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SEVERAL COMMENTS CONCERNING A RECENTLY PROPOSED MAGNETOSPHERIC MODEL*

by

L. A. Frank

Department of Physics and Astronomy
THE UNIVERSITY OF IOWA
Iowa City, Iowa

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Department of Physics and Astronomy
The University of Iowa
Iowa City, Iowa 52240

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Errata

Several Comments Concerning a Recently Proposed Magnetospheric Model

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L. A. Frank

The contents of the section beginning on page 5 have been modified as follows.

Relationship of the polar cusp and the auroral oval and electrojet.

The intersection of the polar cusp with the earth's ionosphere is located at magnetic latitudes near or at the auroral electrojet and the auroral oval (for reviews of ground-based observations of these phenomena see Hultqvist [1969] and Feldstein [1969]). In fact we tentatively interpret the relationship as (1) the electromotive force driving the auroral electrojet is provided by the convection of field lines in the polar cusp, although the exact nature of this energy transfer is not yet known, and (2) the polar cusp intersects the ionosphere in a zone immediately adjacent to and lying poleward of the auroral oval. The polar cusp at intermediate altitudes between the magnetosheath and the ionosphere comprises two field-aligned sheets, an electron sheet lying equatorward of the proton sheet. The compositions of these two sheets are not mutually exclusive. In other words, measurable intensities of protons and electrons are observed in both sheets with bands of enhanced proton and electron intensities delineating the proton and electron 'sheets', respectively. We have currently completed an examination of a larger series of observations than were reported previously by Frank [1970] for the latitudinal widths of these sheets as projected onto the ionosphere. Typical widths of each sheet were $\sim$ 100 kilometers and were approximately equal for a given polar cusp crossing. Apparent sheet thicknesses varied over a range $\sim$ 10 to 200 km. These two sheets intersect the sunlit ionosphere in a zone of $\sim 1°$ to $3°$ in latitudinal width adjacent to and poleward of the visual auroral oval; the observational evidences supporting this claim will be presented in a forthcoming report. Hence the polar cap region of Figure 1 intersects the ionosphere at latitudes greater than $\sim 1°$ to $3°$ poleward of the high-latitude boundary of the visual auroral oval.

Recent observations of the plasmas in the distant polar magnetosphere have been interpreted in terms of a new model of the magnetosphere [Frank, 1970]. These measurements demonstrated that magnetosheath plasma gains direct access to the magnetosphere through two wide bands along the sunlit magnetopause at high latitudes, one each in the Northern and Southern hemispheres. The region in the sunlit magnetosphere to which the magnetosheath plasma has direct access is designated as the 'polar cusp'. The spatial relationship of the polar cusp and the plasma sheet in the magnetotail is shown in Figure 1 [Frank, 1970]. Principal features of the proposed magnetospheric model are:

- plasma sheet protons gain direct access to the magnetosphere through the dayside polar cusps,
- all magnetic field lines, B' and b', threading the distant plasma sheet beyond 10 or 12 R_E were convected from the dayside polar cusps, i.e., originally field lines B and b,
- magnetic merging of geomagnetic field lines with magnetosheath field lines occurs along the polar cusps,
- these field lines are reconnected, B" and b", along the neutral sheet within the magnetotail and are convected toward the earth,

- field lines B" and b" are subsequently convected into the dayside outer radiation zone,

- magnetic field lines in the polar cap region, C and D, do not merge in the magnetotail, are not populated with auroral particles and do not pass through the plasma sheet,

- at the dayside magnetopause magnetic field lines of the polar cap region (C and D) and of the outer zone merge with the field lines in the magnetosheath to form polar-cusp field lines (B and b),

- field lines of the type B' and b' which do not merge at the neutral sheet become polar cap field lines C and D and provide the return of field lines which were lost to the polar cap region at the dayside polar cusps,

- field lines in the polar cap region (C and D) are connected to the field lines of the interplanetary medium, and

- this magnetospheric model has three distinct convection patterns, inner magnetospheric and Southern and Northern polar cap, which are coupled via magnetic merging along the dayside polar cusps and in the neutral sheet in the magnetotail.

Although the details of this model differ in many ways from previously proposed models of magnetospheric convection and magnetic merging, it is clear that important guidelines from models such as those proposed by Alfvén [1950], Axford and Hines [1961], Dungey [1961] and Piddington [1962] have been incorporated into the presently proposed magnetospheric model [see the recent review by Axford, 1969].

Our present purpose is to briefly comment on several of the properties and implications of this magnetospheric model. A more thorough analysis of these comments will be presented in future reports.

Energy source for magnetospheric and auroral phenomena.

Magnetic merging at the sunlit magnetopause is the mechanism by which the energy associated with magnetosheath plasma is allowed into the magnetosphere; the magnetosheath protons are the dominant contributor to the power transferred from the magnetosheath to the magnetosphere through the dayside polar cusps. A current estimate for the magnitude of this energy source based upon *in situ* observations of the polar cusp plasmas is $\sim 3 \times 10^{18}$ ergs$(\mathrm{sec})^{-1}$ during periods of relative magnetic quiescence. This is a sufficient energy source to account for auroral substorms [cf. Parker, 1962; Sharp and Johnson, 1968]. Magnetic merging appears to be a continually active process at the sunlit magnetosphere as evidenced observationally by the persistent presence of the polar cusp. The polar cusp is spatially continued into the magnetotail as the plasma sheet; polar cusp plasma is convected directly into the plasma sheet. A rough estimate of the magnetic flux convected into the plasma sheet from the polar cusps (or rate of magnetic merging) can be obtained from observations of the bulk velocity (V_C of Figure 1) of the plasma within the polar cusp and its dimensions; this estimate yields $\sim 0.5\ \gamma\ R_E^{\ 2}\ (\mathrm{sec})^{-1}$ during periods of relative magnetic quiescence.

Length of the magnetotail.

An estimate of the length of the magnetic tail follows closely the spirit of a similar calculation given by Dungey [1965]. The length of the tail is determined by its 'age', or the time required for a polar cap field line (C or D) to move from local night to the sunlit magnetopause (cf. Figure 1), and the velocity of the solar wind. The time required for the remainder of the path, i.e., motion along polar cusp to plasma sheet and return to the polar cap region is neglected here. Note also that the field lines over the polar cap region move in the solar direction for the present model, whereas in Dungey's model these field lines move the antisolar direction. Dungey estimated the velocity of the 'foot' of a polar cap field line from DS patterns. Since our polar cap convection is in qualitative disagreement with the sense of the DS current pattern we invoke the measured length of the magnetic tail [Ness et al, 1967], $\geqslant 10^3\ R_E$, to estimate the magnitude of the polar cap electric field due to convection. The result of this estimate is $\leqslant$ ten millivolts (meter)$^{-1}$. In the present model it is possible to have one of the tails (say, the magnetic tail associated with the Northern polar cap) longer than the magnetic tail from the Southern polar cap region if the merging rates at the sunlit magnetopause for the two regions differed for a substantial period of time, $\geqslant$ 1 day. A magnetotail geometry such as this would provide a delay for the arrival of solar protons over the earth's Northern polar cap relative to the arrival of solar protons over the Southern polar cap even if the angular distributions of the solar proton intensities in the interplanetary medium were isotropic.

<u>Relationship of the polar cusp and the auroral oval and electrojet</u>.

The intersection of the polar cusp with the earth's ionosphere is located at magnetic latitudes near or at the auroral electrojet and the auroral oval (for reviews of ground-based observations of these phenomena, see Hultqvist [1969] and Feldstein [1969]). In fact we tentatively interpret the relationship as (1) the auroral electrojet is directly driven by the convection of field lines in the polar cusp and (2) the precipitation of charged particles, specifically electrons, from the polar cusp into the upper atmosphere is responsible for the visual auroral oval.

In other words, the electromotive force driving the auroral electrojet is derived from the magnetosheath plasma via the polar cusp, the exact nature of this energy transfer is not yet known. The polar cusp at intermediate altitudes between the magnetosheath and the ionosphere is comprised of two field-aligned sheets, an electron sheet lying equatorward of the proton sheet. We have currently completed an examination of a larger series of observations than were reported recently by Frank [1970] for the latitudinal widths of these sheets as projected onto the ionosphere. Typical widths of each sheet were $\sim$ 100 kilometers and were approximately equal for a given polar cusp crossing. Apparent sheet thicknesses varied over a range $\sim$ 10 to 200 km. In the sunlit ionosphere we associate the electron sheet with the visual auroral oval. Hence the proton sheet intersects the ionosphere poleward and adjacent to the visual auroral oval. The polar cap region of Figure 1 intersects the ionosphere at latitudes greater than 1° or 2° above those of the visual auroral oval position.

Polar and magnetospheric substorms.

It is of interest to outline several of the qualitative effects of increased magnetic merging rates at the polar cusps in this magnetospheric model, which in turn would result in increased plasma flow into the magnetosphere through the dayside polar cusps. These results can be compared favorably with ground-based and *in situ* observations as discussed in the text describing magnetospheric and polar substorms by Akasofu [1968]. With reference to Figure 1, consider the effects of an increased rate of magnetic merging for a period $\sim$ 10 minutes (arbitrarily chosen). Since the auroral electrojet is directly coupled to the polar cusp, during midday it will be immediately activated coincident with changes in the form and intensities of the auroral oval. If the auroral oval moves equatorward during local day then, since the plasma associated with increased merging rates has not yet penetrated the magnetotail and the number of polar cap field lines is less than or equal to those in this region before the increased merging rates, the nighttime auroral oval must move poleward without a large intensity variation. Further, with increased merging at the sunlit magnetopause the inner magnetospheric convection pattern must increase in intensity and drive the original plasma sheet toward the earth resulting in an intensification of the equatorward auroral arc and the injection of substorm plasma into the inner magnetosphere. After periods $\sim$ 15 to 30 minutes following the onset of increased magnetic merging the new plasma and its associated polar cusp magnetic field lines have been convected from polar cusp to the magnetotail. The arrival of the new plasma and magnetic field lines in the magnetotail accounts for the mid-substorm expansion of the plasma sheet. It is quite possible that this new plasma sheet is imbedded in the remains of the old sheet. The magnetosphere must subsequently return to equilibrium. Closed field lines (B" and b") are created by reconnection at the neutral sheet at a greater rate relative to the equilibrium state resulting in a larger number of closed field lines in the near-earth magnetotail during this recovery process. This recovery phase provides both equatorward and poleward motions of nighttime auroral phenomena and a poleward motion of the energetic electron 'trapping boundary' at low altitudes. With regards to symmetry of these phenomena about the noon-midnight meridional plane, we mention here that the entrance of magnetosheath plasma into the magnetosphere is controlled by magnetic merging. If the rate of magnetic merging is greatest, say, at $\sim$ 10:00 local time (i.e., corresponding to the direction of the average interplanetary field then a dawn-evening asymmetry of polar cusp related phenomena can be expected.

Finally it is noted that, although the above comments are quite general, these examples do provide a 'working guide' as to the various applications of this proposed magnetospheric model.

Acknowledgments

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References

Akasofu, S.-I., Polar and magnetospheric substorms, D. Reidel Publishing Company, Dordrecht-Holland, 1968.

Alfvén, H., Cosmical Electrodynamics, Oxford University Press, New York, 1950.

Axford, W. I., Magnetospheric convection, Rev. of Geophys., 7, 421-459, 1969.

Axford, W. I., and C. O. Hines, A unifying theory of high-latitude geophysical phenomena and geomagnetic storms, Can. J. Phys., 39, 1433-1464, 1961.

Dungey, J. W., Interplanetary magnetic field and the auroral zones, Phys. Rev. Letters, 6, 47-48, 1961.

Dungey, J. W., The length of the magnetospheric tail, J. Geophys. Res., 70, 1753, 1965.

Feldstein, Y. I., Polar auroras, polar substorms, and their relationships with the dynamics of the magnetosphere, Rev. of Geophys., 7, 179-218, 1969.

Frank, L. A., Plasma in the earth's polar magnetosphere, J. Geophys. Res. (submitted for publication), 1970.

Hultqvist, B., Auroras and polar substorms: observations and theory, Rev. of Geophys., 7, 129-177, 1969.

Ness, N. F., C. S. Scearce and S. C. Cantarano, Probable observations of the geomagnetic tail at 10^3 earth radii by Pioneer 7, J. Geophys. Res., 72, 3769-3776, 1967.

Parker, E. N., Dynamics of the geomagnetic storm, Space Sci. Rev., 1, 62-99, 1962.

Piddington, J. H., A hydromagnetic theory of geomagnetic storms, Geophys. J., 7, 183-193, 1962.

Sharp, R. D., and R. G. Johnson, Satellite measurements of auroral particle precipitation, Earth's Particles and Fields, ed. by B. M. McCormac, pp. 113-125, Reinhold, New York, 1968.

Figure Caption

Figure 1. Diagram for the spatial relationship of the polar cusp and plasma sheet and the interpretation of these plasma regimes in terms of the topology of the distant geomagnetic field. (The principal elements of this magnetospheric model are summarized in the text.)

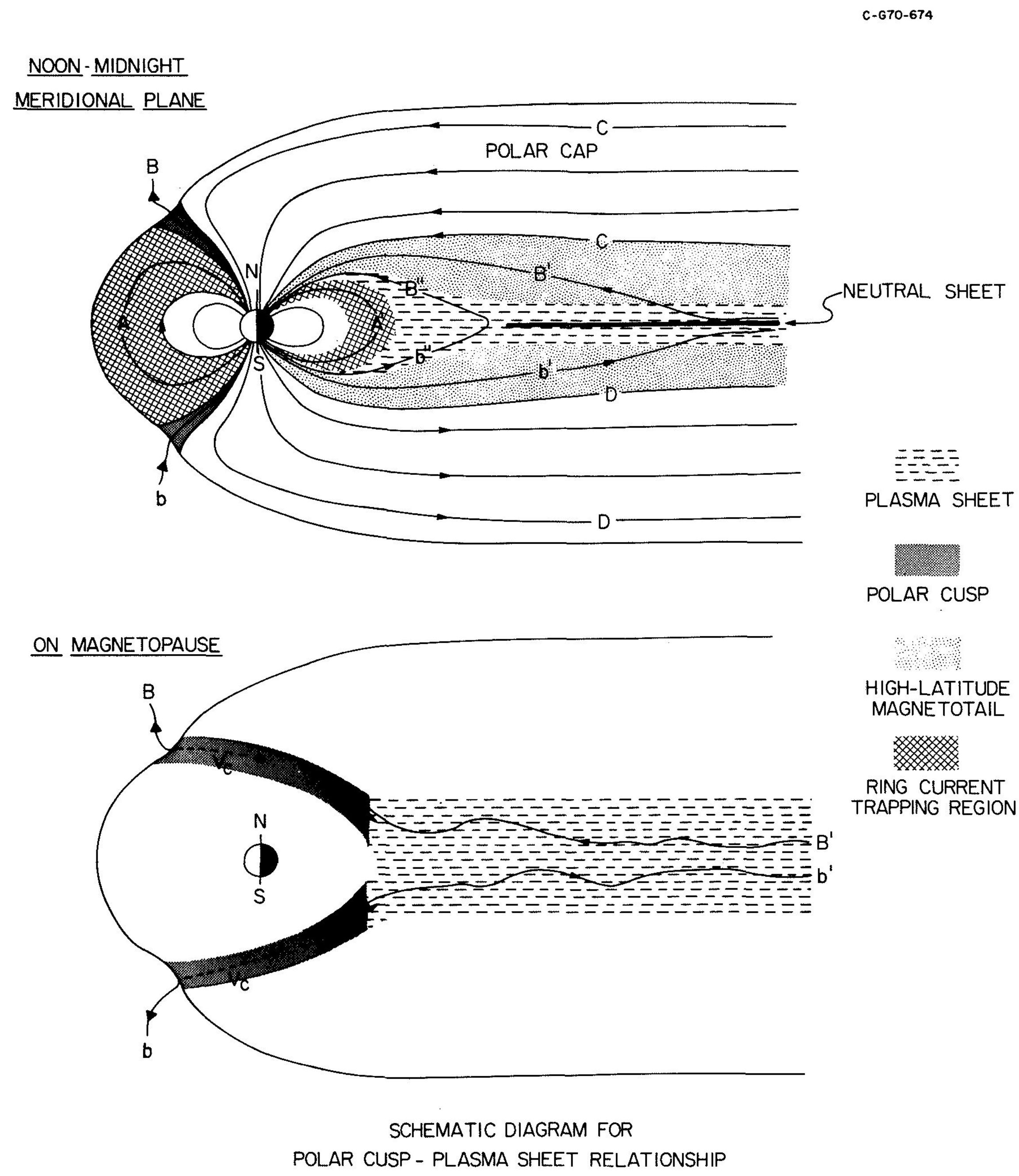
C-G70-674
NOON-MIDNIGHT
MERIDIONAL PLANE
POLAR CAP
C
B
N
S
B'
B''
b''
b'
D
b
NEUTRAL SHEET
PLASMA SHEET
POLAR CUSP
HIGH-LATITUDE
MAGNETOTAIL
RING CURRENT
TRAPPING REGION
ON MAGNETOPAUSE
B'
b'
SCHEMATIC DIAGRAM FOR
POLAR CUSP - PLASMA SHEET RELATIONSHIP

Figure 1.