"Physics of Auroral Phenomena", Proc. XXIII Annual Seminar, Apatity, pp.15-16, 2000

Polar Geophysical Institute

Estimates of the magnetosheath conductivity from the characteristic time of the magnetospheric response to the IMF changes

O. M. Ryzhova *(Petrozavodsk State University, Kola Branch, Apatity)*
Yu. P. Maltsev *(Polar Geophysical Institute, Apatity)*

Abstract. The observed time of the interplanetary magnetic field (IMF) penetration into the magnetosphere τ = 20 min yields the estimate of the effective electric conductivity in the magnetosheath $\sigma = 10^{-7}$ Sm/m. The corresponding magnetic Reynolds number is $R_m = 5$. The effective frequency of electron scattering appears to be $\nu = 2\times10^6$ s^{-1}, that is 11 orders higher than the Coulomb collision frequency and 3 orders higher than the electron gyrofrequency. A possible cause of an extremely low conductivity is instability of the enhanced pressure layer, which arises near the magnetopause when the IMF is directed southward and prevents the IMF from penetrating into the magnetosphere.

1. Introduction

Most of geomagnetic disturbances are the result of the solar wind-magnetosphere interaction which is commonly described by the MHD equations

$$\mathbf{j} = \sigma (\mathbf{E} + [\mathbf{v}\times\mathbf{B}]) , \quad (1)$$

$$\mathrm{curl}\,\mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} , \quad (2)$$

$$\mathrm{rot}\,\mathbf{B} = \mu_o\,\mathbf{j} , \quad (3)$$

$$\mathrm{div}\,\mathbf{B} = 0 , \quad (4)$$

where **j** is the electric current, σ is the plasma conductivity, **E** and **B** are the electric and magnetic fields, **v** is the plasma velocity, μ_o is the magnetic permeability of vacuum. Excluding j and E from (1)-(4) we obtain

$$\frac{\partial \mathbf{B}}{\partial t} - \mathrm{curl}[\mathbf{v}\times\mathbf{B}] = \frac{1}{\mu_o \sigma}\Delta\mathbf{B} \quad (5)$$

When $\sigma \to \infty$ equations (1)-(5) show that the magnetic field is frozen into the plasma. The magnetic field lines can not penetrate from the solar wind to the magnetosphere in this case.

According to observations by *Lui* [1986] and *Sergeev* [1987], about 50% of the IMF y component penetrates into the magnetotail plasma sheet. Measurements of the electric potential difference between the dawn and dusk sides of the polar cap [*Doyle and Burke*, 1983; *Boyle et al.*, 1997] show that 10-15% of the dawn-to-dusk electric field penetrates from the solar wind into the magnetosphere.

Hence one can see that the solar wind conductivity is finite. Since direct measurements of the conductivity are impossible, one has to estimate it from indirect data. *Liperovsky and Pudovkin* [1983] supposed that solar wind electrons are scattered by electrostatic turbulence and obtained $\sigma \approx 10^{-2}$ Sm/m. *Pudovkin and Semenov* [1985] estimated $\sigma \approx 10^{-1}$ Sm/m from the observed thickness of the magnetopause. *Denisenko et al*. [1992] obtained $\sigma \approx 10^{-2}$ Sm/m from the thickness of the bow shock. *Alexeev* [1986] estimated $\sigma \approx 2\times10^{-5}$ Sm/m from the observed thickness of current sheets in the solar wind.

Further we shall find σ from the observed time of penetration of the IMF into the magnetosphere.

2. Estimate of the conductivity

Neglecting the convective term with the solar wind velocity in equation (5) we obtain

$$\frac{\partial \mathbf{B}}{\partial t} = \frac{1}{\mu_o \sigma}\Delta\mathbf{B} \quad (6)$$

Hence it is easy to get

$$\sigma = \frac{\tau}{\mu_o l^2} \quad (7)$$

where τ is the characteristic time of the IMF penetration into the magnetosphere, l is the characteristic size of the magnetosphere. *Bargatze et al*. [1985] examined the delay of the *AL* index relative to changes in the southward IMF and found it to be τ = 20 min. Assuming $l = 10^5$ km we obtain from (7) $\sigma \approx 10^{-7}$ Sm/m.

Instead of conductivity investigators usually utilize the magnetic Reynolds number

$$R_m = \mu_o \sigma V l \quad (8)$$

where V is the undisturbed solar wind velocity. Substitution (7) into (8) yields

$$R_m = \frac{V\tau}{l} \quad (9)$$

Assuming V = 400 km/s, τ = 20 min, $l = 10^5$ km, we have $R_m \approx 5$.

3. Discussion

The electric conductivity of completely ionized plasma is

$$\sigma = \frac{ne^2}{m\nu} \quad (10)$$

where n is the number density of charged particles, e and m are the electron charge and mass, ν is the frequency of electron scattering.

It is interesting to estimate the effective frequency of electron scattering in the magnetosheath. Assuming $\sigma \approx 10^{-7}$ Sm/m, $n = 8$ cm^{-3},we obtain $\nu = 2\times10^6$ s^{-1}.

This frequency is considerably higher than all other characteristic frequencies in the solar wind such as the Coulomb collision frequency (~10^{-5} s^{-1}), Langmuir frequency ($\omega_{oe} \approx 2\times10^5$ s^{-1}), and Larmor frequency ($\omega_{Be} \approx 10^3$ s^{-1}). Thus, electrons are not magnetized in the magnetosheath.

The mechanism of such an intense scattering is not clear. It is impossible that the scattering occurs not at the micro- but at the macrolevel. As it is shown by *Alexeev and Maltsev* [1990], *Rezhenov and Maltsev* [1994], *Maltsev and Rezhenov* [1996], the presence of a southward IMF leads to the formation of a thin enhanced pressure layer (EPL) near the magnetopause. The EPL does prevent the IMF from penetrating into the magnetosphere. However the EPL is unstable. In particular, the interchange instability destroys the EPL. The growth time of the instability makes a few minutes. It is possible that the process of the EPL destruction can be phenomenologically described in terms of the extremely low electric conductivity. In this case the low effective conductivity exists in the close vicinity of the magnetosphere only. The conductivity upstream the bow shock can be much higher.

Acknowledgements. This work was supported by the Russian Basic Research Foundation (grant 99-05-64557).

References

Alexeev, I. I., The penetration of interplanetary magnetic and electric fields into the magnetosphere, *J. Geomag. Geoelectr.*, *38*, 1199-1221, 1986.

Alexeev, I. I., and Yu. P. Maltsev, Estimate of the penetration rate of the IMF into the magnetosphere due to interchange instability (in Russian), *Geomagnetism and Aeronomy*, *30* (1), 134-137, 1990.

Bargatze, L. F., D. N. Baker, R. L. McPherron, and E. W. Hones, Magnetospheric impulse response for many levels of geomagnetic activity, *J. Geophys. Res.*, *90*, 6387-6394, 1985.

Boyle, C. B., P. H. Reiff, and M. R. Hairston, Empirical polar cap potentials, *J. Geophys. Res.*, *102*, No A1, 111-125, 1997.

Denisenko, V. V., N. V. Erkaev, A. V. Kitaev, and I. T. Matveenkov, *Mathematical Modelling of Magnetospheric Processes* (in Russian), Nauka publ., Novosibirsk, 197 P., 1992.

Doyle, M. A., and W. I. Burke, S3-2 measurements of the polar cap potential, *J. Geophys. Res.*, *88*, 9125-9133, 1983.

Liperovsky, V. A., and M. I. Pudovkin, *Anomal Resistivity and Double Layers in Magnetospheric Plasma* (in Russian), Nauka publ., Moscow, 180 P., 1983.

Lui, A. T. Y., Solar wind influence on magnetotail configuration and dynamics, in *Solar Wind Magnetosphere Coupling*, vol. 126, edited by Y. Kamide and J. A. Slavin, p. 671-690, Astrophys. and Space Sci. Lib., Terra Sci. Publ. Comp. Tokyo, 1986.

Maltsev, Yu. P., and B. V. Rezhenov, Subtle Iayer of enhanced pressure preventing the IMF from penetration into the magnetosphere, in "*Magnetic Reconnection and Aurora Dynamics*", edited by V.S.Semenov, H.K.Biernat, R.P.Rijnbeek, and H.O.Rucker. Verlag der Osterreichischen Akademie der Wissenschaften, Wien, pp. 93-98, 1996.

Pudovkin, M. I., and V. S. Semenov, *Theory of Reconnection and the Interaction of the Solar Wind with the Earth Magnetosphere* (in Russian), Nauka publ., Moscow, 128 P., 1985.

Rezhenov, B. V., and Yu. P. Maltsev, Role of the interchange instability in flux transfer event origin, *Ann. Geophys.*, *12*, No 2, 183-187, 1994.

Sergeev, V. A., Penetration of the IMF B_y-component into the magnetotail (in Russian), *Geomagnetism and Aeronomy*, *27* (4), 612-615, 1987.