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The Magnetism of the Earth. A Lecture on the Distribution and Direction of the Earth's Magnetic Force at the Present Time: The Changes in Its Elements, and on Our Knowledge of the Causes

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DONATIONS TO THE MAP-ROOM BETWEEN FEBRUARY THE 25TH AND MARCH 11TH, 1878.—Language Map of India and the Border lands, and Language Map of Further India and the Indian Archipelago (*R. N. Cust, Esq.*). Equatorial Africa, 3 copies (*James Fergusson, Esq.*). Rufu or Kingani (*F. Holmwood, Esq.*). Nos. 17, 18 and 19 of Spruner's Hand-Atlas (*Justus Perthes*). United States Charts, 1 sheet (*Commodore R. H. Wyman*, U.S.N.). Addenda to Dr. Ami-Boué's Itineraries in European Turkey (*Dr. Ami-Boué*). Sheet 1 of Map of Turkey in Europe (*Quartermaster-General's Department*). Admiralty Charts, 9 sheets (*The Hydrographer*).

The CHAIRMAN said the honorable charge of giving the second of the series of lectures on scientific branches of geography had been assigned by the Council to Captain Evans. It was unnecessary to remind the Meeting of Captain Evans's intimate connection with magnetic science for many years; a science which peculiarly lay within the province of that great Department over which he so worthily presided—the Hydrographical Department of the Admiralty.

The following Lecture was then delivered by the Author:—

The Magnetism of the Earth. A Lecture on the Distribution and Direction of the Earth's Magnetic Force at the Present Time: the Changes in its Elements, and on our Knowledge of the Causes. By Captain F. J. EVANS, C.B., F.R.S., Hydrographer of the Admiralty.

THE Fellows of the Society will recollect that in the introductory lecture on Scientific Geography given in February, 1877, by our colleague General Strachey, it was assumed that the outline so graphically sketched by him, should be filled up in detail by succeeding lecturers. The Magnetism of the Earth, as having an unusually close connection with the progress of geographical research, and especially so with the art of navigation, was then prominently brought to our notice: and now, in the opinion of the President and Council, the time appears to have arrived for an exposition of the details, and this duty has been confided to me.

But here, at the outset, a few preliminary remarks are necessary. Magnetism, so far as in its essence and nature it is capable of being grasped by the human mind, appears illimitable. It may be described as one of those great forces of nature everywhere and at every moment exerting influence; for the magnetic condition of all matter has been demonstrated by modern science, and no doubt remains as to the universality of the force. The consideration of this broad generalisation is, however, outside the subject matter of this lecture: which comprehends only the magnetic condition of

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our globe, in so far as it is exhibited in that kind of magnetism principally resident in iron. A simple conception of this magnetic condition is, that by the agency of a distinct force in nature, one particle of iron is attracted by another particle of iron, and that these particles may be retained in vertical suspension the one from the other in opposition to the force of gravity.

The magnetic force of the Earth, or what we commonly speak of as Terrestrial Magnetism, is perhaps most familiar to us as being that energy which causes the compass needle to point in a fixed direction: but it has other effects, and one of these specially affects navigation; for, from its capacity to impart a kindred force to iron, an iron ship in the process of building acquires what may be termed a magnetical "constitution," and this constitution, whether by time or circumstances, is never afterwards parted with. In this case we have the ship's magnetic force superimposed on the Earth's force, and most complicated phenomena, so far as the action of the compass is concerned, follow: fortunately these are reducible to law, and so can be provided against by skilled appliances.

The mariner's compass, even in its most primitive form, has been a marvellous agent in facilitating the progress of the human race. Its influence on the world's history, by opening up the navigation of the oceans and thereby the knowledge of remote countries, cannot but be recognised by geographers; and therefore all that we can learn of the laws affecting its action, and by what means and under what conditions these laws have been developed; what we know of them in our own generation, and what is concealed from us by a mysterious veil which as yet we cannot penetrate, are subjects which may be considered not unworthy of attention.

HISTORICAL SKETCH FROM THE TIME OF THE DISCOVERY OF THE DIP OF THE MAGNETIC NEEDLE.

About three hundred years ago the fact was becoming familiarly known to those interested in travel, whether by sea or land, and thus to the geographers of the day; that a bar of iron, when freely suspended by a thread through its centre of gravity,—and so taking up when at rest a position indefinite as to direction,—would, when rendered magnetic by the touch of the loadstone, no longer remain at rest parallel to the earth's surface, but incline at a constant angle to it; as also that it finally rested in a definite direction. The angle that the inclined bar makes with a hori-

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zontal line in the same vertical plane, and the angle between that horizontal line and another in the astronomical meridian, being known respectively as the "*dip*" and "*variation*" of the magnetic needle.

These two elements of dip and variation became thus associated in men's minds, although seamen had known fully a century earlier that the variation of the compass had not a constant value, but changed as their ships altered their geographical position. This fresh knowledge gained as to the action of magnetised iron, excited the attention of the philosophers of the period, and the year 1600 marks an epoch in magnetical science. Dr. Gilbert of Colchester, physician both to Elizabeth and James I., then published a treatise in Latin, 'On the magnet (or loadstone), and magnetical bodies, and of that great magnet, the Earth.'* He clearly pointed out for the first time the magnetic properties of the earth; its inductive action, as exemplified on the upright iron bars in the crosses on old church towers, rendering them, in short, magnets; and demonstrated that the earth, by its directive force, performed relatively to the compass needle the office of a real magnet. Gilbert stood high among his contemporaries and admirers, some of whom ranked him with Harvey—the discoverer of the circulation of the blood—with Galileo and Descartes. Galileo himself, the famous astronomer, regarded Gilbert "as great to a degree which might be envied."

During the 17th century, our seamen, in their then newly-opened navigation to the East and the West, diligently made observations at sea of the dip and of the variation of the compass. We find, for example, in the early part of the century, Henry Hudson and others making special determinations of the dip in the Spitzbergen and Nova Zembla seas; men's minds had already become familiar with some of the marvels of magnetism and their practical bearings on navigation. Towards the close of the century, Halley, one of the most distinguished men of science of the day, presented to the Royal Society two papers [1683 and 1692], the first giving a theory of the variation of the compass; the second, an account of the cause of the change of the variation of the needle, with an hypothesis concerning the structure of the internal parts of the earth. Halley subsequently added materially to the observations made by the old navigators—on which his theories were based—for the Government recognising the value of his labours, gave him a ship of war and a commission

* '*De magnete, magneticisque corporibus, et de magno magnete tellure; Physiologia nova, plurimis et argumentis, et experimentis demonstrata.*' Londinis, Anno 1600.

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as a naval captain to command her, in order to make a voyage of research. On the completion of this voyage, which embraced both shores of the Atlantic, Halley compiled a magnetical chart, including also the Indian Ocean, wherein the variation of the compass was shown by a system of connecting lines, drawn through the positions where equal values had been determined by actual observation. This proved a valuable adjunct to navigation.*

Hereafter I shall have to refer to the remarkable hypothesis advanced by Halley, concerning the magnetic condition of the earth, and of the causes of the changes in the direction of the needle at the same geographical position; suffice it here to say that on this subject, in common with all those who have studied the matter even to the present time, he was sorely perplexed. Halley foresaw that the minds of many generations would be exercised in arriving at a sound theory, and wisely appealed to "all masters of ships, and all other lovers of natural truths," diligently to make observations of the compass variations in all parts of the world, and to communicate them to the Royal Society, "in order to leave as complete a history as may be to those that are hereafter to compare all together, and to complete and perfect this abstruse theory."

Halley's appeal was not in vain; those glorious navigators of the eighteenth century,—Wallis, Carteret, Cook, D'Entrecasteaux, La Pérouse, Vancouver,—were diligent observers. Their results, with those of their no less worthy predecessors in the seventeenth century,—Davis, Baffin, Keeling, Narborough, Tasman, Dampier—have been in later times collected by the able and diligent Norwegian magnetician, Hansteen, and embodied by him in a series of magnetical charts (dip and variation) for several distinct epochs, ranging between the years 1600 and 1787.†

In the eighteenth century, the almost microscopic movements of the compass needle from hour to hour were detected, and its daily oscillations during the several months of the year were recorded in London. Towards the end of the century, doubts began to arise as to the invariability of the earth's magnetic force, the assumption that it was so invariable at all points of the earth's surface having apparently, until then, been generally accepted. Humboldt, during his American travel (1798-1803), devoted much time, when in the equatorial regions, to the elucidation of the facts, and he clearly traced that the earth's magnetic force increased with the latitude.

* See Plate I., for similar Lines of Equal Variation drawn for year 1878.

† '*Atlas: Magnetismus der Erde.*' Christiania, 1819.

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This brings us to the present century. Within its first quarter, a few earnest thinkers discerned in the slow and mysterious daily movements of the needle, and in the suggestion that they were regulated by a law, some possible connection with the sun and other bodies in space; and that these mysterious relations implied cosmical influences which might some day be found to pervade the whole universe.

An impetus to inquiry at this juncture was not wanting from the navigators' point of view. The voyages of Ross, Parry, and other worthies to the Polar Regions—primarily undertaken to open a passage between the Atlantic and Pacific Oceans—passed near the region where subsequently it was found that the dipping needle stood vertical, and where, as the consequence, all directive action on the horizontal or compass needle vanished. The seamen were naturally embarrassed with this, to them, novel condition of navigation; the opportunity was therefore eagerly seized for making many observations in this exceptional magnetic area. In one of these Arctic voyages [1831] James Ross planted the British flag on what he assumed to be the Magnetic Pole. Here let me incidentally mention that it is to a then young captain of artillery who accompanied Parry in his earlier voyages [1818–20], Edward Sabine, and who is still among us one of the most honoured veterans of science, that this country is deeply indebted for much that has been done in advancing our knowledge of Terrestrial Magnetism.

Encouraged by the ardour of Humboldt and by the additions resulting from voyages and land journeys in which magnetical observations were special objects, new lines of observation and experimental research were now undertaken by Continental philosophers; refined instruments for detecting the minutest movements of the needle and for measures of the earth's force in reference to a fixed standard were devised by Gauss, of Gottingen, a physicist and mathematician of profound ability; and simultaneous watchings, rigorous in character, were established at localities on the European continent widely distant from each other.* This devotion was soon rewarded, for it demonstrated that the needle moved in obedience to one and the same law at stations the most remote from each other. At times, too, a certain agitation of the needle was detected;

* '*Intensitas vis magneticæ terrestris ad mensuram absolutam revocata; auctore, Carolo Friderico Gauss.*' Gottingæ, 1833.

'Results of the Observations made by the Magnetic Association in the year 1836.' Gottingen. Edited by C. F. Gauss and W. Weber. See Taylor's 'Scientific Memoirs.'

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it then appeared to be tremblingly alive to some sudden shock or impulse from without. Occasionally these trembling oscillations were of unexpectedly large angular values. The periods of large oscillations were also found to be often synchronous at the remotest stations. So striking and general were these disturbances, that they were aptly designated "magnetic storms." It was further observed that the most violent storms of wind appeared to be wholly without influence, provided the needle was effectually protected from any effect of their direct mechanical action: as with *wind* storms, so it was with *thunder* storms, which even when close at hand exercised no perceptible influence on the magnetic needle.*

These phenomena, so deeply interesting in their nature, engaged in this country the attention of the Royal Society, and of the British Association for the advancement of Science. A combined plan for extending observational operations was arranged with the leaders of the original movement in Germany and Russia—Humboldt, Erman, Gauss, and Kupffer; this country being represented by Professor Lloyd of Dublin, and Sabine. Appeals to Government for support in aid of a national scheme for making observations of the three magnetical elements by land and by sea were made, and promptly attended to. By the year 1840, four well-equipped observatories had been established in our colonial possessions. Toronto in Canada, and Hobarton in Van Diemen's Land, were selected as being antipodal. St. Helena and the Cape of Good Hope had also their special recommendations. The East India Company equipped three stations, and a Hindu native prince munificently added another, at Trevandrum, in his own territory. Russia established some ten or twelve; extending from Finland to Eastern Siberia, and from St. Petersburg to Tiflis, and even one at Pekin. In various degrees most of the Continental Governments, and also the United States of America, joined in the movement.

To Great Britain, as the chief maritime State, was allotted the collection of observations in the southern hemisphere, more especially in those oceanic regions which, from their high latitudes, were unlikely to be visited in commercial interests. An expedition, consisting of two ships under James Ross, quitted our shores in 1839 for an exploration of the South Polar seas, and returned in 1843, having well fulfilled its mission. The high dip of nearly 89°

* Extended modern observations would appear to verify these results. The late distinguished Roman astronomer and physicist, Father Secchi, however, held the opinion that relations existed between magnetical and meteorological phenomena.

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was attained, and thus the south magnetic pole nearly reached—a close approach to the position of vertical dip being rendered impossible by massive barriers of ice.

From 1835 to 1845 was thus a time of unparalleled activity in the extension of systematic and accurate magnetical observations over the earth's surface. At the same time a remarkable region in British North America was examined in detail; so also were the British Islands; and from that time to the present, magnetical surveys of limited areas in all parts of the world have been and are being made. Numerous State observatories, equipped with self-recording instruments, are now dotted over the globe. Observations at sea, too, are not disregarded. The recent *Challenger* expedition, for example, throughout the voyage, contributed almost daily perfect observations, and the late Arctic expedition did good service.

The work of the four colonial observatories, comprising in some cases a period of eight years, as also the results of the Antarctic expedition under James Ross, and the observations of other navigators in all parts of the world during the past fifty years, have been closely analysed by Sir Edward Sabine. These laborious analyses, given to the world in a series of volumes, and in papers in the 'Philosophical Transactions of the Royal Society,' form a solid and endurable foundation for the activity of coming generations in this field of inquiry, and will long keep in memory the perseverance and clear intellect of one among the foremost magneticians of the century. The latest and not the least valuable of these contributions by Sabine to terrestrial magnetism, is a magnetic survey of the earth's surface for the epoch 1842–3, chiefly derived from the sources just mentioned. It embraces the three elements: *Declination*, *Inclination*, and *Intensity*—terms which, in the language of modern science, take the place of the old and time-honoured words of *variation*, *dip*, and *total force*.

Having thus rapidly passed in review the progress of this science during three centuries, and explained how the vantage-ground we now stand on was from time to time approached—a review indeed necessary for an intelligent appreciation of the breadth and depth of our subject—I proceed first to the consideration of some general principles, and then to the leading features of the distribution of magnetism over the surface of the globe, as we find it in our own day.

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MAGNETS, THEIR CHARACTERISTIC FEATURES: THE COMPASS AND DIPPING NEEDLES.

Gilbert's affirmation,—made, as I have related, so far back as the year 1600,—that the earth by its directive force performed relatively to the compass needle the office of a real magnet, was a bold and a fairly accurate generalisation. With this generalisation in view, it is important that clear conceptions should be entertained of the analogy existing between the magnetic character of the earth and that of an ordinary bar-magnet: I venture therefore, at the risk of being deemed to have entered unduly into elementary details, to enlarge somewhat on this point.

It is no doubt a familiar fact to most present, that a steel bar can be rendered magnetic by various well-known artificial means; and that when so excited, two opposite and equal forces are produced at each end, one acquiring that kind of magnetism which is called north, the other south magnetism. Also that the N. end of one bar will repel the N. end of another bar, but attract its S. end, and *vice versâ*.

There are other characteristics of a magnetic bar deserving, for our purpose, special mention. If we suspend this bar so as to move like the compass needle in a *horizontal* plane, the N. (or marked) end will always point towards the magnetic north, the other end towards the magnetic south. We are here assured that the force by which the bar assumes this definite position is not an attractive but a *directive* force; because while it attracts one end of the bar it equally repels the other, so that on the whole the suspended bar is not drawn either to the north or south. Another characteristic is, that the points of the bar magnet in which the attractive and repulsive forces may be considered as concentrated, are situated just within the ends. These imaginary points are known as the *poles* of the magnet.

To prepare ourselves for a familiar conception of the earth's magnetism, one more elementary proposition must be advanced:—the action, under certain conditions, of magnets on each other.

If we take a bar magnet, and suspend over its entire length a number of small magnetic needles by their centres and thus free to move in every direction, this will be the result: at the N. pole of the bar the S. end of the adjoining suspended needle will be attracted; at the S. pole of the bar the N. end of the adjoining suspended needle will be attracted to that pole. The suspended needle near the centre of the bar will take up a position parallel to the bar, with its poles *opposed* to that of the bar; the needles

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suspended between either pole and the centre of the bar will incline or dip at various angles, dependent on their relative distances between the poles and the centre of the magnet. We have in this simple illustration, easily verified by experiment, a series of results analogous to the direction and angular amount of the "dip" of the needle to be found extending from magnetic pole to magnetic pole on the earth's surface.

Keeping the illustration in view, let us now see where are those places situated geographically at which a freely suspended needle would take up a vertical position, in the one case with its N. end downwards, in the other with the S. end downwards, and where would it assume a horizontal position.*

To the N.N.W. of Hudson's Bay, in lat. 70° N., long. 96° W., the N. end of the needle points vertically downwards, *i.e.* the dip is 90°. To the south of Tasmania, in lat. 73½° S., long. 147½° E., the S. end of the needle points vertically downwards. These are the earth's magnetic poles. [See Plates II. and III.]

The line of successive places round the globe where the same freely suspended needle takes up a horizontal position (its N. end always pointing towards the magnetic pole in the northern hemisphere), lies near the geographical equator. In the Atlantic and eastern half of the Pacific Ocean it is to the south; in the Indian and western half of the Pacific Ocean it is to the north of the geographical equator. By analogy this encircling line of no "dip" is known as the "magnetic equator." [See Plates II. and III.]

A few explanatory words on the "dipping" needle are here necessary. Wishing to observe the full effect of the earth's magnetism, we must not only allow the needle to move in a horizontal plane, as in the compass; but must also allow it freedom of movement in a vertical plane. The dipping needle is the instrument employed for thus measuring the angle which the N. end of a compass needle would take up were it permitted to move in a vertical plane.

On the "Lines of Force" over the Globe.

We must now advance another stage in our definitions. The direction assumed by a freely suspended needle (*i.e.* one capable of

* As the magnetism of the North end of a needle is of the opposite kind to that of the North Pole of the earth, physicists are not agreed as to which should be called *north* magnetism; and it has therefore been found convenient to distinguish them by colour, calling the first red, the second blue. The distinction may be easily remembered by supposing the needle coloured, and from R occurring in noRth and in Red; U in soUth and in blUe.

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moving freely about its centre of gravity in all directions), in obedience to the earth's magnetism, is known to science as the "line of force." This line of force, as we know by the action of the compass in nearly all parts of the globe, diverges to the east or west of the geographical or true north. By the action of the dipping needle the "line of force" is further found to be only horizontal in the equatorial and tropical regions, and to lie below or above the horizontal plane when to the north or south of the magnetic equator.

Observations made of these "lines of force" all bear the same testimony. If we follow the direction of the horizontal (or compass) needle, we are invariably led to the two points where the needle takes up a vertical position; in other words, to the magnetic poles: when thus mapped, the earth's surface is traversed from north to south and south to north by a system of imaginary lines converging to two points, analogous to the representation on maps of geographical meridians and poles. [See Plate II.]

As to similar teachings of the "dip" of the needle: if lines traced on the earth's surface where the "dip" is equal in amount are followed, we shall always be led in a series of circular or elliptical paths round the adjacent magnetic pole, but not reaching it: here an analogy to the geographical parallels of latitude is obvious, as these vary from 0 at the terrestrial equator to 90° at the terrestrial poles; similarly the angle of dip from the horizon, which is zero at the magnetic equator, becomes 90° at the magnetic poles. [See Plate II.]

Thus far, in what may appear elaborated detail, but not more than is necessary to a clear conception of our subject, the general distribution of the "lines of force" as represented on maps, and the terms "magnetic" poles, meridians, parallels, and equator, have been explained.

On the Distribution of Magnetic Force over the Earth's Surface.*

We have now to enter on another, and possibly, as ultimately bearing on sound theory, the most important phenomenon in Terrestrial Magnetism. This is the distribution of magnetic force over the earth's surface: and here it is well to again revert to the simple bar-magnet for illustration.

The magnetic power of the bar, though, in fact, distributed throughout its mass, acts in an approximate way as if concentrated

* See Plate III.

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at points (*the poles*) just within the ends. We may assume, as indeed cannot be doubted, that the magnetic power of the earth is distributed throughout its mass; this being so, a concentration of force would, as in the bar, exist at two points or poles in each hemisphere. To a limited degree such is the case, inasmuch as the numerical value of the force at the magnetic poles is twice as great as at the magnetic equator; but here we are confronted with a fact, divergent in a striking degree from our conceptions derived from a bar-magnet. The maximum magnetic force of the earth does not occur at the magnetic poles, nor does this force appear to be associated directly with the "lines of force" as indicated by the freely suspended needle. Observation proves that the two elements—*Intensity* and *Inclination*—(*i.e.* total force and dip), vary, independently of each other, with the position of the place of observation; and there is no such connection as would justify the one being spoken of as an immediate function of the other.

Observations made with rigid accuracy show us where these regions of maximum force are situated at the present time. In the northern hemisphere there are two of these regions: they are widely separated and of unequal power. The stronger of the two is situated to the south-west of Hudson's Bay, near the great system of the North American lakes; its central part is in lat. 52° N., long. 92° W.: this is known as the American focus of force. The weaker, or the Siberian focus, may be assumed to be near the mouths of the River Lena, in lat. 65° N., and long. 115° E. Geographically these foci of force are thus far distant from the north magnetic pole.

In the southern hemisphere, the central part of the region of maximum force is to the south of Australia, and may be considered in 65° S. and 140° E. The indication of a second focus is scarcely, if at all marked; if, however, from analogy as to what exists in the northern hemisphere, we assume there is one there, it is scarcely if at all weaker, and is alone separated from the major focus by 15° of latitude, and 20° of longitude, which would place it in 50° S. and 120° E. Geographically, therefore, these foci are not far distant from each other, or from the south magnetic pole, thus differing markedly in their terrestrial distribution from the two foci in the other hemisphere.

The term power, or force, or intensity, as we here apply it to denote these attributes of a bar-magnet, or of the earth considered as a magnet, is indefinite, unless numerical values are attached to convey ideas of the relative power of their several parts. We state, in general terms for example, "that the intensity of each point in

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the axis of a linear magnet is proportional to the square of the distance from the magnetic centre," or "the force in the axis increases as the square of the distance from the middle point," and I have already incidentally remarked that the earth's magnetic force is twice as great at the magnetic poles as it is at the magnetic equator; but these values are only relative, and fail to give the conception which might be found in absolute numbers based on some invariable standard or unit.

Modern science, in its demands for exactitude, has devised instruments for the determination of the earth's magnetic intensity in real absolute measure. In this country, the units of force to which these intensities are referred, are the unit of mass (a grain), the unit of time (a second), the unit of space or length (a foot). Thus, in London, at the present time, the *absolute* intensity in the line of force (or, as sometimes expressed, "total force," to distinguish it from its component parts vertical and horizontal) is 10·28; that is to say, it may be conceived as a force capable of generating in a mass of one grain, a velocity of 10·28 feet in one second.*

In these numbers, then, the values of the two foci of the force in the northern hemisphere are respectively 14·2 (American), 13·3 (Siberian). In the southern hemisphere the Antarctic focus has a value of 15·2:—the magnetic charge, if we may apply the term, of the two hemispheres, is thus seen to be sensibly different.

The lowest force observed in any part of the globe in absolute measure is 6·0: this region is on the west side of the Atlantic Ocean, between the parallels of 15° and 25° S.

If we trace over the earth's surface lines of the "total force" of equal value as we have done in the case of magnetic meridians and parallels, some singular anomalies in their symmetrical arrangement present themselves, and especially so if the analogy of arrangement in a magnetic bar be kept in view. We have seen that these lines indicate in the northern hemisphere two centres of force, and what in strictness can alone be termed one centre of force in the southern hemisphere; and all these are shown to be unconnected with the magnetic poles. The result is that the lines of equal force have no relation with the lines of equal dip, inasmuch as they do not run parallel with each other. But the most remarkable diver-

* The units of length and weight adopted in foreign measures are the millimetre and the milli-gramme. To convert a numerical value obtained on the British system into the corresponding value obtained on the foreign system, the British number must be multiplied by ·46108; or to convert the foreign system into the British, multiply by 2·1688.

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gence from symmetrical arrangement in the distribution of the earth's force, is in its inequality, if we divide the globe into eastern and western hemispheres; in which case the one hemisphere is stronger than the other, in the proportion of 4 to 3. In the hemisphere comprising the Pacific Ocean, with Eastern Asia, Australia, and Western America, the *minimum* intensity expressed in absolute measure is 8. In the other half, including Europe, Africa, and the Atlantic Ocean, it is 6. Again, if we trace along the parallels of 60° N. and 60° S., in the central part of the Pacific Ocean, the values of the "total force" are respectively 12 and 14. In the central part of the Atlantic Ocean, on the same parallels, the respective forces are 12 and 10.

RESEARCHES ON THE NATURE OF TERRESTRIAL MAGNETISM, AND ITS DISTRIBUTION.

Hypotheses have been advanced, and experiments made so far to discover the nature of terrestrial magnetism, as to whether it is produced in any important degree by magnetic forces external to the earth, such as electro-magnetic currents; whether superficial, or deep-seated. The arguments in favour of the first two assumptions are slender, and may here be passed by. Tobias Mayer in the last century, and Biot in the early part of the present, considered that the principal phenomena of the earth's magnetism could be explained by the action of a powerful magnet of limited dimensions near the centre of the earth. Hansteen (1813-19) investigated the effects of two small magnets within the earth and inclined to the earth's equator in different planes. Both of these hypotheses so far failed, that in special cases the results could not be reconciled with observations; though the broader facts of terrestrial magnetism were fairly represented. At the time of these later investigations but little was known of the nature of the distribution of force, but this defect as bearing on theory was soon to be removed—Sabine, in 1838, presented to the British Association an Intensity map for a great part of the earth's surface, accompanied with all the observations on which it was based and also some very able deductions. This marked an epoch.

In 1839, a general theory of terrestrial magnetism was given to the world by Gauss;* and here we begin to tread on firm ground. Gauss assumed, as the foundation of his researches, that the terres-

* '*Allgemeine Theorie des Erdmagnetismus.*' See translation in Taylor's 'Scientific Memoirs,' with Supplement, vol. ii. ('General Theory of Terrestrial Magnetism').

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trial magnetic force is the collective action of all the magnetic particles of the earth's mass. Having before him fairly assured values of the *three* elements at some ninety points on the earth's surface, he on this data, by a geometrical investigation which has been characterised as "one of the most beautiful and the most important that has appeared for many years in physical mathematics," elaborated formulæ from which were obtained certain "constants" now known by his name. From calculations based on these "constants," results in terms of the magnetic elements were derived; these being then graphically rendered on charts, it was seen that the complicated phenomena of the magnetic lines, as broadly traced from actual observation, were reproduced with a remarkable approach to accuracy.

Among the important conclusions arrived at by Gauss in these investigations were: that the agents producing the magnetic force of the earth, or the greater part at least of them, are situated exclusively in the interior of the earth. The fallacy of the hypothesis which would place the cause of terrestrial magnetism in space external to the earth he considered as proved. Another result is very striking. Estimating the total magnetic power or "moment of magnetism" of the earth, as compared with that of a steel bar, one pound in weight thoroughly magnetised, he found the earth to be 8464 trillion times greater; or, supposing the magnetism of the earth to be uniformly distributed throughout its volume, it would be equal to eight such bars (more exactly 7·831) for every cubic metre.

It would be wearisome to enter on a description of the geographical boundaries and directions of the lines of the several magnetic elements, whether as represented by the theoretical deductions of Gauss, or drawn from observation: an inspection of the charts devoted to this subject will more readily convey to the mind their varying and complicated features. I am desirous, however, of pointing out some of the special characteristics that present themselves in the geographical distribution of the more marked phenomena.

As to the magnetic poles. We must not conceive these as absolute points on the surface of the earth, but rather as regions limited in area. That in the northern hemisphere has been traversed as well as encircled by many travellers and voyagers (James Ross, as we know, obtained in 1831 the dip of 89° 59′ in lat. 70° 5′ N., long. 96° 43′ W.), and we are now fairly assured that the dipping needle stands as nearly vertical as can be shown by the best instruments, over an area of some fifty geographical

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miles square. In this region we must remember that all compass action ceases, there being no horizontal force to give it direction.

The magnetic pole in the southern hemisphere has not been approached nearer than about 200 geographical miles; the highest dip recorded in the Antarctic voyage of James Ross, when in this position of lat. 76° 30′ S., long. 166° 0′ E., was 88° 56′; the assumed position for the needle standing vertical being then readily deduced from calculation.

As to the foci of the maximum force. These are large areas of nearly uniform value in absolute measure. The American focus is elliptical in form, and, as deduced from a large number of observations, the semi-axes of the ellipse are some 225 and 85 geographical miles long. The limits of the Siberian focus are but indefinitely determined. The region of maximum force in the southern hemisphere has a vast area; it may be considered as elliptical in shape, with values exceeding 15·0 in absolute measure, ranging over approximately 35 degrees of latitude and 50 of longitude.

The "magnetic equator" admits of being determined with great precision instrumentally, for the change from the well-marked amounts of 10° N. to 10° S. dip is, as a rule, included within 10° of latitude, *i.e.* in every minute of latitude the dip alters two minutes. The broad geographical features of this imaginary line are its devious courses on each side of the terrestrial equator.

Magneticians, whose opinions are entitled to respect, attach more value, on theoretical grounds, to the "dynamic" equator (*i.e.* to the line of least *total force*) than to the "magnetic" or "dip" equator. In my opinion the "dynamic" equator has no special bearing on any hypothesis connected with the subject; the reversal of the dip on passing from one hemisphere to the other is, however, a phenomenon having direct influence on the iron of a ship and thus sensibly affecting her magnetic character; and so far the "dip" equator becomes a zero line of some importance, at least from a practical though possibly secondary point of view.

On similar practical grounds the knowledge of the line of greatest horizontal force (*i.e.* the *horizontal* component of the *total force*) round the globe has interest, inasmuch as in its region the directive force acting on the compass-needle is at the maximum. The horizontal force diminishes as the magnetic poles are approached, and vanishes, we must remember, when they are reached; hence the sluggishness of the compass in high latitudes and its uselessness in the neighbourhood of the magnetic poles. This, as will be readily understood, arises not from any diminution of the magnetic force of the earth, for that increases as we go to the poles, but from its

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direction becoming more and more inclined to the horizon. An interesting physical fact further exists in connection with the line of maximum horizontal force: it corresponds nearly with the mean annual line of greatest heat over the globe; and this latter, as we know, is, except in a limited region in the Eastern Archipelago, wholly to the north of the terrestrial equator.

As to the prime phenomena of the variation of the compass, it will here suffice to say the surface of the globe is, speaking generally, divided into two regions: one, the smaller, in which the variation is westerly; the other and larger, in which it is easterly. Westerly variation prevails in the Atlantic and Indian Oceans; easterly, in the Pacific Ocean. In all parts of the globe, open to ordinary navigation, the variation rarely exceeds 30°, it is only as we reach the neighbourhood of the magnetic poles that the larger values are to be found, and thus it is that our Arctic voyagers and travellers, traversing a comparatively small geographical area, record all values from 0 to 180 degrees of difference between the true and magnetic meridians.

This, limited by the time at my command, in many details, completes the tale of the earth's magnetism as we know it in our own day; a knowledge gained, as we have seen, by instrumental methods, which in their precision and number compare favourably with those made in astronomy, or indeed in any other branch of physical science. But our task is not completed; we have now to consider another and singular section of our subject.

MAGNETIC ELEMENTS IN A CONSTANT STATE OF CHANGE.

The magnetic condition of our globe, as represented by the three elements observed on its surface, is ever varying; but in what manner, or to what end, is unknown to us. For a clear conception of this singular physical fact, I would quote the words of a great philosopher* but lately passed away from us. He says, "The relations of terrestrial magnetism lie among those mysterious powers which seem to constitute the chief arcana of inanimate nature, and its phenomena form a singular exception to the character of stability and permanence which prevails in every other department of the general subject. The configuration of our globe; the distribution of temperature in its interior; the tides and currents of the ocean; the general course of winds and the affections of climate; whatever slow changes may be induced in them by

* Sir John Herschel. 'Quarterly Review,' 1841, Art. "Terrestrial Magnetism."

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those revolutions which geology traces, yet remain for thousands of years appreciably constant. The monsoon, which favours or opposes the progress of the steamer along the Red Sea, is the same which wafted to and fro the ships of Solomon. Eternal snows occupy the same regions and whiten the same mountains, and springs well forth at the same elevated temperature from the same sources now as in the earliest recorded history. But the magnetic state of our globe is one of swift and ceaseless change. A few years suffice to alter materially, and the lapse of half a century or a century to obliterate and completely remodel, the form and situation of those lines on its surface which geometers have supposed to be drawn, in order to give a general and graphical view of the direction and intensity of the magnetic forces at any given epoch."

Sir John Herschel, in these eloquent words, refers to those great changes in the direction of the magnetic needle as observed during the historical period. Two or three examples will illustrate the nature and extent of these changes. In London, between the years 1580 and 1818, the pointing of the needle had gradually changed from $11\frac{1}{4}°$ east of the terrestrial pole to $24\frac{3}{4}°$ to the west (or an included arc of one-tenth of the circle). Then a brief pause in the annual movement ensued, which was succeeded by a retrogressive movement to the eastward, and the needle now [1878] has gone back from its westerly maximum to $18\frac{1}{2}°$ w., and we may believe that the grand oscillation will continue until the easterly maximum is again arrived at. In the southern hemisphere, at the Cape of Good Hope, the needle pointed directly to the terrestrial pole in the year 1608; in 1840 it pointed 29° to the west of it. There was then a pause in movement, and afterwards a slow progression in the same direction. The variation now exceeds 30°.

Similarly with the dip of the needle:—from the year 1576, when it was first observed in London that the north end inclined below the horizon [71° 50′], the amount increased till about 1723 [74° 42′]; since then it has gradually and uniformly decreased from 2 to 3 minutes a year, and now stands at $67\frac{3}{4}°$.

Philosophers, the most conversant with magnetical science, declare their inability to divine the nature of the causes which in such brief spaces of time effect so material an alteration in the direction of the magnetic forces. M. Arago, who took a very active part in making observations between 1815 and 1835, writes: "Nothing in the vast domain of terrestrial physics is more obscure and more uncertain than the causes which everywhere occasion the three elements of terrestrial magnetism, viz., the declination, inclination, and

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intensity of the force to vary." Sir Edward Sabine, writing some twenty years later, "All attempts that have hitherto been made to connect the secular magnetic change with any other physical phenomena, either terrestrial or cosmical, have signally failed." This is so important a branch of our subject, that I must again revert to it; in the meantime it is necessary we should distinguish these "secular" changes, as they are termed, from those constant but slow movements of the needle which specially attracted the attention of men of science in the early part of this century.

MOVEMENTS OF THE MAGNETIC NEEDLE DEPENDING ON THE EARTH'S POSITION IN REGARD TO THE SUN.

Some of the, to them, mysterious movements, and which may be truthfully termed microscopic, are by comparatively recent investigation found to correspond in period to the earth's revolution round the sun and to its rotation on its own axis. The simplest classification of these movements are thus included in a day and in a year. Taking first the daily movement of the compass or variation needle: in the middle latitudes of the northern hemisphere, the N. end of the needle at about 8 A.M. points generally farther to the east than at any other hour of the day; it then gradually moves to the westward till about 1½ P.M., when it attains the farthest westerly position; between this time and the following morning, the long march to the east is interrupted towards the midnight hours by a short one to the westward. In the middle latitudes of the southern hemisphere the movements of the N. end of the needle are in the opposite directions, for there it is the *south* end of the needle that is obedient to this law of movement.

In the low latitudes, such as at St. Helena, Singapore, and especially at Trevandrum, the daily movements of the needle conform alternately to the general movement in either hemisphere, according to the season of the year. Thus between May and September the movement has the characteristic march of the northern, and from October to March that of the southern hemisphere.

The diurnal affections of the dip and total force, though very small in value, are found obedient to law, having their well-marked periods of maximum and minimum values.

Directly connected, however, with these diurnal movements of the needle, being as it were intermixed with them, are those dependent on the position of the sun in respect to the earth's equator; these superimposed values are thus classified as "annual" in distinction to the "diurnal," the latter being chiefly dependent

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on the sun's hour angle at the time of observation, the "annual" being dependent on the earth's position in his orbit.

All the magnetic elements are distinctly affected in the earth's yearly revolution, and we must remember that their observed phenomena *are common to the whole globe.* Thus in the pointing of the N. end of the needle; when the sun is north of the equator it stands to the east, and when the sun is south of the equator to the west of its average position, the turning-points approximating to the equinoxes. Similarly with the dip: the inclination (of either end of the needle) is greater during those months when the sun is south of, than during those months in which he is north of the equator, and passes through its mean values about the time of the equinoxes.

Generalising, the following law obtains for both hemispheres: *when the earth is nearest to the sun and therefore moves with the greatest velocity in its orbit, then the magnetic force is the greatest, and the direction of the needle approaches nearest to the vertical.*

SUN (AND MOON) DO NOT ACT DIRECTLY ON THE EARTH AS MAGNETS.

In the various discussions of philosophers on these movements of the needle, an inclination to ascribe them to the heating powers of the sun acting successively on different parts of the earth's surface has prevailed; but the generalisation just given is a forcible argument against the sun's thermal action as the sole cause. On the other hand, there is reason to believe that no analogy exists between the sun's action as influencing the magnetic condition of the earth, and the action of a magnet on a mass of soft iron placed at a great distance from it: nevertheless the movements described are certainly due to the sun's direct action, and a conjectural view is, that the influencing forces proceed from the sun in a form different from that of magnetic force, to which they become converted by their action on the matter of the earth or its atmosphere.

Modern investigation has further brought to view that a magnetic influence is exercised by the moon. Everywhere and in each of the three elements manifestation of her action is sensibly felt though in a minute degree.* In a lunar day, between each two successive passages of the moon over the meridian of the observing station, the direction of the needle has two epochs of greatest easterly and two epochs of greatest westerly pointing; the intermediate changes of direction being continuous and progressive.

* See especially Mr. Broun's investigations; Edin. Royal Soc. Trans., vol. xxvi., 1872; and Proceedings Royal Soc., London, 1872, pp. 756–758.

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The same reasoning as to the sun's magnetic action is applicable to that of the moon's, for we are told on competent authority that she must be a magnet, thousands or millions of times more intense than the earth, to produce a sensible effect of the character of any of the observed terrestrial disturbances.*

ON THE DISTURBANCES AFFECTING THE MAGNETIC NEEDLE.

The magnetic disturbances, to which I shall presently refer, would certainly appear from their periodicity to result from the sun's power, whether it be magnetic or otherwise; and that this power varies with the size and frequency of the openings in the sun's outer envelope, as evidenced to us by the spots on its surface, is an accepted fact. Here we have a curious episode in magnetical science. It was the favourite occupation of an amateur astronomer (Schwabe of Dorpat) to watch from day to day and record the spot groups on the sun's disc. After an experience of some twenty-five years in this self-imposed and apparently unremunerative task, he was in a position to announce to the astronomical world that there was law and sequence in the distribution and numbers of these spots; in short, that in a cycle of some ten or eleven years their alternate increase and decrease were presented with unfailing regularity. At about the time of this announcement [1850], Sabine had analysed the observations made at the colonial observatories; he had remarked that year by year the disturbances of the magnets varied in number and magnitude, and this without grounds for suspicion of the existence of instrumental or observational errors: and comparing then cautiously the yearly ratios of these disturbances in the frequency of occurrence and amount of aggregate effects with the yearly ratios of Schwabe's sun-spot record, he established an identification of the most confirmatory character; and thus an unsuspected cosmical influence, differing from gravitation and very mysterious in its nature, was brought to view.†

These magnetic disturbances may be described as sudden and abrupt changes taking place in the earth's magnetism and not unfrequently occurring simultaneously over all parts of the globe. The disturbing force is of a throbbing or pulsatory character; under its influence the needle oscillates in a capriciously rapid manner, now

* Mr. C. Chambers and Sir William Thomson, Phil. Trans., 1863, Art. xxiii.

† See also on this subject a valuable discussion by J. A. Broun, F.R.S., "On the decennial period in the range and disturbance of the diurnal oscillations of the magnetic needle and the sun-spot area." Edinburgh Royal Soc. Trans., vol. xxvii., 1876.

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on the one side and now on the other of the normal position for the time. In the larger disturbances observed in this country, the intervals of smaller pulsations vary from about half a minute to four or five minutes; the longer period of pulsatory force lasting from forty to fifty minutes: a careful observer (Balfour Stewart) has described the smaller pulsations "as being superimposed on the larger, like ripples traversing the surface of a great ocean wave." The disturbances are obedient to law: for they have daily periods depending on the solar hours, and, as we have seen, the same decennial periods of maxima and minima as are manifested by the sun spots.* Every region, according to its geographical position, receives these shocks with distinctive effect: in one region they either press the needle's N. end to the eastward during the day hours, and to the westward during the night hours, or the reverse. The dip and the total force occasionally increase and also decrease in their mean values: or, again, in the day hours the maximum number of shocks will take place and in the night hours the minimum number: this action may be reversed, so that the phenomena, viewed as a whole, are extremely complicated.† In their aggregate sum the geographical relations are no less distinctly marked; in intertropical regions the amount is small, and augments in the middle latitudes: as the higher latitudes are approached the disturbances rapidly increase in intensity, but this intensity appears to vary in different meridians.

Perhaps their distinctive character will be more clearly understood if we broadly follow out the movements of the needle at stations, widely distributed. The experiences at Kew (near London), and at Nertschinsk in Eastern Siberia [117° of longitude apart]; at Toronto in Canada, and at Point Barrow near Behring Strait, the most northerly point of the American continent [28° of latitude and 77° of longitude apart], will illustrate the effects in the European, Asiatic and North American continents respectively.

At Kew the westerly deflections prevail during the hours of the *day*, the easterly deflections prevail chiefly during the hours of the *night*: there being a very slight preponderance of the easterly deflections. At the *same time* that the easterly disturbances at Kew are at their maximum—*i.e.* from 9 P.M. to 3 or 4 A.M.—the westerly disturbances in their maximum values are going on at Nertschinsk:

* Mr. Broun has established the mean duration of the decennial period of the magnetic disturbances to be 10·45 years—this being also accordant with the sun-spot period.

† The investigations of Mr. Broun would lead to the conclusion that the magnetic disturbances have their maximum effect near the equinoxes, and the minimum near the solstices.

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the time of cessation or nearly so of these disturbances is, however, less distinctly marked; Kew is little affected between 9 and 11 A.M.; at Nertschink the quiescent period is some hours later. At the two stations, Toronto and Point Barrow, the easterly disturbances have their greatest development at times which are nearly 12 hours apart; and the westerly disturbances have their greatest development at the one station in the forenoon, at the other in the evening. Again, at the stations in North America, the easterly disturbances predominate in amount, while in Northern Asia the westerly predominate. In the southern hemisphere, westerly deflections preponderate at St. Helena, Cape of Good Hope, Hobarton; but at the Falkland Islands easterly deflections have the mastery, and thus are in accord with the North American stations. Sir E. Sabine has remarked on this, that so far as the phenomena are yet known the classification might rather be into *eastern* and *western* than into northern and southern hemispheres, the easterly deflections prevailing in the western or American hemisphere and the westerly deflections at the stations in the eastern hemisphere.

On Auroras and Earth Currents as connected with Magnetic Disturbances.

Connected with these disturbances are auroral displays; excessive disturbances being accompanied with magnificent auroras which are visible at the same time in both hemispheres. This association is especially interesting: at Point Barrow where the recorded aggregate amount of disturbance greatly exceeds that found in any part of the American continent, even in the highest Arctic latitudes, there is a no less extraordinary prevalence of aurora, displays having been visible at this place during two winters [1852–54], for nearly one-third of the time that the hourly magnetic observations were in progress. The several Arctic voyagers—confined, it may be observed, between the 115th and 60th degrees of west longitude—from the early time of Parry to the recent time of Nares, have on the other hand, traced but little connection between the aurora and disturbances of the needle; while if we proceed farther east to the newly-discovered Franz Josef land (north of the confines of Europe and Asia) Weyprecht and Payer tell us that during the two winters they spent there [1872–74], "the northern lights shone with incomparable splendour;" that "the magnetic disturbances were of extraordinary magnitude and frequency," and that they were closely connected with the aurora. (In all the disturbances observed in the Austrian expedition, the declination needle it is stated moved

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towards the east; at the same time the horizontal intensity decreased and the inclination increased.)

Connected too with the larger at least of the magnetic disturbances and more vivid auroras, are certain electrical currents passing through the surface materials of the earth which sensibly disturb telegraphic operations. The Astronomer Royal has devoted attention to this subject: he says, "that it is impossible to avoid the conclusion that the magnetic disturbances are produced by terrestrial galvanic currents below the magnets, though these currents will not account for all that are observed in the magnetometer records."* All that can be said at present is that earth currents are certainly obedient to law; their records, however, throw no light on the sources of the ordinary diurnal inequalities of magnetism: neither do they bear out the supposition of Barlow and other magneticians, by accounting for the existence of the principal part of the earth's magnetism.

ON THE GREATER MAGNETIC CHANGES KNOWN AS "SECULAR" CONSTANTLY GOING ON, AND HYPOTHESES CONCERNING THEM.

We have now passed in review the successive stages of development of our branch of knowledge, from the pregnant epoch when its principles were enunciated by Gilbert, till the period when the well-directed munificence of our own and other Governments dotted the earth's surface with observatories, and despatched land and sea expeditions, specially equipped, for the determination of the magnetic elements. We have seen how a few earnest and gifted men have, by long and patient analysis, laid the foundations for future generations to build upon as regards theory, and unravelled the apparently inextricable web surrounding the needle's daily and yearly movements; tracing these movements to their primary source, the sun: and how by the perseverance of states and of individuals, we are now in possession of accurate knowledge as to the distribution of magnetism over the surface of our globe, as represented by the variation and dip of the needle, and by the measure of the force connected with those component elements. But the task, from a scientific point of view, is far from completed while we remain in ignorance of the causes of the greater changes in the earth's magnetism going on from year to year, and so on, possibly through æons of time. From a practical point of view, so far as the interests of man are concerned, the collection of records will be a never-

* Phil. Trans., Art. xvii. p. 471.

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ending task, for every generation must observe and chart the magnetic elements of its time.

The subject of secular change is thus one of such great interest that the remaining portion of my lecture must be chiefly devoted to it. The active mind of Halley was drawn, as one of the first, to the probable nature of the causes: collecting such observations of the variation of the compass as had then been made, and projecting them on polar maps, he found that the convergence of the several directions of the needle led to two points in each hemisphere. On this he enunciated the proposition "that the whole globe of the earth is one great magnet, having four magnetical poles or points of attraction; near each pole of the equator two; and that in those parts of the world which lie near adjacent to any of these magnetic poles the needle is governed thereby, the nearest pole always being predominant over the more remote." Halley saw, as he confessed with despair, the difficulties attending the proposition "as never having heard of a magnet having four poles," but there were the facts manifested by the earth, and he was too sagacious and sound a philosopher to pass them by. He accordingly propounded a theory which, however fantastic it may now appear and perhaps did at the time he wrote, has nevertheless within it the fire of genius, and may probably yet be found to contain some sparks of truth. To account for the four poles, and at the same time for the secular change of the variation, he conceived that the earth itself might be a shell, containing within it a solid globe, or terella, which rotated independently of the external shell: each globe having its own magnetic axis, passing through the common centre; but the two axes inclined to each other and to that of the earth's diurnal rotation. It is not difficult to follow the movements of the consequent four imaginary poles in solution of the problem.

Hansteen working at the same problem a century after Halley [1811–19] and much on the same lines, came nearly to the same conclusion with regard to the four poles of attraction: and he rendered justice to Halley by recognising him as the first who had discovered the true magnetic attraction of the globe. Hansteen, with the material at his command, went however a step farther, and computed both the geographical positions and the probable period of the revolution of this dual system of poles or points of attraction round the terrestrial pole. From these computations he found that the North American point or pole required 1740 years to complete its grand circle round the terrestrial pole, the Siberian 860 years; the pole in the Antarctic regions south of Australia, 4609 years; and a secondary pole near Cape Horn, 1304

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years.* The influence of these laborious investigations on the minds of subsequent inquirers may easily be imagined.

The matured views of Sir Edward Sabine on the secular changes —enunciated in the clearest manner in 1864–72—are deserving of the highest consideration. An ardent admirer of the genius and no less of the sagacity of Halley, he in part follows Halley's views, and considers that two magnetic systems are directly recognisable in the phenomena of the magnetism of the globe; the one having a terrestrial, the other a cosmical origin. The magnetism *proper* of the globe with its point of greatest attraction (*i. e.* in the northern hemisphere) in the north of the American continent is the stronger; the weaker system, or that which results from the magnetism induced in the earth by *cosmical action*, with its point of greatest attraction is, at present, in the north of the Asiatic continent. Sir Edward Sabine also expresses his belief that "it is the latter of these two systems which by its progressive translation, gives rise to the phenomena of secular change, and to those magnetical cycles which owe their origin to the operation of the secular change." †

Reviewing these several hypotheses by the light of observations made in recent years, it is difficult, and indeed in some directions, impossible, to recognise their accordance with changes now going on: there can be no doubt, notwithstanding, that Halley and Hansteen analysed their facts with skill, and that their deductions were borne out by those facts. In explanation of this anomaly it is necessary to glance retrospectively on the changes in progress at the times in which these philosophers gave utterance to their views [1700–1819]. During this long interval, and, so far as relates to parts of the northern hemisphere, for a century before, there was in the higher latitudes a general movement of the N. end of the needle in the following directions:—

Over all that area (embracing the Atlantic and Indian Oceans) from Hudson's Bay to about the meridian of the North Cape of Europe, and from Cape Horn to about the western part of Australia, the N. end of the needle was successively drawn to the west at a maximum rate of 8′ or 10′ a year. From the meridian of the North Cape of Europe to that of 130° E., it was successively drawn to the east, while from thence to Hudson's Bay it was nearly stationary, or perhaps oscillated a little: in the southern hemisphere, from about the western part of Australia to Cape Horn, the

* '*Untersuchungen über den Magnetismus der Erde.*' Christiania, 1819.
† Phil. Trans., 1864, Art. vi.; 1868, Art. xii.; 1872, Art. xvi.

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movement was throughout to the east at the maximum rate of about 7′ a year. There was thus a general uniformity of movement: in that hemisphere [dividing the globe into *eastern* and *western* hemispheres] which includes the Atlantic and Indian Oceans, the needle was constantly drawn more and more to the west; in the hemisphere embracing the Pacific Ocean more and more to the east.

So far then to the early part of the present century we can trace a harmonious movement of the needle over the whole globe, justifying the conclusions of our old philosophers; but in the year 1818 at London, and generally contemporaneous with that epoch throughout Europe and North Africa, the westerly progress of the N. end of the needle ceased, and an easterly movement commenced; this continues to the present time, and with a yearly increasing rate. But in the South Atlantic during this period the westerly movement has never ceased; it is still going on, and in some parts with rapidity. Here, then, is a marked dislocation of the harmonious regularity embodied in Halley's and Hansteen's calculations and conceptions.

The matured views of Sir Edward Sabine, to which I have drawn attention, seem to anticipate the difficulties attendant on this new and complex movement; for, if I apprehend his meaning correctly, they imply that the poles of attraction which have a terrestrial source, *i.e.*, the *magnetic poles*, are not subject to translation.*

The hypothesis, if further followed, is nevertheless beset with difficulties; for we can scarcely conceive changes due to *cosmical* action to be otherwise than general in character, and to affect the whole globe. Thus, if the progressive translation of the induced or weaker system in Northern Asia—and presumably of that in the southern hemisphere—were the direct causes of the secular changes, we should anticipate uniformity in the general movements of the needle as manifested by its variation and dip over the earth's surface. But this is contrary to modern experience; for in some regions great activity of movement, both in the direction of the pointing and in the inclination of the needle, is going on; in others there is comparative repose in both elements; while in another region the needle remains nearly constant in its direction, while its inclination sensibly varies from year to year. For example:—

A region of remarkable activity presents itself in the South Atlantic Ocean: a great part of the seaboard of South America

* So far as modern observations bear on the position of the magnetic poles, they indicate permanency rather than change of place.

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extending to Cape Horn, and including St. Paul's Rocks, Ascension, St. Helena, and the Falkland Islands, with their adjacent seas, are embraced therein. In some parts of this area the westerly movement of the needle exceeds 7′ or 8′ a year, and has so progressed for nearly three centuries. On the American coast the dip of the s. end of the needle *decreases* from 7·5′ to 4′ yearly, while from the Cape of Good Hope to Ascension it *increases* from 5′ to 10′ yearly. We have here, within narrow limits, a noteworthy dislocation of the observed phenomena.

Another region of activity, so far as are denoted by the changes of variation, extends over Europe, Western Asia, and North Africa. Here the needle, in opposition to the protracted westerly movement going on in the South Atlantic, commenced moving to the eastward in the early part of this century; it has a progressive rate which in some parts now amounts to 10′ a year. The dip diminishes in this region seldom more than 3′ a year.

A region of activity, so far as the dip is concerned, but with little change in the variation, is to be found on the west coast of South America; at Valparaiso, as at the Falkland Islands, the south dip decreases at the rate of 7′ yearly, but in sailing northward and reaching the 10th degree of south latitude, this active movement appears to cease.

But little activity in either element now exists over the habitable part of the North American continent or in the West Indies. Throughout China there is little change in the variation, but an *increasing* dip of 3′ or 4′, and thus a reverse movement to that going on in Europe.

Over a great part of the Western Pacific Ocean, as also in Australia and New Zealand, there is so little change in the two elements that this may be termed a region of comparative repose.

These are a few facts relating to secular changes going on in two magnetic elements within our own time; and what are the inferences to be drawn therefrom? They appear to me to lead to the conclusion that movements, certainly beyond our present conception, are going on in the interior of the earth; and that so far as the evidence presents itself, secular changes are due to these movements and not to external causes: we are thus led back to Halley's conception of an internal nucleus or inner globe, itself a magnet, rotating within the outer magnetised shell of the earth.

We need not here pause to discuss the probability of this fanciful conception of the old philosopher, but proceed to examine how far

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the behaviour of another element, the intensity of the earth's magnetism, confirms the view that movements are going on in the interior of our globe. In common I believe with all those who have pursued the study of this element from the time when Sabine's original memoir to the British Association [1837] threw so much light on this special division of the subject, I had conceived that stability, within very limited conditions, was a distinctive condition of the earth's force; and that it was alone by watchful attention to the instruments of precision devised for its determination that changes in short intervals of time, such as a generation, could be detected.* If we turn to the results obtained in this country through nearly half a century, it is possible that an *increase* of two or three hundredths of the total force may be found. In Italy at the present time the annual *decrease* has been given by that active observer, the Rev. Father Perry, as ·004; so also on the North American continent, where, as we are told by the zealous magnetician, Schott, there is evidence of the force slightly increasing at Washington, of being stationary at Toronto, in Canada, and slightly decreasing at Key West, in the Gulf of Mexico. So far, stability, within very small limits, obtains over a large part of the northern hemisphere. If, however, we turn to the continent of South America and its adjacent seas (parts of which are regions of marked activity as denoted by changes in the variation and dip of the needle), we shall find a diminution of the intensity of the earth's force now going on in a remarkable degree; an examination of the recent observations made by the *Challenger's* officers † at Valparaiso and Monte Video, compared with those made by preceding observers, show that within half a century the whole force has respectively diminished one-sixth and one-seventh—at the Falkland Islands one-ninth. Farther north we find at Bahia and Ascension Island, in the same period of time, an equally marked diminution of one-ninth of the force. This area of *diminishing* force has wide limits; it would appear to reach the equator and to approach Tahiti on the west and St. Helena on the east: at the Cape of Good Hope there is evidence of the force *increasing*.

Such are the facts, and how are we to interpret them? Which-

* The investigations of that able magnetician, Mr. Broun, lead him to consider that the earth's magnetic force increases and diminishes from day to day by nearly the same amount over the whole globe. These increases and diminutions have been traced to the action of the sun in such a way that the greatest of them recur frequently at intervals of 26 days, or multiples of 26 days—a period attributable to the sun's rotation.

† This extended and carefully made series are prepared for publication; we cannot too highly estimate this valuable contribution to magnetical science.

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ever way we look at the subject of the earth's magnetism and its secular changes, we find marvellous complexity and mystery; lapse of time and increase of knowledge appear to have thrown us farther and farther back in the solution. The terella of Halley, the revolving poles of Hansteen, and the more recent hypotheses of the ablest men of the day, all fail to solve the mystery. We must not, however, be discouraged at these repulses in the great conflict for the advancement of human knowledge. The present century has been productive of keen explorers in the field of terrestrial magnetism; others emulous of fame are pressing rapidly from the rear, and knowing as we do that knowledge shall be increased, we may confidently anticipate the day when this, one of Nature's most formidable secrets, shall be revealed.

The CHAIRMAN said they had listened with great interest and instruction to this comprehensive epitome of the present state of our knowledge of magnetic science, which when printed would form a most valuable addition to the publications of the Society. Perhaps the leading idea that Captain Evans's remarks had left in their minds referred to the strangeness and magnitude of the earth's magnetic force, of whose primary causes our ignorance was almost absolute. Very little was known of the causes even of the magnetic storms, and nothing whatever of those of the secular changes. There was therefore a wide field for future research in a primary geographical subject. They were irresistibly led by what they had heard to think of the fluid interior of the globe, and of the vast changes that were slowly going on beneath its surface. He was sure that all present would agree in returning thanks to Captain Evans for his address.

ADDITIONAL NOTICES.

(Printed by order of Council.)

1. *Barometric and Hypsometric Observations to fix the Height of Demavend.* By Captain the Hon. G. NAPIER.

Gulahek, near Teheran, Persia,
September 4, 1877.

To the SECRETARY *of* THE ROYAL GEOGRAPHICAL SOCIETY.

SIR,—The following barometric and hypsometric observations which I have lately had the opportunity of making on the peak of Demavend may possibly prove of interest. The barometric observations are, I believe, the first ones made on the summit of the crater. The Italian Scientific Expedition of 1863 carried a barometer as far as the foot of the crater, where it was broken. The remaining altitude was computed, and, judging by my own

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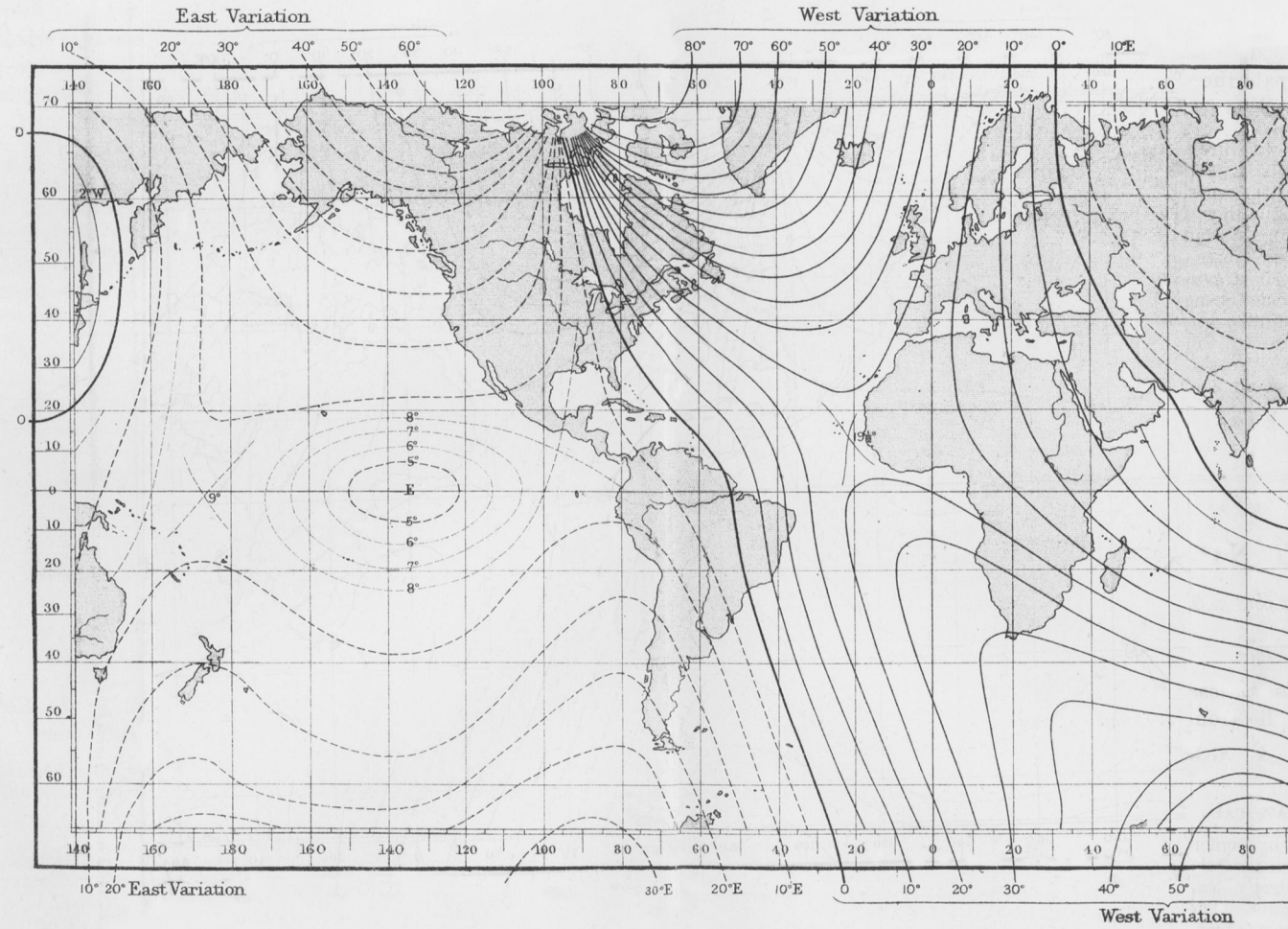
LINES OF EQUAL MAGNETIC VARIATION, OR DECLINATION (ISOGONIC LIN



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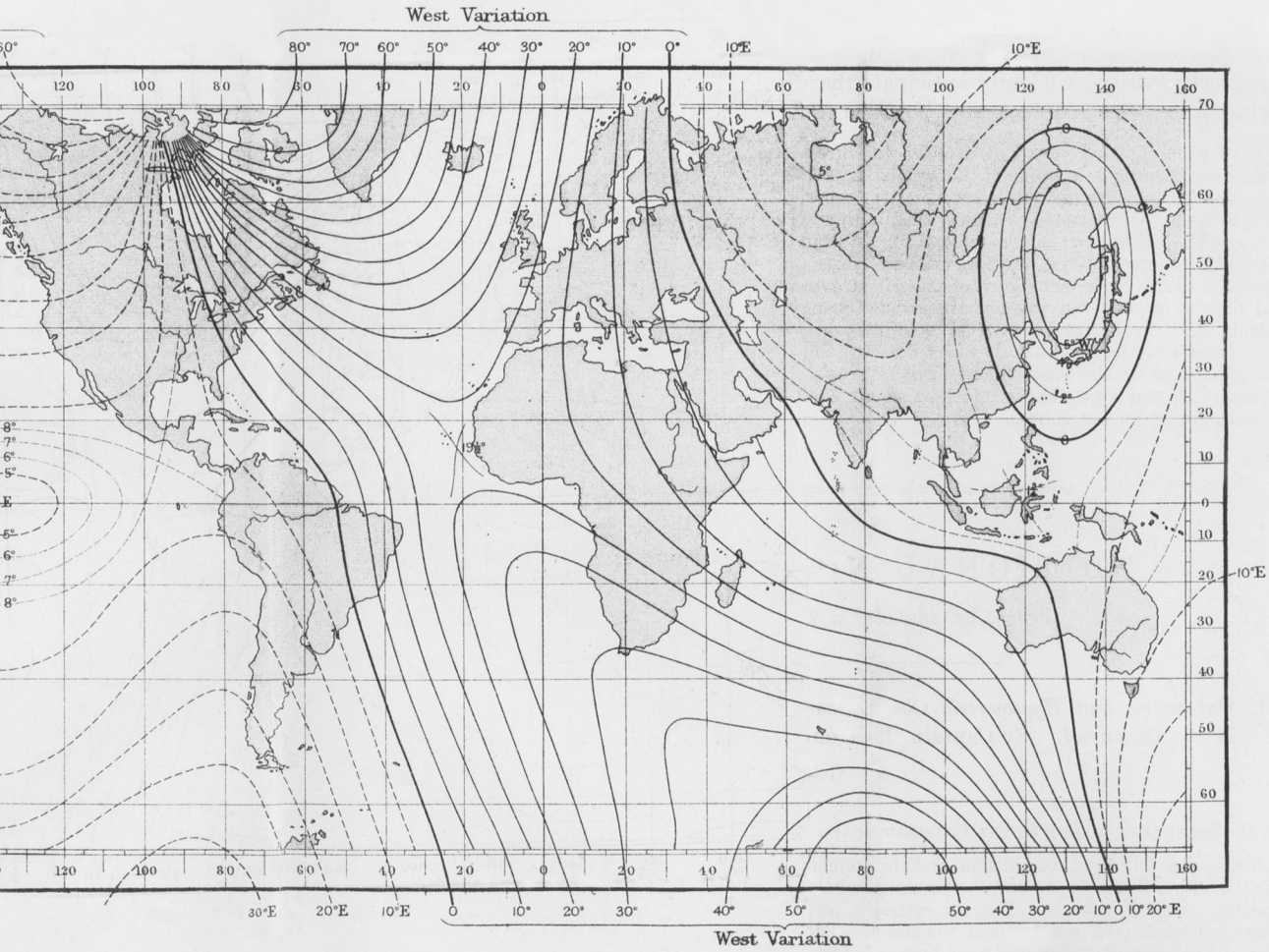
UAL MAGNETIC VARIATION, OR DECLINATION (ISOGONIC LINES). 1878.



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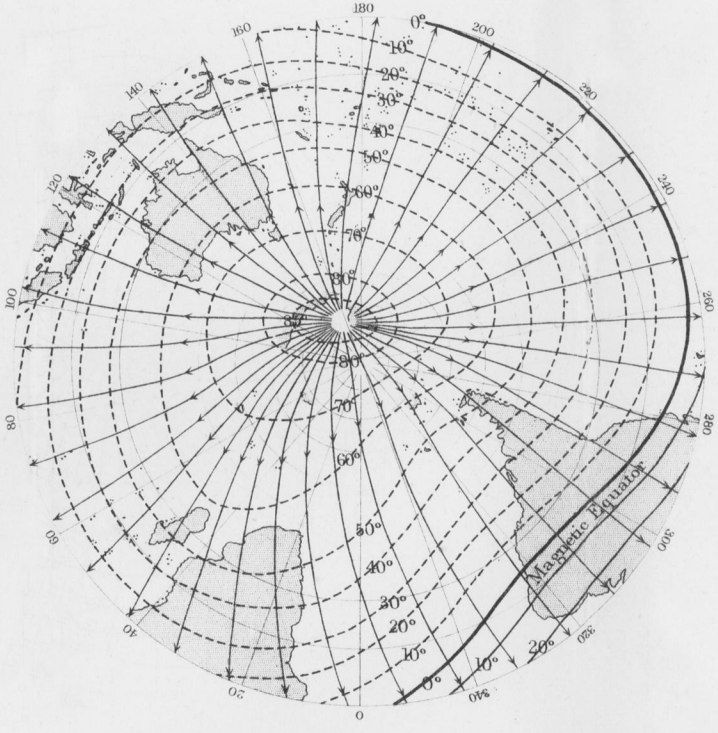
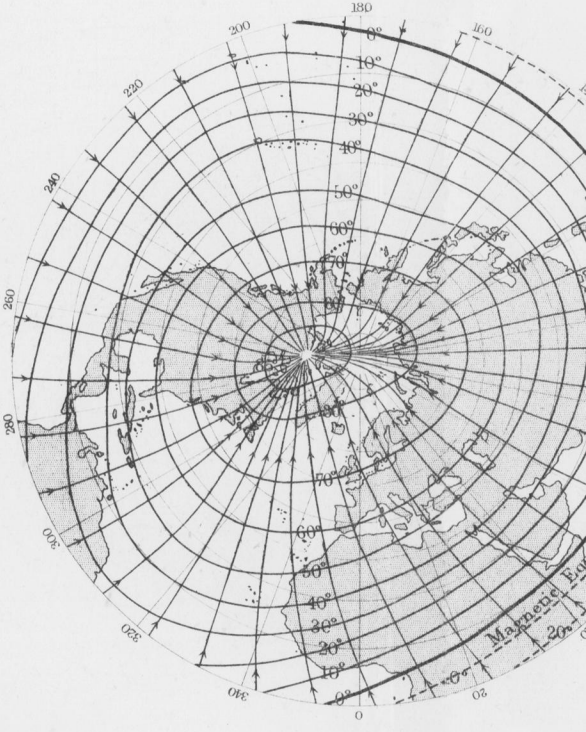
TERRESTRIAL MAGNETIC MERIDIANS, AND CURVES OF EQUAL DIP, OR INCLINATION (ISOCLINAL LINE

(WITH THE MAGNETIC POLE IN EACH HEMISPHERE.)





1. The Magnetic meridians,—— or lines showing the angle made by the "line of force" with the Geographical meridians — are marked with arrow heads. The arrow heads also show the direction of the North end of the compass needle.
2. Curves passing through points of equal North Dip are shown by continuous lines: South dip by broken lines.

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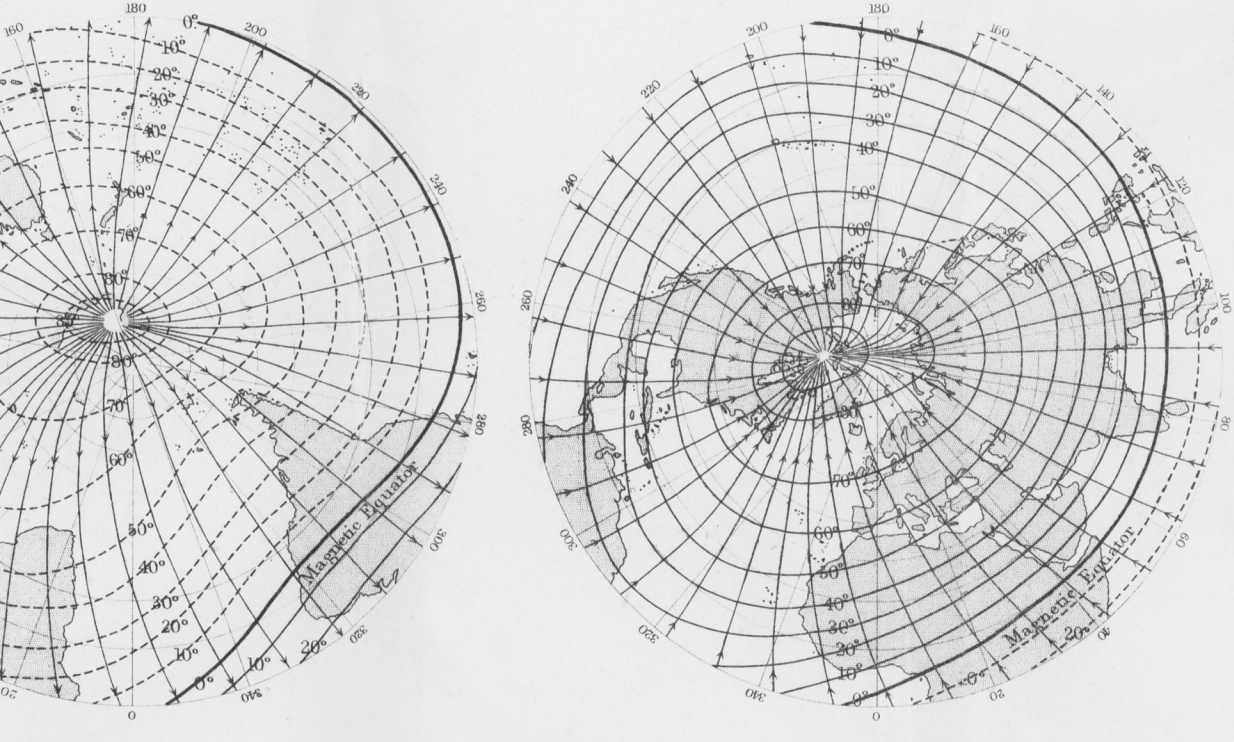

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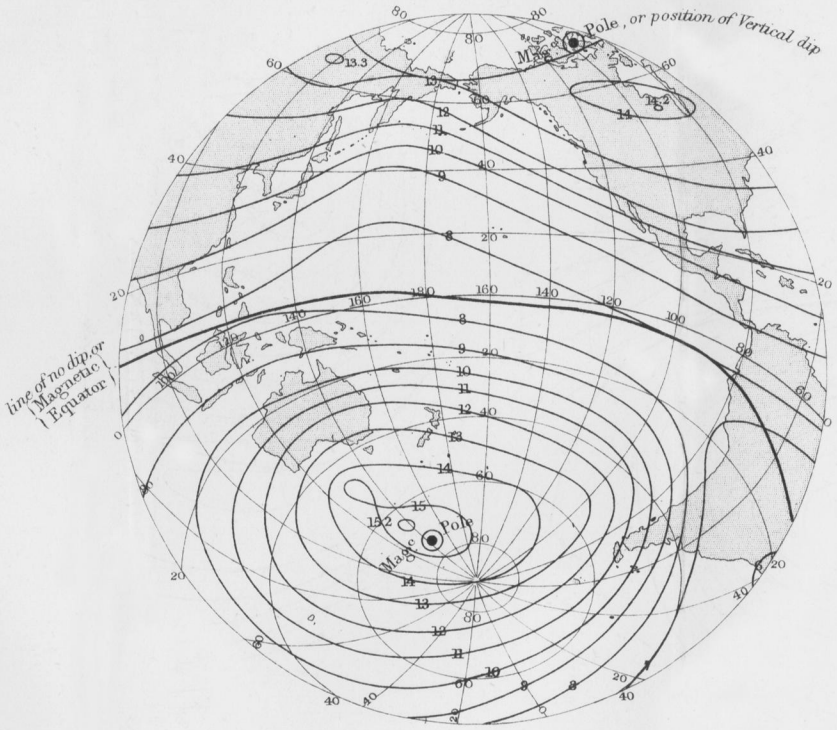
THE EARTH'S MAGNETISM,

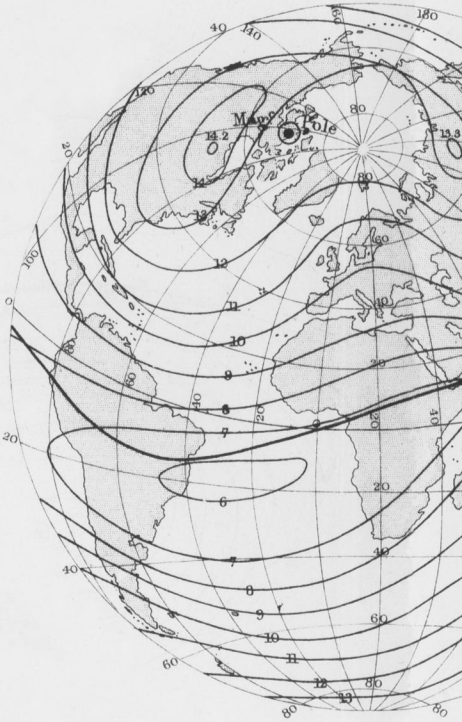
AS SHOWN BY

1. The distribution of lines upon the Earth's surface passing through points of equal Total force.(18
(The force being expressed in Absolute measure, British units).

2. The position of the Magnetic poles and the line of no dip, or the Magnetic Equator.

3. The regions of blue and red Magnetism.





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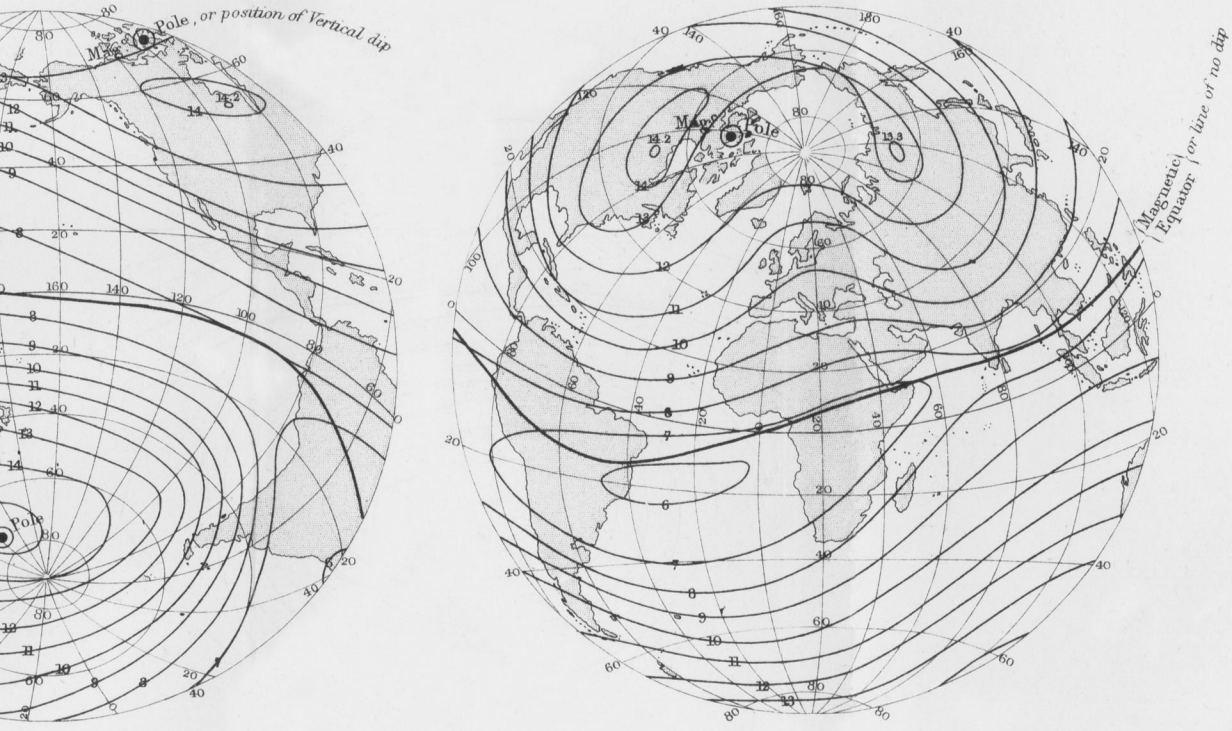

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