THE EARTH'S MAGNETISM

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Reproduced from The Marine Observer, *M.O.* 512, *Vol. XIX, N° 146, October* 1949.
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For a very long time navigators have relied on a magnetic needle to indicate to them the north. Indeed it is difficult to imagine one so foolhardy as to venture out of sight of land without a compass, unless he were sure that the sun or the stars would be visible in his necessity. Claims have been put forward that the Chinese knew, many thousands of years ago, that a natural magnet would point southwards if properly suspended. This, however, has been disputed, and it appears doubtful if the Chinese knew of the directive property of the loadstone any sooner than early in the twelfth century, when it was evidently widely known and used in navigation in western Europe and the Mediterranean. The first arrangement appears to have been that of a piece of loadstone or steel magnetised from a naturally occurring magnet placed in a wooden bowl floating in water. The arrangement must have been exceedingly awkward, and pivoted needles made their appearance about the year 1200 A. D. Two great advances in knowledge were made in the next 300 years ; first that the needle did not point exactly along the geographical meridian (magnetic declination) and second that the declination (1) was not constant over the earth's surface. Exactly when or by whom these discoveries were made is not known, but towards the end of the fifteenth century the manufacturers of portable sundials were marking the difference between the true and magnetic meridians on the magnets they included in their dials. From these and the measurements made by seamen we know that, at that time and in the west of Europe, the compass needle pointed to the east of true north. Columbus has been credited with the discovery that the declination changed from easterly to westerly somewhere about the longitude of the Azores as he voyaged from Europe to the West Indies. This is doubtful, but certainly about the time of his voyages the discovery was made. It aroused an interest even greater than its immediate practical value, because it seemed to promise a means of determining longitude at sea. Although the promise was never fulfilled, it probably encouraged the measurement of declination by voyagers and increased more quickly the knowledge of the earth's magnetic state. Thus by the time (1600) Gilbert, Queen Elizabeth's physician, wrote his great treatise "De Magnete" there was a considerable body of knowledge amassed.

It is curious to reflect that there is only one naturally occurring substance which could have been of use in making a compass, that until the nineteenth century no substitute could conceivably have been manufactured, and from this to speculate what would have been the history of navigation and hence of the world if loadstones had not been available for the use of mankind.

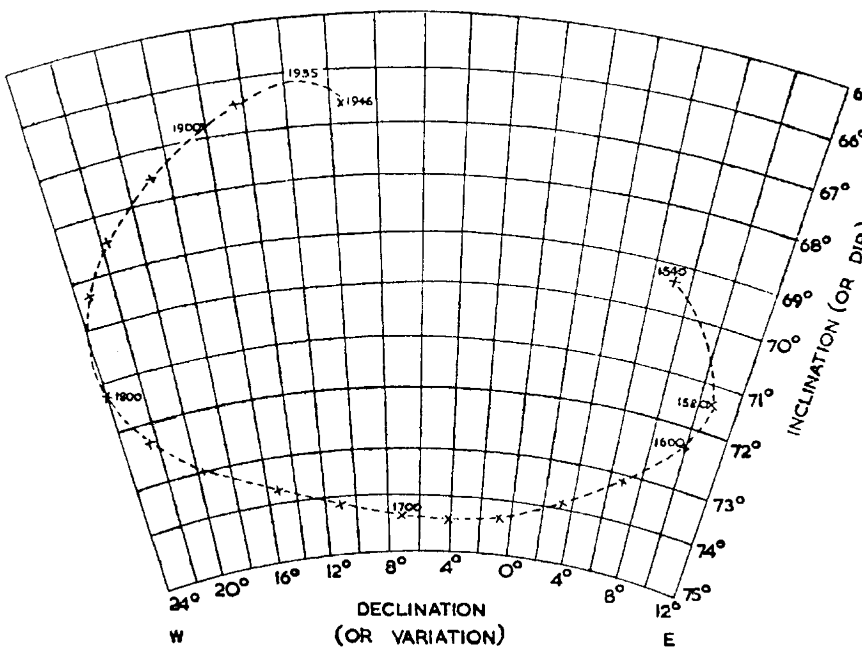
From 1600 to the present time the mass of knowledge of the magnetic effects on the earth has grown steadily. A subject which at once arouses interest from its mystery and offers immediate practical applications will find no lack of investigators. It is easier to summarise existing knowledge from our present standpoint than to pursue a historical sequence.

The earth behaves very much as though it were composed of material rather feebly magnetised, with the axis joining the magnetic poles inclined at an angle to the geographical axis. Models of this sort have been made to demonstrate the magnetic conditions actually found, and a fairly close approximation can be made. If little magnets freely pivoted about the centre are put in various positions on the model's surface they will bring out the main features. Along the "magnetic equator" they will lie horizontally. Nearer the poles they will still lie in the magnetic meridian but will dip more and more ("inclination"), and at the two (magnetic) poles the little magnets will be vertical.

(1) Throughout this article the word *declination* refers to magnetic declination, commonly known to seamen as *variation.*

The general pattern of the isogonal lines (the lines of equal declination) can be fairly closely imitated. It appears reasonable to say the earth shows a magnetic field because it is composed of magnetic material which has somehow or other become magnetised, but there are considerable difficulties in an explanation so simple. So far as is known the surface layers of the earth do not contain anything like sufficient magnetisable material to account for the intensity of magnetic force actually observed. But at quite small depths compared with the radius the interior of the earth is so hot that it is above the temperature at which iron can be magnetised at all. It is true that this critical temperature has not been determined at the tremendous pressures which must exist in the interior of the earth, but, subject to this doubt, it does not seem likely that matter capable of magnetisation could exist far below the surface of the earth. Recently it has been suggested that magnetism is a fundamental property of rotating matter as gravity is of all matter. The strength of the magnetic field should depend on the moment of inertia and the speed of rotation. There are difficulties in devising satisfactory tests of this theory because we know so little of the magnetic condition of other celestial bodies : an obvious difficulty in the case of the earth is the fact that its magnetic field is not symmetrical round the axis of rotation. We can sum up that, although we know for certain that the main part of the cause of the earth's magnetic field resides within the earth, we do not as yet know the cause of the field.

The magnetic field of the earth is constantly changing. There is a secular change going on which is illustrated by the diagram opposite showing the direction of the magnetic force in London since 1580. It is tempting to close the gap and say that the circuit will be completed after about 480 years, but we know no reason why it should. Attempts have been made to infer the former magnetic state of the earth from the orientation of old churches, the magnetic axis of ancient pottery made of magnetic materials and even, going back into geological times, of the direction of magnetisation of beds of intrusive rock. The subject is fascinating, but no great certainty can be claimed for the conclusions reached. The existence of the secular change and the fact that it cannot be predicted entails the constant revision of navigational charts by new magnetic surveys.



Direction of the Magnetic Force in London since A. D. 1580. (*After L. A. Bauer*).

A feature of the secular change is that although it may affect very large areas, for instance a whole continent or ocean, in a regular way in the sense that one can draw smooth "isoporic" lines or lines of equal change, one cannot infer the changes in the

Pacific, say, from those in the Atlantic. If the cause of the secular variation were a mere shifting of the magnetic poles of the earth, the changes of one region would be simply related to those of another region. There is another curious feature. Although we have a fairly accurate knowledge of the declination over several hundred years, it is only during a much shorter length of time that we have sufficiently reliable observations of force from which to compute the magnetic moment of the earth. These suggest that the moment is decreasing by about 1/1,000 every year. It appears hardly possible that such a decrease could have been maintained even during historic times, and going farther back it would imply an impossible degree of magnetisation in, geologically speaking, very recent ages.

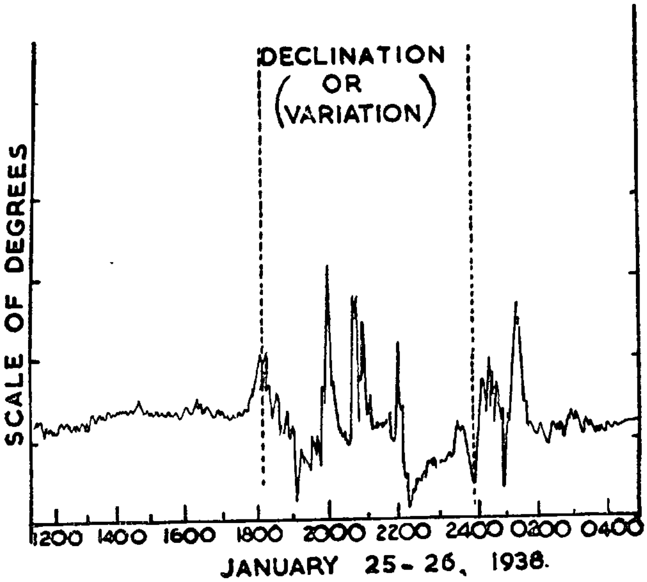
In addition to the secular change there are fairly regular diurnal changes having the period of a solar or lunar day. The solar diurnal change varies with the seasons and amounts to a few tenths of a degree of declination. It is appreciably bigger at times of sunspot maximum than at sunspot minimum. The lunar diurnal change is very much smaller but is interesting because it helps to elucidate some of the problems of the upper atmosphere which are of importance in radio work.

These diurnal changes are caused by the movement of the heavily ionised layers of the earth's atmosphere at very great heights (100 km. and more) under the influence of the thermal or gravitational tides caused by the sun or moon. The more or less regular movements of these ions in girdles round parts of the earth will cause a modification of the permanent field of the earth just as electric currents in the degaussing equipment of a ship would modify the magnetic field round a ship. Although these changes are small in themselves, are of much less immediate practical importance and have only been discovered or investigated for a comparatively short time, much more is known about them and their causes than about the main problem of the earth's magnetism or its secular change.

Superimposed on these fairly regular diurnal changes there is always some degree of irregular "disturbance". When the disturbance is sufficiently great there is said to be a magnetic storm. In general the degree and the frequency of disturbance increase from the Equator to polar regions. Disturbance is a world-wide phenomenon in the sense that a particular period will be quiet or disturbed all over the world, but the degree of disturbance at any moment will vary very considerably from one place to another. There is a close connection between magnetic disturbance, sunspots and auroral activity. All tend to increase and decrease together, but severe magnetic storms have occurred with no sunspots of note and without displays of aurora. Conversely, fine displays of aurora and large sunspots have been observed without magnetic storms. Although the variation of magnetic force in even the greatest storms only amounts to 1 or 2 per cent of the total, it changes very rapidly with wild fluctuations in even a few seconds. By the currents induced it can cause considerable dislocation in communication circuits, and the effect of a "storm" on wireless transmission is very great. The actual change of the declination during a magnetic storm rarely exceeds a degree or so, but as the storm is, in general, not accompanied by any other visible or audible manifestation, the cause of the erratic behaviour of the compass has not always been immediately appreciated. Anomalies have at times been reported on Admiralty charts which other ships, subsequently in the same neighbourhood, have failed to confirm.

The greater part of the changing field superimposed on the permanent earth's field in a magnetic storm can be shown to have its cause external to the earth and is in fact due to a stream of electrified particles ejected from the sun. Storms are liable to recur at intervals of about twenty-seven days, as the same disturbed portion of the sun again faces the earth. The diagram opposite is a reproduction of the magnetogram from the observatory at Eskdalemuir for 25th-26th January, 1938. It shows a photographic recording of the declination. The instrument consists simply of a small magnet on a torsionless suspension. The movement of the magnet is recorded by a spot of light reflected from an attached mirror. Lest an unwary reader is led to expect his ship's compass to behave in this wild manner, attention is directed to the line on the left, which shows the scale of the movement and the fact that ships' compasses are constructed so as to discourage rapid oscillations.

Nothing has been said about applications of our knowledge of earth magnetism to problems other than navigation. The miner shut off from celestial objects in his mole-like activities is entirely dependent on the compass for his direction, but this is perhaps a type of navigation. An increasing use of magnetic instruments and intensive magnetic surveys is made in prospecting for all sorts of minerals, not only those with pronounced magnetic properties. It is, however, the use of radio which has brought a new interest to the problems of the earth's magnetism. The propagation of wireless waves for long distances over the earth's surface depends on the existence of the various heavily ionised layers at great heights in the earth's atmosphere, but it is the state of ionisation under the sun's influence and the movement of these ions which are the cause of the variations in the earth's magnetic field. Thus the phenomena of the two sciences are closely related and the technique of each serves for the advancement of knowledge of the other.



Reproduction of Magnetogram, Eskdalemuir Observatory.

An exceptionally fine display of aurora was visible over the British Isles on 25th and 26th January, 1949, accompanied by a magnetic storm of very great magnitude. There happened to be severe gales immediately following the display and many enquiries were made whether there was any connection between the magnetic storms and the wind storms. We have seen that magnetic disturbances are world-wide, so that any direct connection with the weather of one locality is hardly to be expected and no claims that such a connection has been found will bear investigation. On the other hand the variations of the earth's magnetic force are due to movements of the earth's atmosphere at very great heights under the influence of energy from the sun, so that some connection between weather and earth's magnetism may well exist but probably in a very remote and complex form.

Some of the problems for students of the earth's magnetic state have been indicated in this article. They are of a different nature from those confronting the astronomer Halley, who produced world isogonal charts 250 years ago, but the need for facts is as great as when he wrote : "Here I must take leave to recommend to all masters of ships and all others, lovers of natural truths, that they use their utmost diligence to make, tor procure to be made, observations of these variations in all parts of the world... and that hey please to communicate them...".

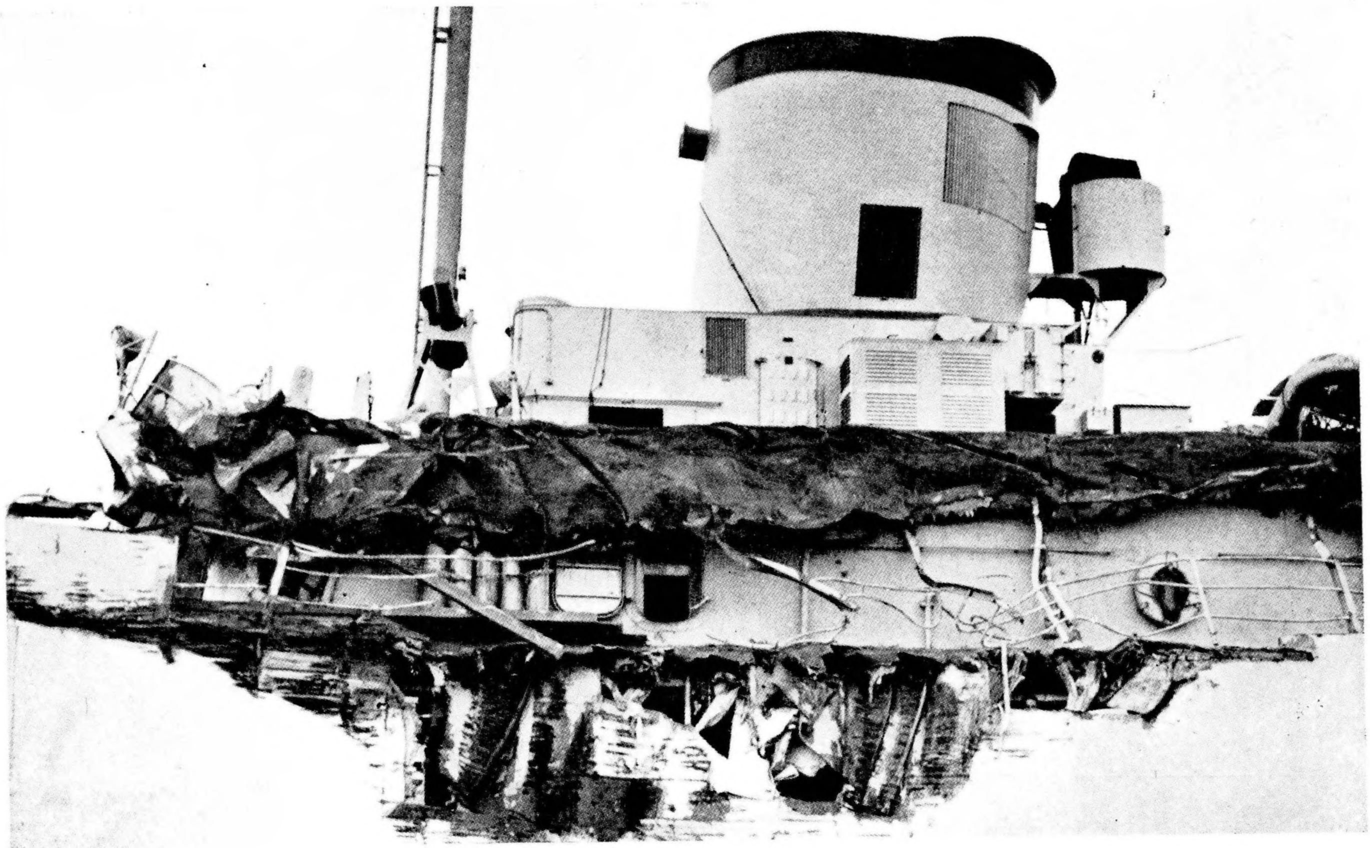


FIG. 1. — Radar cannot always prevent Collisions.

The radar-equipped U. S. S. *Nespelen* after collision with the French motor vessel *Indochinois* in a thick fog in Ambrose Channel.