A THEORY OF THE PERMANENT MAGNETIC FIELDS OF THE SUN AND EARTH: A CORRECTION

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Abstract

Calculations by Page applied to the problem of the origin of the magnetic fields of the sun and earth show that earth currents arising from internal electric or gravitational fields crossed with a self-generated magnetic field tend to magnetize the earth rather than demagnetize it as was originally assumed. By attributing the observed field to electric and magnetic effects alone, ion free paths of only 10^{-7} cm are required whereas the original current systems which were attributed to an inhomogeneous magnetic field indicated that free path lengths of 3×10^{-6} cm were necessary. The qualitative features of the original theory are unchanged.

In a letter to the writer, Professor Leigh Page kindly pointed out an error that entered the calculations made in the author's recent paper on "A Theory of the Permanent Magnetic Field of the Sun and Earth."[1]

A re-examination of the calculations in the light of his criticism showed that in the transition from Eq. (8) of the original paper to Eq. (9), a constant term that should have been included in the expression for the ion drift was neglected. Actually, in electric or gravitational fields crossed with a magnetic field, a constant drift is imposed on the ions which is independent of the angular distribution of the ion paths in a plane perpendicular to the impressed magnetic field. This constant drift is of opposite sign and larger than the drift originally computed. The corrected expressions lead to a more satisfactory form of the theory than the original one.

Professor Page in a recent paper[2] has carefully considered the problem of drift currents produced by crossed electric and magnetic fields and has calculated the mean ion displacement between collisions for all possible values of the free path. The second term of Professor Page's Eq. (8), for the case of short free paths, corresponds (after division by the mean free time) to the third term of the writer's Eq. (9). The second term of Page's Eq. (8) for the case of short free path reduces to

$$\bar{x} = \frac{e^2 H E s^3}{cm^2 V^3}\left[\frac{1}{6}+\sin^2\theta\left\{\frac{-1}{2\gamma}\sin\phi\cos\phi+\frac{1}{6}\cos^2\phi-\frac{1}{2}\sin^2\phi\right\}\right] \qquad (1)$$

where $\gamma = eHs/cmV$. In the two dimensional case considered by the writer the mean value of the above expression is zero but if it is averaged over all three dimensions the mean drift velocity is given by

$$V_x = \frac{e^2 H E s^2}{18 cm^2 V^2} \qquad (2)$$

[1] Gunn, Phys. Rev. **34**, 335 (1929).

[2] Page, Phys. Rev. **34**, 763 (1929).

and the current density expressed in the units employed by the writer is

$$i_x = \frac{Ne^3\lambda^2 H_z E_y}{54mkT}.$$

(3)

The sign of this quantity is opposite to that originally obtained and indicates that inside the sun and earth circular ion currents are set up due to crossed electric and magnetic fields which tend to magnetize the body rather than demagnetize it as was originally supposed.

It therefore becomes necessary to consider a slight revision of the original theory and the emphasis must now be placed on magnetizing currents which arise from crossed electric and magnetic fields rather than magnetizing currents arising from an inhomogeneous magnetic field even though this current sheet is in the correct direction to produce the observed field. The original calculations showed the earth possessed an internal electric field of 0.3 e.m.u./cm which was always radially outward and which arose from the gravitational separation of the ions within the earth. The mean westward current density necessary to account for the earth's magnetic field is 4×10^{-11} abamps/cm^2 and the mean free path of the ions necessary to give this observed current density can be calculated by aid of Eq. (3). Taking the mean internal value of $H=0.5$ gauss, $N=10^{23}$ ions/cm^3 and the mean internal temperature as 5000°C, the necessary free path turns out to be 2×10^{-7} cm. This is far more satisfactory than the requirement of the original theory that the free path approximate 3×10^{-6} cm. Such a value was very difficult to account for and constituted perhaps the major objection to the original theory. A calculation shows that ion currents due to the inhomogeneity of the earth's magnetic field or to crossed gravitational and magnetic fields are negligible for free paths of the magnitude required by the present considerations. A mean free path for the ions of 10^{-7} cm seems to be readily allowable inside the earth and this value lends support to the modified position that the primary current system of the earth results from the ion motions imposed by the internal gravitational-electric field crossed with a self produced magnetic field in the regenerative manner described previously. This view is complicated by the fact that the resulting current density is a linear function of the resulting field and it is not yet clear just what limits the field to its observed steady value. Many things have been left out of the theory which might account for the field building up to a steady state and some of these factors are now being studied. While the present view is able to account quantitatively for the observed field in a very simple manner it is perhaps well to point out that many features of ordinary electrical conduction theory do not agree with experiment and we have no assurance that the ions in the hot interior of the earth behave in any simple manner. Until many of the present difficulties of simple conduction theory are cleared away, the original form of the theory should, perhaps not be completely discarded.