Terrestrial Magnetism
and
Atmospheric Electricity

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THE CAUSE OF THE EARTH'S MAGNETISM.

By William Sutherland.

In this Journal for June, 1900, it was shown that a sphere of radius a charged with electricity of volume density ρ, and revolving round an axis with angular velocity Ω, would have a magnetic potential at a point r, θ where θ is the colatitude,

$$\int_0^a \frac{4}{3}\pi\,\Omega\cos\theta\,\rho\,R^4\,dR/r^2. \qquad (1)$$

If an equal amount of the opposite sort of electricity were distributed through a sphere of radius $a - da$, its volume density ρ' would be determined by the condition,

$$\rho'(a-da)^3 = \rho a^3;\ \text{hence, } \rho' = \rho(1+3\,da/a), \qquad (2)$$

and its magnetic potential would be,

$$\int_0^{a-da} \frac{4}{3}\pi\,\Omega\cos\theta\,\rho(1+3\,da/a)R^4\,dR/r^2.$$

The magnetic potential of the two distributions together would be

$$\frac{4}{3}\pi\,\Omega\,\frac{\cos\theta}{r^2}\left\{\rho_a\,a^4\,da - \frac{3\,da}{a}\int_0^a \rho\,R^4\,dR\right\}.$$

If ρ is assumed to be not a function of R, this becomes

$$\frac{8}{15}\pi\,\Omega\,\frac{\cos\theta}{r^2}\,\rho\,a^4\,da. \qquad (3)$$

This is the right form of expression for the average magnetic potential round parallels of latitude on the Earth's surface.

J. J. Thomson

As to the two distributions of electricity throughout the substance of the Earth, we have now strong evidence. In Helmholtz's theory of chemical valence of the atoms, each bond between the atoms in a molecule is supposed to consist of two opposite electrons associated with the atoms. For convenience I have proposed (*Phil. Mag.*, Feb., 1902) to denote the positive electron by ♯ and the negative by ♭. With the aid of this notation, Helmholtz's theory can be summarized by writing the chemical formula for *NaCl* in the form *Na*♯♭*Cl*, in which *Na*♯ and ♭*Cl* are the two ions into which *NaCl* is resolvable. I have sought to show (*Phil. Mag.*, Dec., 1902) that all the phenomena of cohesion can be traced to these electric doublets ♯♭ in molecules, for they act as the electric analogues of minute magnets.

Thus, then, every ordinary molecule involves in its own existence that of at least one ♯ and one ♭. The whole Earth, then, contains two opposite enormous charges of electricity. These charges are so nearly equally distributed throughout the Earth that they produce no external electrical effect; they help to hold the atoms together in chemical combination, and they cause the cohesion of the Earth's material with the assistance of gravitation. If the two charges of electricity were distributed through the Earth in absolute equality, their magnetic fields would exactly neutralize one another, and we should have no terrestrial magnetism. It is of importance therefore to inquire what difference in the distributions of the Earth's two charges of electricity would be required to account for its magnetic field. With this end in view the opposite charges were supposed above to be distributed through spheres of radii a and $a—da$. For the average magnetic potential Ψ, in electro-magnetic units, round a parallel of latitude $\pi/2 - \theta$, in 1880 von Bezold has given

$$\Psi = .330\ a \cos\theta.$$

Accordingly we have from (3) with $r = a$ at the surface of the Earth, and with c for the velocity of light

$$\frac{8}{15}\pi\Omega\ \rho\ a\ da = .330\ c. \qquad (4)$$

Now we can determine the order of magnitude of ρ by the following argument. Each molecule of the Earth contains at least one ♭, the amount of whose charge is usually denoted by e. We may take the average molecular weight of the Earth's substance to

be in round numbers 100, so that, if h is the actual mass of an atom of hydrogen, the mass of the average molecule in the Earth is 100 h. But the whole mass of the Earth is $4\pi D a^3/3$, where D is its mean density, so the total number of molecules in the Earth is $4\pi D a^3/300\ h$, and therefore the total charge of negative electricity in the Earth is $4\pi D a^3 e/300\ h$, and its density ρ is $De/100\ h$. But e/h is a fundamental electrical constant having the value $10^{17}/345$, and

$$a = 637 \times 10^6\ cm.,\ \Omega = 2\pi/24 \times 60 \times 60,\ D = 5.7,\ \text{and}\ c = 3 \times 10^{10}.$$

These values in (4) furnish the value 8×10^{-9} for da. But the order of magnitude for the diameter of ordinary molecules is about 10^{-8} *cm*, and (*Phil. Mag.*, Dec., 1902) this seems to be about the distance between ♯ and ♭ in a binary molecule. Thus we have found that if the negative and the positive electricity in the Earth are spread over concentric spheres whose radii differ by only the diameter of a single molecule, they can account for the Earth's primary magnetic field. This separation of the two electricities would produce no external electric effect. It implies a minute tendency of each ♭ of a molecular doublet to turn farther from the center of the Earth than ♯ does.

In my paper of June, 1900, above cited, a cosmical separation of large charges of the two electricities in the interior of the Earth was treated as a possible cause of its magnetism. Now I would propose that an inequality in the distribution of its atomic charges, such as has just been considered, is a much more probable cause. We know that the Earth does contain two enormous opposite charges of electricity, which are almost certainly in rotation with it. It remains now only to prove that there must be such an inequality in the distributions of the two charges as we have briefly investigated, in order to demonstrate that the atomic electric charges are the true source of the Earth's magnetism. Helmholtz suggested that to account for the contact difference of electric potential in metals, we must suppose atoms to exert different attractions on the two sorts of electron. Many physicists see in the cathode rays evidence that the metals attract negative electricity less than positive. J. J. Thomson has pointed out (*Phil. Mag.*, [5] xxxvii, p. 358) that if there is this difference of attraction for the two electricities in the atom, then a large rotating body should generate a magnetic field. Kelvin and other physicists have suggested that magnetism may be a property of rotating masses,

which becomes measurable only when the masses are large enough. From our equation (3) we can estimate what ought to be the magnetic field of any heavenly body of which we know the radius a, the angular velocity of rotation Ω, and also the density D, with which to estimate the electric density ρ as we have done above. Until we know more, it will be simplest to assume either that da is the same for all heavenly bodies, or is proportional to their masses.

On the present theory magnetism must be a property of all rotating bodies. It is the comparatively minute outstanding difference between the two opposite magnetic fields generated by the opposite electricities associated with matter. In this aspect it reminds one of surface-tension, which reveals the play of molecular forces that escape ordinary observation.

With the aid of equation (3) it is possible to show that the effects of the Sun's magnetic field on the Earth are beyond our existing means of detection. The Sun's effect on terrestrial magnetism must be indirect, as is the prevailing opinion. Concerning the Sun's magnetism, special importance attaches to Bigelow's location of the solar magnetic poles by means of the polar rays of the corona shown in eclipse photographs and drawings. The solar magnetic poles, like the terrestrial, do not lie in the axis of rotation, nor do they lie on a diameter. The repetition of the magnetic asymmetry of the Earth in the solar magnetic field is an important fact in planetary magnetism.

To carry the present theory of stellar magnetism farther, the main desiderata are (1) a demonstration of the difference in the attraction of matter for the two sorts of electricity, and (2) determination of the law of attraction between matter and electricity, to ascertain whether it is such as to cause negative electrons in molecules to take up a position which on the average is farther from the center of the Earth than that taken by positive electrons.

Melbourne, June, 1903.