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MAGNETOPAUSE STRUCTURE AND DYNAMICS OF THE MAGNETOSPHERE

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The final report on Grant NGR 30-001-011 to Dartmouth College consists of the following papers:

1. "Magnetopause Structure and Attitude from Explorer 12 Observations", B. Sonnerup and L. J. Cahill, Jr., J. Geophys. Res. 72, 171-183, 1967.

2. "Large-Amplitude Whistler Waves in a Hot Collision-Free Plasma", B. Sonnerup and S. Y. Su, The Physics of Fluids, 10, 462-464, 1967.

3. "Explorer 12 Observations of the Magnetopause Current Layer", B. Sonnerup and L. J. Cahill, J. Geophys. Res. 73, 1757-1770, 1968.

4. "First-Order Orbit Theory of the Rotational Discontinuity", S. Y. Su and B. Sonnerup, The Physics of Fluids, 11, 851-857, 1968.

5. "Motion of Charged Particles in Growing or Decaying Circularly Polarized Waves", B. Sonnerup, The Physics of Fluids, 11, 682-683, 1968.

6. "Nature of the Rotational Discontinuity", G.A. Gerdin and B. Sonnerup, The Physics of Fluids, 12, 145-148, 1969.

7. "Acceleration of Particles Reflected at a Shock Wave", J. Geophys. Res., 74, 1301-1304, 1969.

8. "Resonant Vibration of the Magnetosphere Observed from Explorer 26", B. Sonnerup, L. J. Cahill and L. R. Davis, J. Geophys. Res., 74, 2276-2288, 1969.

9. "Magnetic-Field Re-connexion in a Highly Conducting Incompressible Fluid", B. Sonnerup, Journal of Plasma Physics, 4, 161-174, 1970.

10. "On the Equilibrium of the Magnetopause Current Layer", S. Y. Su and B. Sonnerup, J. Geophys. Res., 76, 5181, 1971.

11. "Magnetopause Structure during the Magnetic Storm of Sept. 24, 1961", B. Sonnerup, J. Geophys. Res., 76, 6717, 1971.

Previously NASA has been supplied with 25 reprints of each of the first nine of these papers. Five reprints of papers #10 and #11 are enclosed.

Abstracts of the eleven papers are attached.

Magnetopause Structure and Attitude from Explorer 12 Observations

It is shown how satellite magnetometer data at a magnetopause penetration can be used to determine the vector normal to the magnetopause current layer and the magnetic-field component along this normal. According to theory such a component is a measure of the amount of field reconnection at magnetopause. Results from 22 Explorer 12 boundary penetrations are presented indicating normal-field components of less than 5 γ in two-thirds of the cases. Measured field variations within the current layer are presented to demonstrate the existence of two fundamentally different types of boundary structure, the rotational and the tangential discontinuity. The former of these permits a nonzero normal field component, whereas the latter does not. The rotational discontinuity seems to occur predominantly during magnetic storms and two of these cases, involving substantial normal-field components, provide compelling evidence that field reconnection takes place during the storm main phase. Finally, the calculated normal vector is compared with the normal to the surface of the Mead-Beard magnetosphere model.

Large Amplitude Whistler Waves in a Hot Collision-Free Plasma

A dispersion relation is derived for large-amplitude circularly polarized plane waves propagating along a uniform magnetic field in a hot collision-free plasma.

Explorer 12 Observations of the Magnetopause Current Layer

The variation in magnetic field magnitude at magnetopause is examined with the objective of separating boundaries of the rotational-discontinuity type from those of the tangential-discontinuity type. The field magnitude should remain constant throughout the current layer in the former case but may vary considerably in the latter. Also, the field component normal to the layer may be nonzero in the former case but not in the latter. It is estimated that approximately one-third of the 91 cases examined may have been of the rotational-discontinuity type. The field component along a theoretical vector normal to the current layer is compared for the two groups. The result indicates that the normal field component, on the average, may be less than 5 γ for the rotational-discontinuity group also. For the tangential discontinuities, a normal vector, calculated from the data under the assumption of a vanishing normal-field component, is compared with a corresponding vector obtained from the Mead-Beard theoretical magnetosphere model. Substantial individual, as well as systematic, deviations are found. The latter are related to the angle between the solar-wind and the earth's dipole axis. Finally, the sense of rotation of the tangential magnetic-field component at magnetopause is examined. For rotational discontinuities, the sense of rotation is found to be opposite above and below the solar-magnetospheric equatorial plane. A tentative explanation of this observation, in terms of the electrical structure of the current layer, is proposed.

First-Order Orbit Theory of the Rotational Discontinuity

A study is made of the propagation properties and internal equilibrium structure of a large-amplitude Alfvén wave which conserves the magnitude of the magnetic-field component tangential to the wave front but changes its direction. The propagation properties are found to be identical with those of small-amplitude sinusoidal waves. The equilibrium wave structure is shown to involve an electric field along the wave normal. The sign and magnitude of this field are related to the rate and sense of rotation of the tangential magnetic field component as well as to the particle distributions. In certain cases the electric field may be sufficiently large to cause nonnegligible variations in particle and magnetic pressures within the wave. Observed polarizations of the magnetopause current layer may be explained by the theory.

Motion of Charged Particles in Growing or Decaying Circularly Polarized Waves

A constant of motion is derived for a charged particle in the magnetic and electric fields of a circularly polarized wave with time-variable amplitude. The wave is assumed to propagate along a uniform external magnetic field.

Nature of Rotational Discontinuity

The behavior of a large-amplitude intermediate magnetohydrodynamic wave in the presence of reflected particles is examined. For reflections off its front side, the wave becomes a spreading expansion wave; for reflections off the back side it steepens to a shock wave, i.e., an entropy increase is produced across the wave.

Acceleration of Particles Reflected at a Shock Front

In a recent paper Asbridge et al. [1968] report convincing evidence for particle reflection and acceleration at the magnetospheric bow shock, obtained from the particle experiments on board a series of Vela satellites. Typically, the energy of these reflected particles, believed to be mainly protons, is observed to be of the order of four to six times that of an average solar-wind proton. It is the purpose of the present paper to demonstrate that particle energization of this magnetude or greater is expected to occur in the reflection process. The responsible agent is the interplanetary electric field, and the acceleration takes place because the particles are displaced in the direction of that field in the reflection process.

Resonant Vibration of the Magnetosphere Observed from Explorer 26

This paper examines in detail a set of large-amplitude pulsations in magnetic-field magnitude and proton fluxes (E>98 kev) observed by Explorer 26 in connection with a bay event during the magnetic storm of April 18, 1965. The peak-to-peak amplitude was about 40 γ and the period about 300 sec. These pulsations were such that the field magnitude was high when the proton fluxes were low and vice versa. They were accompanied by field-direction changes corresponding to an elliptical polarization. The observations are compared with four models involving (1) drifting plasma clumps, (2) ripples traveling in longitude on the surface of a particle belt, (3) a particle belt in periodic radial motion, and (4) a particle population sloshing back and forth along the field lines in the acoustic mode. The last of these models is found to be the most attractive one, and its consequences in terms of periodic modulation of the particle energy are examined. The study also indicates that periodic field-aligned currents accompanied the event.

Magnetic-field Re-connexion in a Highly Conducting Incompressible Fluid

A theoretical model is proposed for the process of re-connexion of frozen-in magnetic-field lines at an X-type null point in the field. The model involves a diffusion region, immediately adjacent to the null point and an outer wave-dominated region. For the latter an exact solution to the magneto-hydrodynamic equations is obtained; for the former an approximate relationship is derived between the field-re-connexion rate, measured by the Alfvén number of the incident flow, and magnetic Reynolds number, based on the width of the diffusion region. The maximum field-re-connexion rate is determined entirely by conditions near the null point and may under suitable conditions become large. A condition for maximum conversion of magnetic energy is derived.

On the Equilibrium of the Magnetopause Current Layer

A numerical study was made of the confinement of a uniform magnetic field by a warm plasma with a net velocity parallel to the confined field. Parker's assumptions of a vanishing electric field and vanishing trapped-particle currents and pressures were adopted. For a given proton temperature equilibriums were found whenever the electron temperature exceeded a certain critical value. This result is in qualitative agreement with an estimate presented by Parker, but it is in direct conflict with Lerche's nonexistence proof. A crucial error in that proof is identified. The properties of the equilibrium solutions are discussed. Finally, the equilibrium confinement with the incident streaming plasma tangential to the magnetopause but perpendicular to the confined field is treated. It is concluded that in the geomagnetic equatorial plane equilibriums of Parker's type are possible on the morning side but not on the afternoon side of the magnetosphere.

Magnetopause Structure during the Magnetic Storm of September 24, 1961

Explorer-12 magnetic-field observations of the magnetopause current layer were made on the inbound pass of September 24, 1961, which occurred during the main phase of a moderately strong magnetic storm. The satellite was located near the subsolar point. The accuracy of the Explorer-12 data reported here has been increased by use of an improved filtering procedure. Five magnetopause penetrations were observed in a time period of about 20 min and for each of these, data were used to calculate the vector normal to the current layer, the magnetic-field component along that vector, and the polarization of the current layer. Normal magnetic-field components significantly different from zero were obtained, and it is suggested that the observations during this pass in general are consistent with the so-called open magnetosphere model. In fact, it appears that the first and last of the boundary penetrations may have occurred on opposite sides of, but very near, the X-type magnetic null line, which is located on the front side of the open magnetosphere model. The direction of the normal magnetic-field component as well as the sense of rotation of the tangential magnetic-field component in the current layer were found to be opposite for these two boundaries.