PHYSICAL REVIEW LETTERS

VOLUME 6 JANUARY 15, 1961 NUMBER 2

INTERPLANETARY MAGNETIC FIELD AND THE AURORAL ZONES*

J. W. Dungey†

Ionosphere Research Laboratory, The Pennsylvania State University, University Park, Pennsylvania

(Received November 10, 1960; revised manuscript received December 22, 1960)

The discovery[1] of a regular interplanetary magnetic field by Pioneer V has reawakened interest in Hoyle's[2] suggestion that the primary auroral particles are accelerated at neutral points in the combination of an interplanetary field and the geomagnetic field. Hoyle pointed out that the latitude of the aurora would depend on the distance of the neutral points from the earth and hence on the interplanetary field strength in the observed sense. The estimated particle energy was also reasonable. Dungey[3] discusses the accelerating mechanism. Here a qualitative model of the whole field is outlined and is found to be confirmed by the observed S_D current system.

Consider a model with interplanetary plasma moving relative to the earth, this "wind" lying approximately in the ecliptic plane, and an interplanetary field pointing roughly southward. The problem with no interplanetary magnetic field has been studied by several authors,[4] but the inclusion of this field alters the problem radically. The basic and awkward problem is that of the flow of plasma round the earth. This has not been solved but will be sketched using the physical picture of hydromagnetics. The flow in a plane containing the neutral points is shown in Fig. 1. The flow near the neutral points is controlled by the strong current density existing there (3). The reverse flow between the neutral points is important; it has to flow round the earth, but does so in a normal aerodynamic way. A steady laminar flow will be assumed here for simplicity, but it should be noted that large variations of the field were detected by Pioneer I.[5]

Denoting the local wind velocity by $\vec{u}$, the electric field $\vec{E}$ is approximately $-\vec{u}\times\vec{H}/c$ everywhere outside the ionosphere except near the neutral points. In a steady state $\vec{E}$ has a potential, which is constant on a line of force, with the same exceptions. Far from the earth $\vec{E}$ points out of the paper and the direction is still much the same near the neutral points and in the equatorial part of the region of reverse flow. In order to deduce the ionospheric currents, the topology of the magnetic field must be considered.

In Fig. 1 there will be two lines (not in the plane shown) connecting the neutral points and together forming an approximately circular closed curve C near the equatorial plane. The lines from one neutral point will cover a surface, topologically similar to half a cylinder, extend-

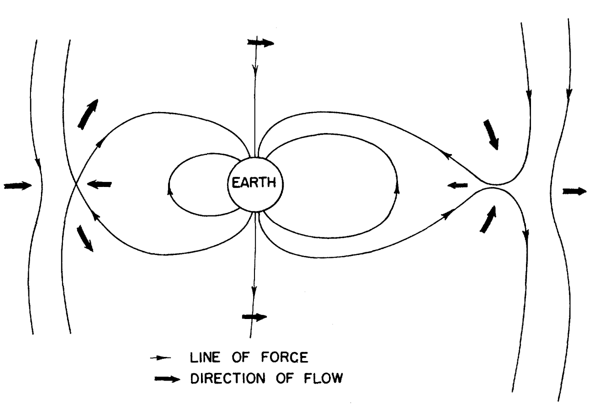

FIG. 1. Interplanetary plasma flow in a plane containing neutral points.

ing from C to infinity to the south and a surface like half a doughnut bounded by C and intersecting the earth's surface in a closed curve A in the northern hemisphere. The lines from the other neutral point complete the cylinder and doughnut and each neutral point has two lines on the other's surfaces. The cylinder and doughnut separate regions where lines of force have both, one, or no feet on the ground, the other ends going to infinity.

The plane of Fig. 1 is at constant potential by symmetry. Consider lines of force leaving the earth in a circle of longitude perpendicular to Fig. 1. The electric field fed in near the pole points out of the paper. Lines outside the curve A (that is, at lower latitude), however, pass through the equatorial plane and $\vec{E}$ here is out of the paper; following the potential up lines of force then gives a reversal of $\vec{E}$ at the curve A, because the lines from the equatorial plane have turned through more than 90°. Consequently the equipotentials in the ionosphere are as shown in Fig. 2. These equipotentials resemble the S_D current lines and the explanation is that Hall conductivity dominates in the ionosphere. Study of the conductivities σ_0, σ_1, and σ_2 in the ionosphere shows that the electric field will extend with only slight diminution down to the E layer, so that the integrated conductivity is appropriate and the current density is nearly perpendicular to $\vec{E}$. The phase of the current may be obtained by taking the direction of $\vec{j}\times\vec{H}$ at the pole to be opposite to that of $\vec{u}\times\vec{H}$ far out and then a wind

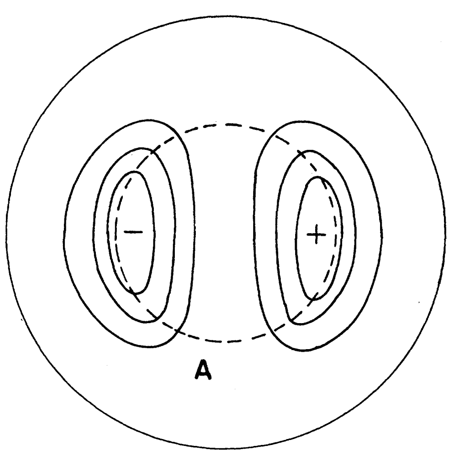

FIG. 2. Equipotentials in northern hemisphere for plasma winds of Fig. 1.

from the sun fits the observations.

The fit with observed S_D suggests the truth of the model. S_D must involve currents in the ionosphere driven from outside and the sudden reversal at the auroral zone seems to require neutral points. If the interplanetary field is northward the topology is quite different, the surface of lines of force enclosing the earth but not meeting it. It is therefore concluded that there is an approximately southward field.

One consequence of the flow in Fig. 1 is a mixing of the interplanetary plasma into the outer atmosphere, which will upset the equilibrium under gravity which would exist in the absence of such a flow. The whistler data suggest that plasma is being lost far out.[6]

The connection between the neutral points and auroras is obvious in this model, but it remains to study the motion of individual particles and the effect of turbulence. The outer Van Allen belt also remains to be discussed; the return flow in Fig. 1 must not upset its symmetry about the geomagnetic axis. The model predicts an asymmetry for auroras: for a wind from the sun there should be proton auroras before midnight and electron auroras after midnight. Recent results[7] from IGY data are of great interest in connection with the model presented here and promise substantial advances in our understanding of the subject.

---

*The research reported in this work has been sponsored by the Geophysics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command, and, in part, by the National Science Foundation.

†Present address: Atomic Weapons Research Establishment, Aldermaston, England.

[1]P. J. Coleman, Jr., L. Davis, and C. P. Sonnett, Phys. Rev. Letters 5, 43 (1960).

[2]F. Hoyle, Recent Researches in Solar Physics (Cambridge University Press, New York, 1958), Sec. 27.

[3]J. W. Dungey, Cosmic Electrodynamics (Cambridge University Press, New York, 1958), Secs. 6.4 and 8.4.

[4]D. B. Beard, J. Geophys. Research 65, 3559 (1960).

[5]C. P. Sonett, Phys. Rev. Letters 5, 47 (1960); C. P. Sonett, E. J. Smith, and A. R. Smith, Proceedings of the First International Space Sciences Symposium, edited by H. K. Kallman Bijl (North Holland Publishing Company, Amsterdam, 1960), p. 921.

[6]R. L. Smith and R. A. Helliwell, J. Geophys. Research 65, 2583 (1960).

[7]T. N. Davis, J. Geophys. Research 65, 3497 (1960).