1833\text{–}1663) \text{ years.}\\ &= \tfrac{72}{19} (\times\ 170) \text{ years} = 644 \text{ years about.}\end{aligned}$$

"The mean of these values is about 655 years; and I think that there is good reason in believing that the northern magnetic pole revolves around the north pole of the earth from east to west in about this time."

The latter reasoning is rather vague in taking means of such extremes, and these extremes between points so close as London and Paris. The permanency of the compass in Jamaica since 1660, says Sir John Herschel, is remarkable. He says:—During the last century all surveys of property there have been conducted solely by the compass. There is very little magnetic variation. Humboldt says:—If we compare Ermen's observations in the southern part of the Atlantic Ocean where a faint zone (0.706) extends from Angola over the Island of St. Helena to the Brazilian coast, with the most recent investigations of the celebrated navigator, James Clark Ross, we shall find that on the surface of our planet the force increases almost in the relation of 1:3 towards the magnetic south pole where Victoria Land extends from Cape Crozier towards the volcano Erebus, which has been raised to an elevation of 12,600 feet above the ice. The intensity near the magnetic south pole is expressed by 2.052 (the unit still employed being the intensity which he discovered on the magnetic equator in Northern Peru) Sabine found it was only 1.264 at the magnetic north pole near Melville Island (74° 27′ north lat.) while it is 1.803 at New York.

All these different systems of magnetic lines—variation, dip, and intensity—have not on the earth that symmetry and regularity which they would present around a steel bar; on the contrary, they are often bent, looped, and turned into devious paths, wherefore none can tell. The fact alone is well established, *while theories fail to account satisfactorily for the earth being an irregular magnet.*

Now, on the earth, the pole nearest the geographical pole is commonly known as the north magnetic pole, and the end of the needle pointing to it is also spoken of as the north pole, whence repulsion, of necessity, would seem to result; but this is an unfortunate use of the terms that has grown up with us. The real state of the case is, that whichever of the two—the earth's pole or that of the compass—we agree to designate as north, the other, having magnetism of the opposite kind, must be called the south; and hence attraction naturally takes place.

To show the variability of this attraction in direction and amount in various parts of the globe, the mariner's compass is everywhere subject to the influence of these magnetic lines of force, and it is their influence that gives steadiness and direction to the needle. At e, e', e'' and e''' is a magnetic needle represented as suspended by a thread from the zenith, and assuming, as it always will, a direction parallel to the line of force. At the magnetic equator, m, m, this line is parallel to the horizon, and so is the needle, e'''; we go north and the line becomes bent, so the needle inclines as at e''; proceeding further, the line bends more, and the needle inclines accordingly; finally, at e, it is bent vertically in the vicinity of the pole. In all these cases the force or intensity of the magnetic field steadily increases from the first towards the last position of the needle, so that it will vibrate slowly at e''', whilst at e'' it will be quicker, the arc smaller, and the time less, and so on, until it comes to e, when it will have a few quick, jerky movements, and then stop short.

Now, a needle dipping thus at every remove from equatorial regions is of no value to guide a ship. It must always be horizontal, and this is practically obtained by placing a small sliding counterpoise on the needle, to overcome the downward pull of the magnetism. It is easily adjusted to change. In this constantly horizontal direction of the needle, however, the portion of the magnetic intensity that gives it steadiness is materially changed, lessened, and more diminished as we proceed from e''' to e'. As we proceed from the magnetic equator towards the pole, the compass becomes less steady and reliable, while at the same time the total intensity of the magnetic field increases.

Humboldt, in the first volume of the Cosmos, after discussing translatory motion, terrestrial phenomena, geographical distribution, and the figure, density and internal heat of the earth, refers to terrestrial magnetism. He says: "If we present to ourselves the interior of the earth as fused and undergoing an enormous pressure, and at a degree of temperature the amount of which we are unable to assign, we must renounce all idea of a magnetic nucleus of the earth. All magnetism is certainly not lost until we arrive at a white heat, and it is manifested when iron is at a dark red heat; however different, therefore, the modifications may be which are excited in substances in their molecular state, and in the coercive force depending upon that condition in experiments of this nature, there will still remain a considerable thickness of the terrestrial stratum which might be assumed to be the seat of magnetic currents. The old explanation of the horary variations of declination by the progressive warming of the earth in the apparent revolution of the sun from East to West must be limited to the uppermost surface, since thermometers sunk into the earth, which are now being accurately observed at so many different places, show how slowly the solar heat penetrates, even to the inconsiderable depth of a few feet. Moreover, the thermic condition of the surface of water by which two-thirds of our planet is covered is not favorable to such modes of explanation, when we have reference to immediate action and not to an effect of induction in the aerial and aqueous investment of our terrestrial globe.

" In the present condition of our knowledge (he wrote in 1844) it is impossible to afford a satisfactory reply to all questions regarding the ultimate physical causes of these phenomena. It is only with reference to that which presents itself in triple manifestations of the terrestrial force, as a measurable relation of space and time, and as a stable element in the midst of change that science has recently made such brilliant advances by the aid of the determination of mean numerical values. From Toronto in Upper Canada to the Cape of Good Hope and Van Diemen's Land, from Paris to Pekin, the earth has been covered since 1828 with magnetic observatories, in which the regular or irregular manifestations of the terrestrial force are detected by uninterrupted and simultaneous observations * * * * * * *;" and he proceeds to say: "Terrestrial magnetism and electrodynamic forces computed by Ampère stand in simultaneous and intimate connection with the terrestrial or polar light, as well as with the internal and external heat of our planet whose magnetic poles may be considered as the poles of cold; the bold conjecture, hazarded one hundred and twenty years ago by Halley, that the Aurora Borealis was a magnetic phenomenon, has acquired empirical certainty from Faraday's brilliant discovery of the evolution of light by magnetic forces." He then follows with a beautiful description of the Aurora.

It is now nearly half a century since Baron Von Humboldt reviewed the opinions of Ersted, Arago, Ermen, Ross, Brewster, Faraday and Sabine on terrestrial magnetism and, although great advances have been since made (in the science of electricity which has many similar manifestations and in dynamical geology which may assist in studying the earth as a magnet), and presented for our guidance and instruction, still these opinions are held in as high esteem to-day as the day the first volume of the Cosmos was presented to an admiring public.

In 1873-1874 Rowland made an extensive series of experiments; the results are said to form one of the most important contributions yet made to our knowledge of magnetic induction. They were published in the Philosophical Magazine of those dates, and are quoted by Professor Chrystal in the article on magnetism in the Encyclopedia Britannica. He treated his results graphically. The general conclusions to be drawn from his experiments are as follows:

"1. The magnetic properties of iron, nickel and cobalt at ordinary temperatures differ in degree, but not in quality.

"2. As the magnetizing force increases from o upwards, the permeability of iron, nickel and cobalt increases until it reaches a maximum, and after that diminishes down to a very small value. The maximum value is reached when the metal has attained a magnetization of from .24 to .38 of the maximum.

"3. The curve showing the relation between the susceptibility and the intensity is of such a form that a diameter can be drawn bisecting chords parallel to the axis.

"4. If a metal is permanently magnetized its permeability is less for low magnetizing forces, but is unaltered for high magnetizing forces. This applies to the permanent state finally attained after several reversals of the magnetizing force; but if we strongly magnetize a bar in one direction and apply a weak magnetizing force in the opposite direction, the change of magnetization will be very great.

“ 5. Iron, nickel and cobalt all probably have a maximum of magnetization, although its existence can never be entirely established by experiment, and must always be a matter of inference.

“ 6. The permeability of any metal depends on the quality of the metal, on the amount of permanent magnetization, on the total magnetization, and on the *temperature.*

“ 7. The permeability of cobalt and nickel varies very much with temperature, etc. The permeability of iron is not much affected by moderate changes of temperature.

“ 8. The maximum of magnetization of iron and nickel decreases with rise of temperature at least between 10° C. and 220° C., the first slowly, the second very rapidly.”

Professor Chrystal adds :—“ The researches of Stoletow and Rowland have undoubtedly made clear the main phenomena of magnetic induction, but in doing so they have raised a host of other questions which have not as yet been settled. * * * The results of the different experiments are not seldom contradictory, and the circumstances of experiment are often so complicated that criticism with the view of reconciling them seems hopeless in the meantime.”

Now, I quote these authorities to show that there exists a relation of magnetism to other physical properties of bodies that may materially affect by mechanical strain (such as jarring or vibration) the tension of iron or steel. The following parallel statements, taken from the results of Weidemann, who has devoted much careful study to these phenomena, will sufficiently illustrate the matter :—

“ 1. Jarring a body under twisting stress causes an increase of twist.	1. Jarring a bar under magnetizing force causes increase of magnetization.
2. Permanent twist in a wire is diminished by jarring.	2. Permanent magnetization in a bar is diminished by jarring.

3. A wire permanently twisted and then partly untwisted loses or gains twist when jarred according as the untwisting is small or great.	3. A bar permanently magnetized and then partly demagnetized loses or gains magnetization according as the demagnetization is small or great."

Mechanical strain produced by magnetization. In 1842, Joule found that a bar of soft iron lengthened when it was temporarily magnetized in the longitudinal direction. (These effects, such as shocks, jarring and vibration in aiding the action of inductive magnetic force, were known to Gilbert.) When the magnetizing force was removed the bar shortened, but in general not quite to the original length. (This last sentence seems almost incredible to an Engineer, to take as granted that the magnetic force should be such as to strain the bar beyond its elastic limit.) Then again he says: "The actual elongation of an iron bar magnetized to saturation was found to be from $\frac{1}{720.000}$ to $\frac{1}{200.000}$ of its whole length. The extension varied approximately as the square of the intensity of magnetization (temporary or permanent). The general character was the same in soft or hard bars, but the effects were smaller with hard bars." The results of Joule have been verified by Buff, Tyndal, Mayer, and others.

The effect of extreme cold was, according to Trowbridge, to diminish the moment of a steel magnet (magnetized at 20° C.) by about 60 per cent.

The temporary magnetism of bars of cast iron, smithy iron, soft iron, soft steel, and hard steel magnetized by the earth's vertical force, was found by Scoresby to be insensible at a white heat, but to be much greater at a dark red heat than at the temperature of the air.

There are many facts that go to prove that the time any magnetizing force takes to develop the maximum magnetization that is capable of being produced is very small. The most wonderful evidence on this head is the fact that the telephone, which depends essentially on varying magnetic action, can reproduce the sounds of human speech even to the consonants.

Now, I think that I have said quite enough on the theory of the subject for my purpose this evening. I shall now advert to the practical adaptations of magnetism that enter into the experience of our daily life. The compass, with its prime importance to navigation, is perhaps the most prominent, and the one that has been of the greatest benefit to man.

We have already referred to the earth as a magnet; an iron ship is a magnet, and the compass that guides the ship is also a magnet. The earth, the ship, and the needle are but magnets of different intensities; there is a very intimate though varying relationship between them; they are not amicable companions; there is a constant struggle between them for mastery; they have certain inherent properties in common; and to these properties and to this struggle we may attribute the essential character of the compass and its convenience, use and benefit to mankind.

To relate what is known regarding the early knowledge, history and development of the compass is beyond the scope of this paper. I shall merely remark that Baron Humboldt says that reference to the use of it is to be found in Chinese history so remote as 2634 B. C. From writers on the subject, it does not seem improbable that a knowledge of the mariner's compass was communicated by the Chinese to the Arabs, and through the latter was introduced into Europe. Hallam, in his *Middle Ages*, vol. 3, cap. 9, says: "the earliest definite mention as yet known of the use of the mariner's compass in the middle ages occurs in a treatise written by Alexander Neckam in the 12th century." It was not used in Scotland by King Robert in crossing from Arran to Carrick in 1306, as Barbour writing in 1375 informs us that he had no needle nor stone, but steered by a fire on the shore. In 1750, Dr. Gowan found that the needles of merchant ships were made of two pieces of steel bent in the middle and united in the shape of a rhombus, and proposed to substitute straight steel bars of small breadth, suspended edgewise and hardened throughout. He also showed that the Chinese mode of suspending the needle conduces most to sensibility.

In 1820 Professor Barlow reported to the Admiralty that half the compasses in the Royal Navy were mere lumber and ought to be destroyed. Since then many improved varieties of ships' compasses have been introduced. The most remarkable and, as shewn by trial, most satisfactory, form of compass is said to be that patented in 1876 by Sir William Thomson.

The conditions that chiefly affect the use of the mariner's compass are those of the declination and variation to which I have already referred. The magnetism of the ship itself, or that induced in it by the earth's magnetic force, was first observed in 1772-1774 by Mr. Wales, the astronomer of Captain Cook. When surveying along the coast of New Holland in 1801-1802, Captain Matthew Flinders made the discovery that there was a difference in the direction of the magnetic needle according as the ship's head pointed to the east or the west. The deviation in wooden ships can be practically obviated, but in iron ships it has to be partly allowed for and partly compensated. Barlow used a corrective plate of iron to overcome the directive action on the compass due to the magnetism of wooden vessels. On Professor Airy's method the permanent magnetism of ships is compensated by a steel magnet placed at a given distance below the compass. It is, however, liable to changes of intensity occasioned by shocks, vibration, unequal heating and other causes, a fact which led to the late Dr. Scoresby to propose the employment of a compass aloft out of the region of the ship's influence.

The induced magnetism of ships can be only imperfectly compensated, since it varies according to the ship's bearing and as she rolls and pitches; but corrections can be made for the heeling error.

In the last January number of the Popular Science Monthly, Lieutenant-Commander T. A. Lyons, U. S. N., very graphically describes induced magnetism, and its prime importance to navigation, in his article on the guiding needle of an iron ship. Lieutenant Lyons says:—

> "Let us conceive a metallically pure cylinder of wrought iron or cast iron that has not been hammered, and let us further conceive it entirely free from magnetism, hold it vertically, and

instantly the upper end becomes a south and the lower a north pole (in this latitude). Reverse it as quickly as we may, and the magnet also reverses, so that the upper and lower ends are still as they were before, a south and a north pole respectively.

"Hold it horizontally in the meridian, and the end towards the north pole becomes a south pole. Revolve it slowly or rapidly in azimuth, and the foci of magnetic polarity also move with the fidelity of a shadow, until, when the cylinder points east and west, all the side facing the north is pervaded by north magnetism, and all facing the south by south magnetism. Again: let us conceive the hull of a ship to be like our cylinder, of metallically pure wrought iron, and as susceptible of magnetic induction in its ever changing courses, as the cylinder is when turned round. Then, as the ship steers north (in this latitude), the bow will become the centre of north polarity. As she gradually changes course to the eastward so will the north focus shift to the port bow, the south focus to the starboard quarter, and the neutral line dividing them, which, while the ship headed north was athwartship, will now become a diagonal from starboard bow to port quarter. When the ship heads east all the starboard side is pervaded with south polarity, the port with the north, and the neutral line takes a general fore-and-aft direction. Continuing to change course to the southward, the poles and the neutral line continue their motion in the opposite direction, until at south the conditions of north are repeated, but this time it is the stern that is a north pole, while the bow is a south pole. At west the conditions of east prevail, only that it is now the starboard side that has north polarity. And this transitory induction in both the cylinder and the ideal ship is solely due to the mild effect of the earth's magnetic field in which they move.

"Now, to consider it in the connection with an actual ship. The hull of no vessel is metallically pure, nor has it acquired shape and stability without much hammering; moreover, it cannot be made an abstraction from a magnetic state. By hammering in the process of construction it has been made as permanent and well defined a magnet as the steel bar, with poles and neutral line as in the bar, but located according to the magnetic direction in which the ship lay on the stocks, in strict conformity to the places they occupied in the ideal vessel just described. Therefore it is not as susceptible of mild magnetic induction of the earth as the cylinder or ideal hull, although the straining when on a passage, and the buffeting of the waves do assist the inducing tendency; besides, once that induced tendency becomes lodged, it does not move and shift with the freedom and facility that it did in the cylinder; and finally, as it already finds a tenacious occupant of the vessel in its permanent magnetism, hammered into it when building, it must adapt itself to the greater power, and thus it is the resultant of both has been always found, and not the individuality of either.

"Time is a chief element in the acquisition and efficiency of this induced magnetism; for the longer a ship steers on a given course, or lies in the same general direction, the greater will be the magnetic charge, and the more slowly will it move and shift with the changing courses of the vessel.

"This induced magnetism has been dwelt upon at some length because of its prime importance to navigation.

"The other magnetic qualities of a ship are comparatively stable, but this is treacherous and changeable to a degree that necessitates constant vigilance to prevent disaster. On the great fleet of transatlantic steamers it is more likely to lead into danger than on the other routes; the ship steers a generally easterly or westerly course going to Europe and returning to America; the magnetic influence on the outward trip is the opposite to that returning; the ship runs at a high rate of speed, and the induction varies on different parts of the route according to the intensity of the magnetic field passed over, the smoothness or roughness of the sea which affects the motion of the ship, and the warmth or coolness of the weather."

"Instead of attributing the loss of vessels when approaching a coast," says Lieutenant-Commander Lyons, "to the magnetic effects of fog and land, and other improbable influences on the compass, it were much more reasonable to ascribe it to the changed conditions of her magnetism by induction during the passage, which has not been discovered or kept account of by frequent azimuths previous to closing in with the land. Suddenly a course the captain thought perfectly safe carries the ship upon a shoal or rock, and the fault is laid upon the compasses, whereas they but obeyed the magnetic influences that became altered, during a long passage, from what these influences were when the ship was last swung to determine the deviations of her compasses.

"The means taken for discovering the permanent magnetic character a ship has acquired in building is a dry dock survey. Let us suppose the ship and dry dock to be parallel to the magnetic meridian. Stations are established at the prominent points on the steps or on the side of the dock. A compass is taken to each station and the direction in which the needle points is noted. Of course, if no disturbing mass was near, it would point to the north at every station. But an iron ship is there, so that at certain stations we find the needle repelled from the vessel. Now, only north magnetism can produce this kind of deflection. It varies in degree at each station, and where greatest there is the pole. Again we find the needle's north end attracted towards the ship, hence we have discovered the body of south magnetism, so we locate its pole where deflection is greatest. Finally at several stations in an irregular path from bottom to rail we see that the needle points everywhere and this is the neutral line. A sketch of each side of the ship is drawn on paper, and the degree of deflection at every station is plotted by means of measurements from a line taken across her bow and from the ship's side.

"An iron ship, frames, plating, decks, beams, stanchions, carlings, engines, masts, &c., is not like the steel bar, a simple magnet, but a network of magnetic entanglement, yet, however complex this may be, proper means are devised for coping with it. The problem is simplified to pairs of parallel forces, each pair having its resultant parallel to the co-ordinate axis, the sum total of all three forces parallel to it, and the whole concentrates upon the north point of the compass; whence the final result that we have imaginary magnets, one laid horizontal to the axis of the vessel, the second also horizontal across the vessel, and the third vertical.

"The individual and combined effect of these three imaginary magnets is the object of investigation, but before entering upon it, it will be necessary to remark that each is not simple but complex, and that, recognizing this we shall have to consider all the component parts, that we may obtain all the prime factors, and then reduce those factors as nearly as practicable to zero."

By swinging a ship at compass buoys or steaming in a circle on the open sea, the magnetic effect of the ship, that is of the three imaginary magnets, is brought to bear on every point of the needle causing it to deflect from the magnetic meridian by different angles at different points. These various deflections being serially arranged constitute what is known as tables of deviation.

Frequently means are provided for opposing the magnetism of the ship by other powerful magnets, thus permitting the needle to point in its natural direction however the ship may head: such a contrivance is known as a compensating binnacle.

In considerable changes of magnetic latitude the magnets have to be slightly moved to counterbalance the altered condition of the deviations, and sometimes, also, to compensate for a partial loss of power in the magnets themselves.

The more immediate object of this paper is to point out what occurs to the author respecting the influence of terrestrial magnetism on iron bridges, iron rails, locomotive machinery, and such other structures and machines as undergo great stress, through blows, shocks, or violent contacts, in latitudes where terrestrial induction is of great moment. I would also wish to make some reference to the frequent and fitful changes exhibited at the different magnetic observatories, as that they might in a great degree be attributed to thermal changes in the body of the great magnet, the earth itself; but as my time is now exhausted, I should prefer deferring any further remarks to a future evening. The plates referred to in this paper will appear in that which is forthcoming.