possible. To keep the state of the thread constant the glass shade should be rendered air-tight, and should contain some substance for absorbing moisture, such as chloride of calcium. It is clear that if the state of the thread remains the same, and if the position of the magnetic axis of the magnet does not change, this instrument should record faithfully the various changes of declination.

The *Horizontal Force Magnetometer* is exhibited in fig. 25. Here the magnet[1] has been twisted round into a position at right angles to the magnetic meridian. It is suspended by means of two very fine steel wires some little distance apart, and thus the instrument is often called the bifilar magnetometer. These wires have the plane passing through their lower extremities differing very considerably from that of their upper. If the magnet should suddenly lose its magnetism the whole arrangement would be twisted round until the two planes coincided. This difference of plane gives rise to a couple tending to twist the magnet round in one direction while the horizontal magnetic force of the earth constitutes an equal and opposite couple, the two couples keeping the magnet in equilibrium. The couple depending upon the bifilar arrangement may for the present be regarded as constant, that depending on the horizontal force of the earth as variable. If the latter increase or diminish, the magnet will be slightly twisted round in one direction or the other.

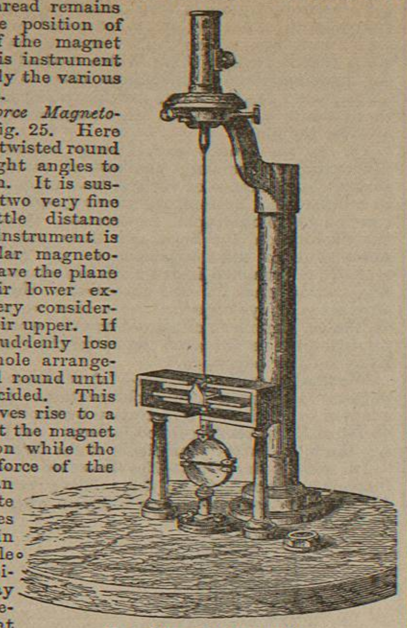

Fig. 24.—Declinometer.

In the *Vertical Force Magnetometer* (fig. 26), the magnet is balanced by means of a knife-edge resting on an agate plane. By means of two screws working horizontally and vertically the centre of gravity may be thrown to either side of the point of suspension, or it may be raised or lowered and the sensibility of the magnet when balanced thereby increased or diminished. There screws are so arranged that there is a preponderance of weight towards the south side of the magnet. This is neutralized partly by the magnetic force tending to pull the north end down and partly by a slip of brass standing out horizontally towards the north side. Let us suppose the system to be in equilibrium at a certain temperature; if the temperature rise (since brass expands more than steel), the leverage of the weight at the north side will increase more than that of the weight at the south. There will thus be a slight preponderance towards the north, and this may be arranged so as to neutralize to a great extent the decrease in the magnetic moment which an increase of temperature produces.

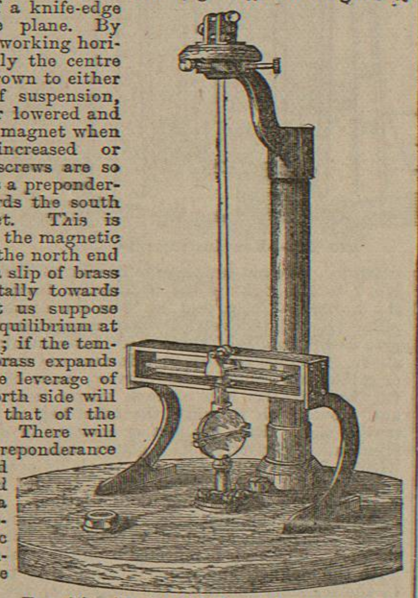

Fig. 25.—Horizontal Force Magnetometer.

21. *Magnetographs.*—The arrangement by means of which these instruments are converted into self-recording magnetographs is very simple. In fig. 23 we see a gas flame burning behind a vertical slit and placed endwise in order to render its light more intense. The light from this illuminated slit passes through a lens, and being reflected from the mirror of the declination magnet throws an image of the slit upon some sensitized paper in the central box. To speak more properly, two images are thrown, one reflected from the upper and movable half and the other from the fixed half of the mirror. The sensitive paper is wrapped round a horizontal cylinder (fig. 27), and the two images are therefore thrown upon different parts of this cylinder. But before reaching the cylinder these two images are by means of a hemicylindrical lens (shown in fig. 27) crushed up into two dots of light. The cylinder moves round regularly by clock-work once in twenty-four hours, and hence the course on the moving paper of the dot of light which comes from the fixed half-mirror will be a straight line, while that of the dot from the moving half-mirror will be a curved line depending on the motions of the magnet. When the paper is developed these lines appear black.

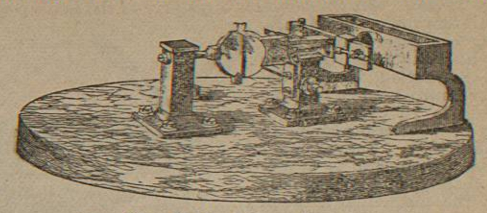

Fig. 26.—Vertical Force Magnetometer.

The arrangement for the horizontal force instrument is precisely similar to that for the declinometer; for the vertical force it is somewhat different, the illuminated slit being horizontal and not vertical, while the mirror oscillates on a horizontal axis and not on a vertical one; the hemicylindrical lens too and the cylinder are vertical and not horizontal. It was found necessary to put the plane of motion of the vertical force magnet 15° out of the magnetic meridian for the following reason. The axes of the telescopes are respectively 30° inclined to the tubes which go from the magnetometers to the central box, and hence had the vertical force magnet swung in the magnetic meridian it would have been necessary to place the mirror inclined at the angle of 15° to the axis of motion of the magnet. This was tried, but it was found that in this position of the mirror the correction for temperature was so excessive that the instrument became a thermometer and not a magnetometer. The mirror was therefore put in a plane passing through the axis of motion of the needle, the needle being made to move in a plane inclined 15° to the magnetic meridian.

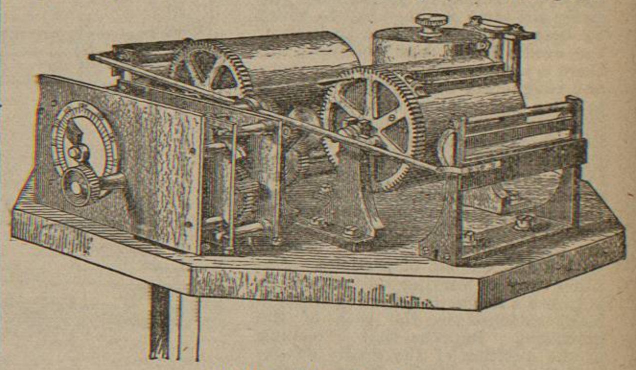

Fig. 27.—Magnetograph.

22. *Scale Coefficients of Differential Instruments.*—It is necessary to know the value of one division of the scale in the magnetometer or of one inch difference in the ordinate of the curve impressed on the photographic paper in the magnetograph. In the declination instrument it is only necessary to obtain the angular deviation corresponding to one division, and this may be done at once by a series of measurements. In the horizontal and vertical force instruments we wish to obtain the value of one division in parts of force. There is more than one method by which this can be accomplished, but that of John Allan Broun is probably the simplest, and it is, we believe, the one adopted at most of the various observatories possessing self-recording instruments. It is given in the *British Association Reports*, 1859.

23. *Temperature Coefficients of Differential Force Instruments.*—Broun has devoted a great deal of attention to the subject of these coefficients, and has come to the conclusion that the best and most unobjectionable method of determining them is to compare the instrumental readings on days when the temperature is high with the readings on days when the temperature is low.

---

[1] All the magnets are of the same size.

24. By differential instruments the components of a force affecting the magnet are determined in three directions at right angles to each other. It does not, however, follow that this force is entirely due to changes in the magnetism of the earth. We know that certain forces connected with the sun affect the earth's magnetism, and on certain occasions at least these forces manifest themselves as currents in the upper regions of the atmosphere and in the crust of the earth. Now such currents will have a direct effect upon the needle as well as an indirect effect through the changes which they may produce in the magnetism of the earth. The total influence on the needle will therefore be made up of these two elements, the one denoting the direct influence on the needle of the disturbing force, and the other the indirect influence through the change produced in the earth's magnetism. No attempt has yet been made to separate the action of these two elements.

25. Self-recording instruments after the Kew pattern have been supplied to observatories at the following places:—

Batavia.
Coimbra (Portugal).
Lisbon.
St Petersburg.
Florence.
Stonyhurst.
Utrecht (declination only).
Melbourne.
Mauritius.
Kolaba (Bombay).
Vienna.
Zi Ka Wei (China).
San Fernando (Spain).
Potsdam.
Brussels.
Nice.

There are also self-recording magnetographs of other patterns at Toronto, Montsouris (Paris), Greenwich, Wilhelmshaven (?), Cape Horn, and Havana (?).

We understand that Professor W. G. Adams is at present engaged in making a comparison of simultaneous curves from various stations of these lists.[1]

Magnetic Poles of the Earth—Secular Variation.

26. *Magnetic Poles of the Earth.*—In the article Magnetism it has been shown that Dr Gilbert of Colchester had at a very early period grasped the important truth that the earth is a magnet, a truth which was afterwards mathematically demonstrated by Gauss. It was reserved for Halley, the contemporary of Newton, to show that the earth must be regarded as having two poles in the northern and two poles also in the southern hemisphere, so that, unlike ordinary magnets, its magnetic system has four poles altogether. Before proceeding further it will be desirable to state what it was that Halley actually did and what are the conclusions to be derived from his investigations. It has been remarked by Professor Stokes that, while in an ordinary bar magnet we may practically regard the pole as having a physical reality and as being the cause of well-known attractions and repulsions, we are not entitled *a priori* to assume that a point of maximum force in a large spherical magnet like the earth must necessarily be the seat of attractions and repulsions after the same manner as the pole of an ordinary bar magnet. It is to be determined by observation to what extent the earth actually preserves an analogy to an ordinary magnet. Now Halley's conclusions were derived from the pointing of the declination needle, since in his day there were no observations possible on total magnetic force. He argued that there are two points or poles in the northern hemisphere to which the needle appears to be attracted, one in the upper region of America and one above Siberia. So far this conclusion is hardly anything more than a formal one derived from the grouping together of observations. He asserted that these would be as they are known to be if we imagine two such poles or foci of force each exercising a causal influence on the magnetic needle. And the justification of Halley's way of regarding the earth is found in the fact that when force observations came to be made two such foci of force were actually found to exist. We do not, however, mean to imply that these foci have causal properties exactly similar to the poles of a bar magnet, for this is not the case.

In order to exhibit the process of reasoning which led Halley to his conclusion, let us first imagine that the earth has only a single pole or force-focus in the northern hemisphere, and that this is coincident with its geographical pole; then, assuming that this pole has a causative influence on the needle's declination, we should expect all needles to point everywhere due north. If, however, this pole be not coincident with the north pole of the earth, let us draw a meridian circle passing through the magnetic pole and complete it round the earth so as to divide the earth into two halves. At all points in this meridian circle the needle might be expected to point due north, while in the one half of the earth so divided it should point to the east and in the other half to the west of true north. In the next place let us imagine that the earth has two north magnetic poles or foci of equal strength, both being at the same latitude, while their difference in longitude is 180°, and let us draw a complete circle of meridian passing through these poles (fig. 28). Let us start from a point in this circle under one of these poles and pursue our journey eastwards along a circle of latitude. At first the needle will point due north. As we move eastwards the needle will point westwards to the pole we are leaving until we come to a region half-way between the two poles, where it will be equally solicited by each, and will therefore again point due north. Let us call the space we have travelled over since we set out A. As we proceed the needle will now be under the predominant influence of the second pole to our right, and will therefore point to the east until we arrive at the meridian under the second pole. This second space which we have travelled over let us call B. As we proceed we pass through a space C where the needle again points to the west until being once more equally influenced by the two poles it will point due north. After this we pass through a space D of easterly variation until we arrive once more at the point from which we started.

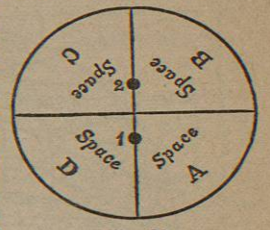

Fig. 28.

Thus there are now four spaces instead of two, and these are shown in fig. 28, where the centre of the circle represents the north geographical pole of the earth, and its circumference the equator. If pole 2 be inferior in power to pole 1 the spaces B and C will be smaller in size than A and D.

27. This last is an arrangement of things that agrees very well with the results of observation, if we add that the two poles are not precisely 180° removed from one another in longitude. Fig. 30[2] represents lines of equal magnetic variation in 1882. There are two lines extending throughout both hemispheres at all points of which there is no variation, and also an oval-shaped district in the northern hemisphere throughout all points in the circumference of which we have no variation. These facts are inconsistent with the hypothesis of a single pole, but they are quite consistent with that of two poles or foci of force, one in northern America and the other in northern Asia, the former being stronger than the latter. In order to see this let us take our stand at the great line of no variation which passes through North America and travel eastwards. We are just south of the American pole or focus, while the Asiatic pole or focus is nearly 180° off, and hence the needle points due north. As we proceed eastwards we leave the American or strongest pole to the westward of us, and hence we have a region of west variation which we have agreed to call A. As we begin to approach the eastern side of Europe we get nearer the Asiatic pole or focus, and at length the line of no variation is reached, the tendency of the American pole to pull the needle to the west being balanced by the tendency of the Asiatic pole to pull it to the east. After this, easterly variation predominates throughout a region B until at length we come to a point in the western boundary of the oval where we may imagine ourselves to be directly south of the Asiatic pole, while the American pole is nearly 180° distant; once more the needle points due north. As we still travel eastwards we leave the Asiatic pole, which is now the predominant one, to our left, and hence we have here a region C of westerly declination. At length we come to the eastern boundary of the oval, where the tendency of the Asiatic pole to pull the needle to the west is balanced by the tendency of the American or stronger pole (acting now towards the right) to pull it to the east, so that we have once more a point of no variation. After this the American pole predominates, and we have a large region D of easterly variation until we travel round once more to the point from which we started.

28. This train of argument receives, as we have already mentioned, corroboration from the fact that in the map of total force we perceive two foci of maximum force, one in northern America and the other in northern Asia, that in America being the strongest. This evidence was not, however, in existence at the time of Halley, and his hypothesis of two poles does the greater credit to his sagacity, inasmuch as he had to deduce it from a comparatively small number of observations of declination and dip, those of force being altogether wanting.

29. We have hitherto spoken of two poles or, more properly, *foci of maximum force*, the positions of which are of course best pointed out in fig. 29; but we have seen that the existence of such

---

[1] We are indebted to Mr Gordon—and to his publishers Messrs Sampson Low & Co., who have obtained them for us—for the sketches of the instruments for absolute determinations, with the exception of that of Kater's compass, for which we are indebted to Mr J. J. Hicks. For the sketch of the self-recording magnetographs together and in detail we are indebted to the Kew committee and to Mr G. M. Whipple, director of the Kew Observatory.

[2] We are indebted for the admirable charts given in figs. 29–32 to the kindness of the hydrographer, Captain Sir Frederick Evans, who, in order to save time, allowed us to make use of the information he had embodied even before it was officially published, and who likewise placed his plates at our disposal.

foci was first conjectured from the behaviour of the lines of variation or declination. Now it will be noticed by looking at the variation map (fig. 30) that all the lines of equal magnetic variation appear to converge to a point in the extreme north of the American continent. This point is not, however, coincident with the chief focus of force, which lies decidedly to its south; but it is no doubt coincident with the point denoting a dip of 90°, the locality of which may be inferred from the map of magnetic dip (fig. 31), and it is likewise no doubt coincident with the position of a zero of horizontal force which may be inferred from the map of horizontal force (fig. 32). Thus we have a point to the extreme north of America which has the following properties:—(1) the various lines of declination converge to it; (2) the needle points vertically downwards at it; and (3) the horizontal force vanishes at it. At this point therefore the horizontally balanced needle, having no horizontal force acting upon it, will point in any direction.

This point is, strictly speaking, the *pole of verticity*, but, inasmuch as there is only one such point in each hemisphere, these may for convenience sake be termed the magnetic poles, so that we speak of two centres or foci of maximum force and one pole in each hemisphere.

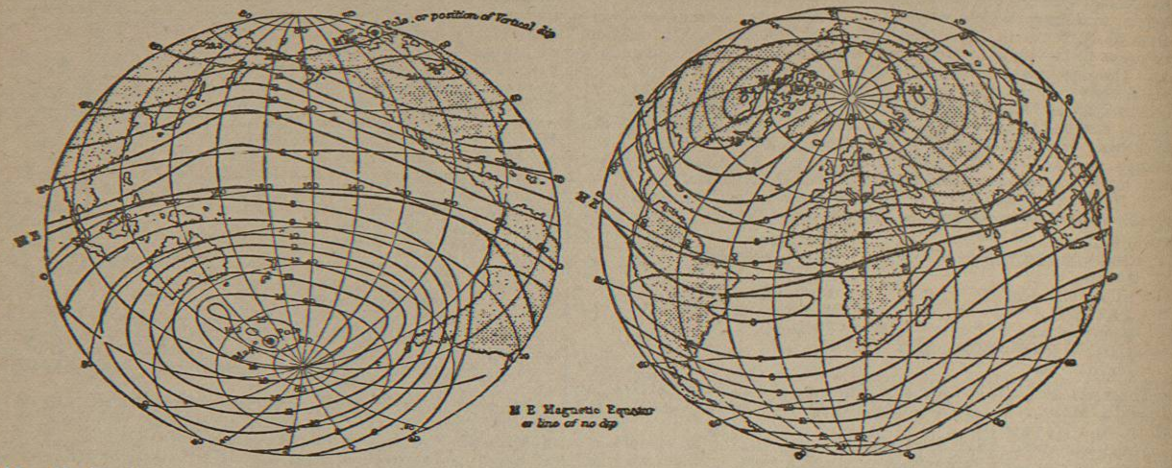

FIG. 29.—The Earth's Magnetism as shown by the Distribution of Lines of Equal Total Force, in Absolute Measure (British miles), with the Position of the Magnetic Poles and Equator,—approximately for 1875.

In the northern hemisphere Sir Frederick Evans[1] assumes the stronger or American focus to be in 52° N. and 90° W., and the weaker or Siberian focus in 70° N. and 115° E. In the southern hemisphere he assumes the position of the stronger focus to be 65° S. and 140° E., and of the weaker focus probably 50° S. and 130° E., these being thus not far separated from each other or from the magnetic pole. The nearness together of the southern foci is probably the reason why the total force is greater at the southern than it is at the northern foci.

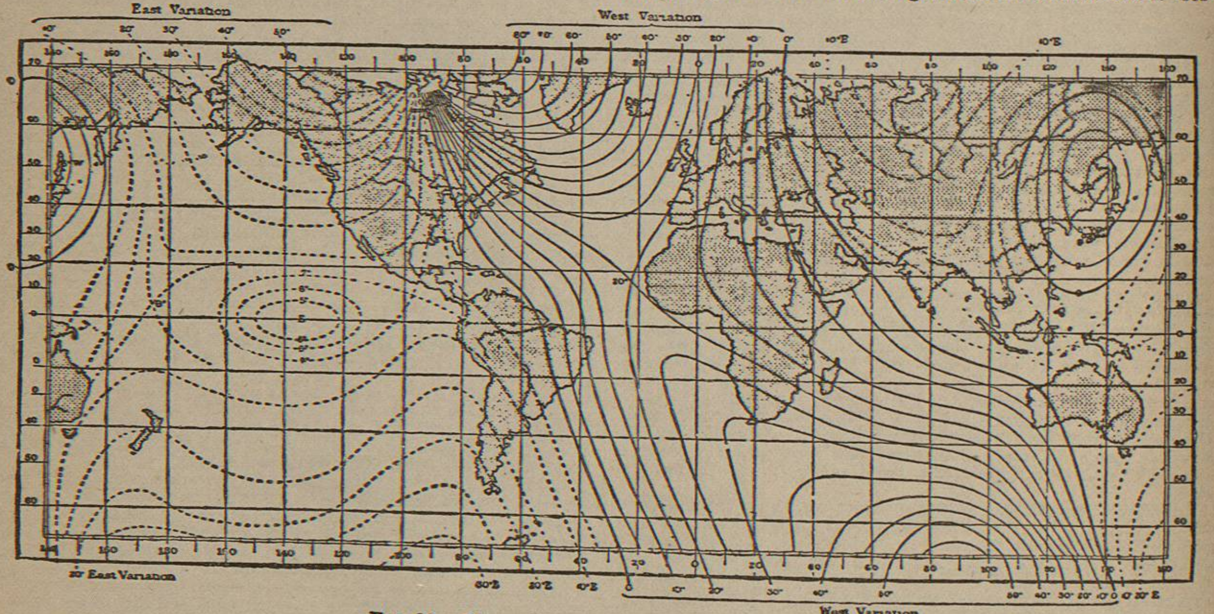

FIG. 30.—Lines of Equal Magnetic Variation, 1882.

The magnetic pole (of verticity) in the northern hemisphere was reached by Sir James Ross in 1831. The position of vertical dip was observed by him to be 70° 5′ N. and 96° 43′ W. The magnetic pole (of verticity) in the southern hemisphere was nearly attained by the same navigator in a voyage made in 1839–43. Its position is probably 73½° S. and 147½° E.

The line of no dip is called the *magnetic* or *dip equator*—its position is given in figs. 29 and 31. The line connecting all the points where the magnetic intensity is least is called the *dynamic equator*. It coincides very nearly with the dip equator.

30. *Secular Variation.*—The earth then as a magnet must be supposed to have two sets of centres of force. We shall next attempt to show that these centres cannot be regarded as constant both in position and intensity.

It should be premised that, while there is no well-established evidence to show that either the pole of verticity or the centre of force to the north of America has perceptibly changed its place, there is, on the other hand, very strong evidence to show that we have a change of place on the part of the Siberian focus and also on the part of its analogue in the southern hemisphere.

Table I. (p. 166), given by Gilpin (*Phil. Trans.*, 1806),[1] exhibits the change in the position of the needle in Great Britain from the earliest observations up to the beginning of the present century.

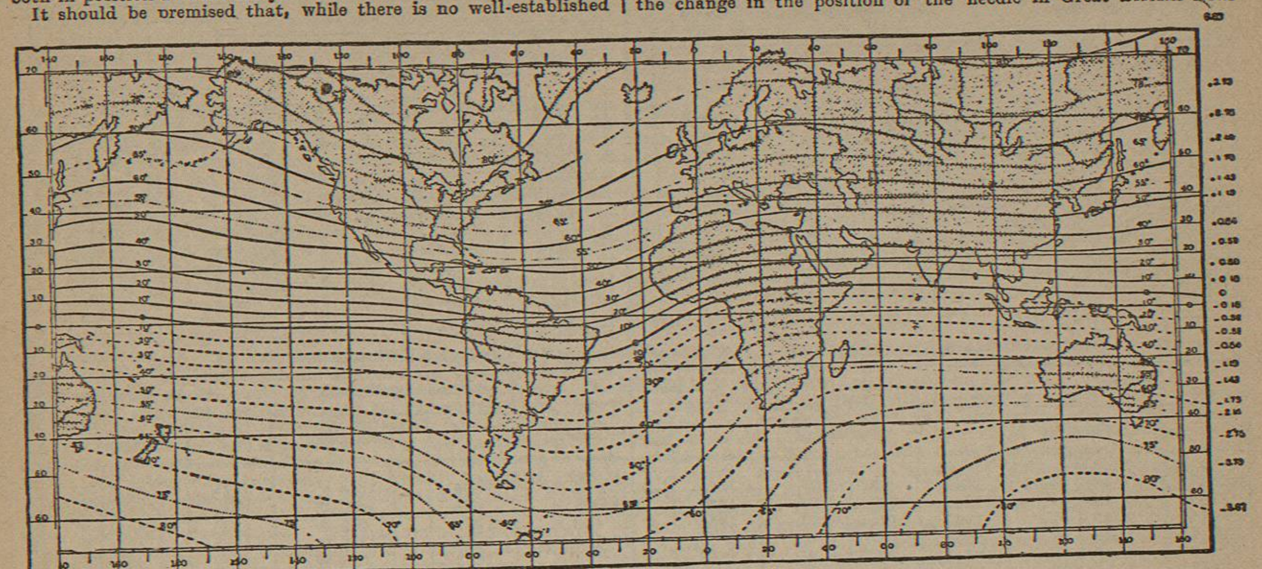

FIG. 31.—Lines of Equal Magnetic Dip, 1882.

31. Between the dates recorded in this table the needle has been pointing more and more to the west, which implies either a relative increase in the power of the American as compared to the Siberian focus, or a motion of the Siberian focus from west to east. On the first supposition the lines to the eastward of the Siberian focus—for instance, the line of no variation depending on a balance between it and the American focus—should be drawn in towards it, or they should travel westwards; but if the latter supposition is true, or this focus has been moving eastwards while retaining its force, the lines to the east of it should be found moving eastwards also. There is strong evidence that the latter is the case, and that in the northern hemisphere there has been a long-continued progression to the eastwards of the system of magnetic lines on both sides of the Siberian focus. In the southern hemisphere also we have proof that the analogous focus has been travelling, not from west to east, but from east to west.

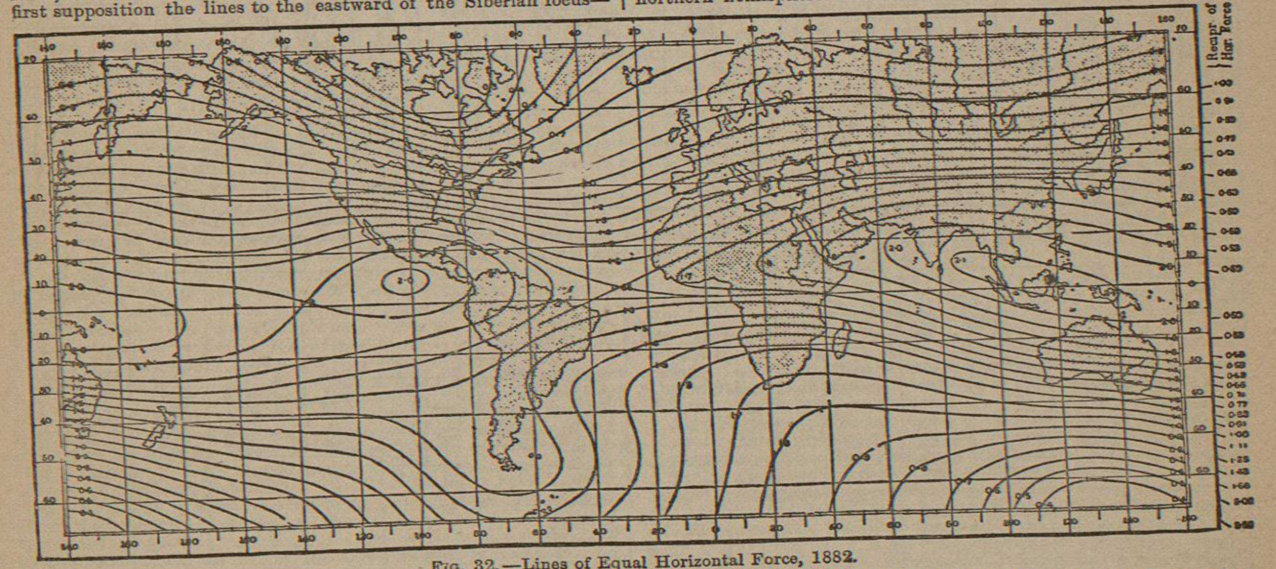

FIG. 32.—Lines of Equal Horizontal Force, 1882.

32. There is some reason to believe that the eastward motion of the Siberian focus has been recently reversed, and that it is now going from east to west. Table II. shows the declination observed at Bushey Heath (Herts) during 1817–20, and at Kew from 1858 to 1882.

It would appear from Table II. that the maximum westerly declination was reached in 1818, and that the needle has since that date been travelling eastwards. A similar change has taken place

---

[1] *Elementary Manual for the Deviation of the Compass in Iron Ships.*

[1] Taken from Walker's *Magnetism.*

at other stations; and, although these changes are not strictly simultaneous at the various stations, they have yet been sufficiently general and near together in point of time to indicate that some change has probably taken place in the movement of one set of the magnetic foci of force.

TABLE I.—*Secular Change of Variation in Great Britain.*

Observer.	Date.	Declination.	Mean Annual Westward Change.
		° ′	
Burroughs	1580	11 15 E.	
Gunter	1622	6 0 E.	7·5
Gellibrand	1634	4 6 E.	9·5
Bond	1657	0 0 E.	10·6
Gellibrand	1665	1 22 W.	10·2
Halley	1672	2 30 W.	9·7
Halley	1692	6 0 W.	10·5
Graham	1723	14 17 W.	16·0
Graham	1748	17 40 W.	8·1
Heberden	1773	21 9 W.	8·4
Gilpin	1787	23 19 W.	9·3
Gilpin	1795	23 57 W.	4·7
Gilpin	1802	24 6 W.	1·2
Gilpin	1805	24 8 W.	0·7

TABLE II.—*Changes of Declination in England,—at Bushey Heath for* 1817–20, *and at Kew from* 1858.

	Declination West.				Declination West.		
	°	′	″		°	′	″
1817	24	36	4	1869	20	26	24
1818	24	38	25	1870	20	18	52
1819	24	36	14	1871	20	10	31
1820	24	34	30	1872	20	0	31
1858	21	54	8	1873	19	57	44
1859	21	47	22	1874	19	51	58
1860	21	39	51	1875	19	41	14
1861	21	31	36	1876	19	31	53
1862	21	23	32	1877	19	22	22
1863	21	13	16	1878	19	13	50
1864	21	3	35	1879	19	6	10
1865	20	59	3	1880	18	57	59
1866	20	51	10	1881	18	50	30
1867	20	40	26	1882	18	44	47
1868	20	33	9	...		...	

TABLE III.—*Exhibiting certain Years' Values of Declination at Various Places.*

Toronto		Makerstoun.		Trevandrum.		Cape of Good Hope.		Hobart Town.	
	Declination		Declination.		Declination.		Declination.		Declination.
	° ′		° ′		° ′		° ′		° ′
1841	1 14·3 W.	1841	25 33·7 W.	1854	0 25·896 E.	1605	0 30·0 E.	1843	9 53·32 E.
1842	1 19·1 W.	1842	25 28·4 W.	1855	0 26·026 E.	1609	0 12·0 W	1844	9 54·93 E.
1845	1 29·1 W.	1843	25 22·9 W.	1856	0 26·400 E.	1622	2 0·0 W	1845	9 56·47 E.
1846	1 30·8 W.	1844	25 17·1 W.	1857	0 27·278 E.	1675	8 14·0 W	1846	9 58·42 E.
1847	1 33·2 W.	1845	25 11·3 W.	1858	0 28·769 E.	1691	11 0·0 W.	1847	9 59·28 E.
1848	1 35·4 W.	1846	25 6·0 W.	1859	0 30·406 E.	1751	19 15·0 W.	1848	9 60·61 E.
1849	1 36·9 W.	1847	24 59·6 W.	1860	0 32·034 E.	1775	21 14·0 W.		
1850	1 38·6 W.	1848	24 51·8 W.	1861	0 34·318 E.	1788	24 4·0 W.		
1851	1 40·9 W.	1849	24 45·2 W.	1862	0 36·654 E.	1792	24 31·0 W.		
1856	1 56·3 W.	1850	24 39·0 W.	1863	0 39·123 E.	1818	26 31·0 W.		
1857	2 0·5 W.	1851	24 31·3 W.	1864	0 41·603 E.	1836	28 30·0 W.		
1858	2 4·5 W.	1852	24 25·2 W.	1865	0 44·007 E.	1839	29 9·0 W.		
1859	2 7·4 W.	1853	24 18·7 W.	1866	0 46·310 E	1841	29 6·2 W.		
1860	2 10·6 W.	1854	24 11·8 W.	1867	0 47·590 E.	1842	29 5·9 W.		
1861	2 14·4 W.	1855	24 5·3 W.	1868	0 48·687 E.	1843	29 6·0 W.		
1862	2 15·7 W.			1869	0 49·735 E.	1844	29 6·2 W.		
1863	2 19·1 W.					1845	29 7·4 W.		
1864	2 21·9 W.					1846	29 8·7 W.		
1865	2 24·8 W.					1847	29 12·4 W.		
1866	2 27·6 W.					1848	29 14·0 W.		
1867	2 29·8 W.					1849	29 16·2 W.		
1868	2 33·2 W.					1850	29 18·8 W		
1869	2 37·1 W.								
1870	2 41·9 W.								
1871	2 47·9 W.								

TABLE IV.—*Exhibiting certain Years' Values of Dip and Horizontal Force at Various Places. The years in this Table are from April to April*; *thus* 1845 *means the year from* 1st *April* 1845 *to* 31st *March* 1846.

London or Kew.				Toronto.				Hobart Town.				Cape of Good Hope.	
	Dip.		Hor. Force.		Dip.		Hor. Force.		Dip.		Hor. Force.		Dip.
	° ′				° ′				° ′				° ′
1857	68 24·87	1857	3·7899	1845	75 15·50	1845	3·5476	1842	70 42·2	1846	4·5054	1841	53 9·1
1858	68 22·56	1858	3·7950	1846	75 14·58	1846	3·5419	1843	70 38·2	1847	4·5001	1842	53 15·3
1859	68 21·41	1859	3·8007	1847	75 15·30	1847	3·5384	1844	70 33·3	1848	4·4991	1843	53 20·2
1860	68 19·29	1860	3·8063	1848	75 18·32	1848	3·5339	1845	70 32·0	1849	4·4997	1844	53 29·4
1861	68 17·42	1861	3·8121	1849	75 18·94	1849	3·5367	1846	70 33·0	1850	4·4998	1845	53 29·3
1862	68 14·89	1862	3·8165	1850	75 19·98	1850	3·5322	1847	70 34·5				
1863	68 11·71	1863	3·8216	1851	75 20·42	1851	3·5299	1848	70 35·7				
1864	68 9·31	1864	3·8284	1852	75 20·52	1852	3·5154						
1865	68 8·50	1865	3·8306										
1866	68 5·44	1866	3·8391										
1867	68 2·62	1867	3·8467										
1868	68 2·13	1868	3·8493										
1869	68 0·41	1869	3·8551										
1870	67 57·98	1870	3·8585										
1871	67 56·12	1871	3·8640										
1872	67 53·60	1872	3·8712										
1873	67 51·19	1873	3·8777										
1874	67 49·64	1874	3·8828										

33. Halley sought to explain the four-pole theory and to account for the secular change by imagining a solid globe or *terella*,[1] concentric with the earth but rotating independently of the external shell and having a slightly different period of rotation,—the shell having two poles and the terella two others. While continuing to admire Halley's sagacity, we shall not now be disposed to allow such a constitution of the interior of the earth, but will rather be led to look to some external influence as the cause of the secular variation.

While we have strong evidence that the Siberian focus has changed its position, we cannot assert that the American focus has been absolutely stationary, or that neither focus has experienced any changes of force. On these points we must be content to be guided by observation alone.

34. It has been supposed by some magneticians that it is possible to compute with something like certainty the particulars of the motions of the magnetic foci. Hansteen more especially (1811–19) computed both the geographical positions and probable periods of revolution of this dual system of foci of force round the terrestrial pole. Sir Frederick Evans has discussed in connexion with the subject all the most recent observations,[2] and points out two objections to any such theory as that of Hansteen, viz., (1) that, while a magnetic turning point has been reached in certain regions, there are large portions of the earth in which this change has not yet been accomplished, and (2) that in certain districts of the earth very great changes in force have taken place. "If we turn," he says, "to the continent of South America and its adjacent seas, 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' officers at Valparaiso and Monte Video, compared with those made by preceding observers, shows that within half a century the whole force has respectively diminished one-sixth and one-seventh,—at the Falkland Islands one-ninth." On the whole, while there is strong evidence that the Siberian focus has until recently been travelling eastwards, and its analogue westwards, and evidence less conclusive that recently a turning point in this motion has been reached, we are disposed to think with Sir Frederick Evans that a formal theory like that of Hansteen does not agree with recent observations. We shall revert to this subject.

35. In Tables III. and IV. certain yearly values of declination, dip, and horizontal force are given for various stations.

INEQUALITIES IN OR CONNECTED WITH TERRESTRIAL MAGNETISM DEPENDING ON THE SUN.

36. As there is a marked likeness between the ways in which the sun dominates over the two great divisions of terrestrial phenomena, meteorology and magnetism, let us endeavour to describe the sun's effect upon the latter by referring to its influence on the former, the chief peculiarities of which are well known to all. We find that the temperature of the air at a given station is subject to a diurnal fluctuation having its minimum value shortly before sunrise and its maximum early in the afternoon. We find likewise that the mean temperature for the day, as well as the amplitude of this diurnal oscillation, depends upon the season of the year, both being greatest about midsummer and least about midwinter. Now, if this were the only manifestation of solar influence upon this particular element, it would be possible to predict the temperature for any hour of any day once the mean temperature, the diurnal variation of temperature, and the modification of these for different seasons of the year had been well ascertained. But this amount of regularity is very far from taking place,—the march of temperature being frequently interrupted, cloaked, perhaps even reversed, by the advent of peculiar weather. Thus we may have very cold weather in midsummer and very warm weather in midwinter, or we may have a very cold afternoon and a very warm early morning, by which means the ordinary conditions of temperature will be completely reversed. In like manner weather interferes even to a greater extent with the diurnal oscillation of the atmospheric pressure, so that, in British latitudes at least, it is only possible to obtain this correctly by means of a long series of observations.

Weather, however, does not consist of a perfectly lawless interference with periodical phenomena, but is subject to laws of its own, some of which we are beginning to discover. Sometimes weather may exalt or depress the diurnal fluctuation of temperature without otherwise affecting its character; but sometimes too the turning-points and the general appearance of this fluctuation are greatly influenced by peculiar weather.

37. Now it is believed that we have something of this kind in those fluctuations depending on the sun to which the elements of terrestrial magnetism are subject. Let us take the declination as the most easily studied of the three magnetic elements, and suppose that we are engaged in considering the traces denoting the fluctuations of declination as derived from a set of self-recording magnetographs in Great Britain. Here we shall at once be able to recognize in an unmistakable manner the diurnal variation depending upon the position of the sun, in virtue of which a freely-suspended magnetic needle reaches the easterly extreme of its range about eight in the morning, and the westerly about two in the afternoon. We shall likewise perceive that the range of this diurnal fluctuation is greatest at midsummer and least at midwinter. In fine, the characteristics of this fluctuation, depending as they do upon the hour of the day and the season of the year, are not very different from those exhibited in the diurnal fluctuation of atmospheric temperature. But, however thoroughly we may have ascertained the mean declination and its diurnal oscillation, as well as the modifications of these depending on the season of the year, we shall nevertheless find it impossible to predict the exact position of a freely-suspended magnet at any moment of a particular day. Here then too we have something which may be called magnetic weather, and which interferes with the regular progress of the systematic fluctuations of the magnet. Magnetic weather has, like its meteorological analogue, a set of laws of its own, some of which we are beginning to find out. Sometimes magnetic weather may exalt or depress the diurnal fluctuation of declination without affecting its character, but it is imagined that at other times the turning points and general appearance of this fluctuation may be greatly influenced by peculiar magnetic weather.

38. There is, however, a kind of magnetic change which, so far as we know at present, is not analogous to anything in meteorology, and introduces an additional element of complexity in any attempt to analyse the fluctuations of terrestrial magnetism. We mean the well-known magnetic disturbances or storms which occur simultaneously in places very widely apart. Under these circumstances it becomes a question how we can best deal in a practical manner with this complicated system of things.

We do not think that with our present knowledge any better system can be adopted than that first introduced by Sir Edward Sabine in his discussion of the results of the colonial magnetic observatories. Suppose that we have hourly magnetic observations at a station, then first of all we should arrange these into monthly groups—each hour by itself. We should then reject as disturbed observations all those which differ by more than a certain amount from their respective normals of the same month and hour,—the normals being the hourly means in each month after the exclusion of all the disturbed observations. This method enables us, by its exclusion of disturbances, to ascertain with much accuracy the true form of the solar-diurnal variation of the magnetic elements at a given place corresponding to every month of every year, provided only that the observations are sufficiently numerous. On the other hand it will probably fail in accurately giving us the variations from day to day of the ranges of these diurnal fluctuations caused by the advent of peculiar magnetic weather,—inasmuch as the records of the extreme effects of such weather will probably be cut off from the undisturbed observations and reckoned among the disturbances.

For instance, it is known that the solar influence on terrestrial magnetism varies from year to year, and it is suspected that there are also short-period fluctuations of solar influence. It would not, however, be a safe proceeding to attempt to estimate numerically this last-mentioned element of fluctuation by taking the successive diurnal ranges of those observations at any station, reckoned as undisturbed, by the above process, and plotting them as successive ordinates of a curve, and then supposing that this curve would give us a true graphical representation of solar changes. It would rather probably represent such changes with the tops and bottoms of the larger fluctuations cut off. But if the undisturbed observations fail in this respect we can hardly be wrong in supposing that there has been eliminated from them, as far as possible, all influence due to magnetic storms, and hence that they will afford us a much better means of estimating small fluctuations, such, for instance, as those due to the moon, than we could have had without their aid.

Finally, with regard to that portion of the observations selected as disturbed, we are probably not certain that every such observation represents a true disturbance, or that the absolute times of occurrence of the various observations selected as disturbed at one station will be the same as those at another. Nevertheless Sir Edward Sabine has shown that at the Kew Observatory certain laws of disturbance deduced from the whole body of observations selected as disturbed are closely reproduced when this selection is made on a narrower basis—ninety-five days of prominent disturbance being alone taken. With these prefatory remarks we shall now proceed to discuss the diurnal inequality of terrestrial magnetism.

39. *Total Diurnal Inequality Defined.*—It will be seen further on that disturbed as well as undisturbed observations are subject to a diurnal variation, but these two variations are different, and the name *diurnal inequality* is generally given to the compound variation which is the joint resultant of the two. *Solar-diurnal variation* is that portion of the compound inequality which refers to undisturbed observations, while that which refers to disturbances has received the name of *disturbance-diurnal variation.* It would appear that in the United Kingdom, and perhaps throughout Europe, the total diurnal inequality is not very greatly different either in character or range from its most important component the solar-diurnal variation, at least so far as the

---

[1] See Walker's *Terrestrial and Cosmical Magnetism*, where the subject is well discussed.

[2] In his lecture to the Royal Geographical Society, March 11, 1878.