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# About the equilibrium and stability of the magnetopause

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**Abstract**

This paper offers a model of the magnetopause based on the theory of the contact discontinuity; the boundary layer between the two states of space plasma. The structure of the magnetopause is explored for the effects of polarization, and the profiles of the polarizing electrostatic field are obtained.

The structural stability of the model of a non-electroneutral magnetopause is studied. The areas of existence of the solutions of the contact discontinuity are revealed. These solutions are realized only within some areas of the 4-dimensional parametric space of the problem. The phase volume of these regions is small in comparison with all phase volumes of the domain of definition of the model parameters.

Methods for studying the stability of the magnetopause by taking into account the effects of plasma polarization are proposed. The kinetic equation with a self-consistent electromagnetic field is solved for the perturbation of the distribution function. Based on this solution, the plasma permittivity tensor of the non-electroneutral contact discontinuity is computed, and the dispersion equation for the examination of possible modes of instability of this discontinuity obtained. The instability of the magnetopause is explored with respect to the tearing perturbation and the effects of plasma polarization on the development of tearing instability.


*Keywords:* Kinetic theory; Distribution function; Polarization of magneto-active plasma; Equilibrium of magnetopause; Stability of magnetopause; Tearing instability

## 1. Introduction

The flow of a solar wind plasma stream around the Earth's magnetic field forms a magnetosphere. A boundary layer called the magnetopause forms in the narrow area between the plasma stream and the magnetic field. In the magnetopause, there are processes defining solar-terrestrial interaction, such as the reconnection of the magnetic field lines of the solar wind and the magnetic field lines of Earth. Those reconnected magnetic field lines are pushed by the solar wind to the night side forming the magnetosphere. The magnetopause ensures the presence of particles of the solar wind plasma along the reconnected magnetic field lines into near-Earth space.

However, creation of the boundary layer theory encounters significant mathematical difficulties (Grad, 1961), particularly from incorrect boundary conditions (the conditions must be formulated at infinity). In a number of other problems of boundary layer theory, the study of the polarization process of the magnetized plasma transition layer is most important. For example, satellite-based measurements in the region of the magnetopause show the presence of stationary and variable components of the electric field in that area of outer space. Thus, researchers believe that the variable component relates to the variations of the geomagnetic field and hence, try to interpret the stationary component in terms of polarization of magnetoactive plasma. However, to date, there is no theory of polarization of the

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inhomogeneous magnetoactive plasma. In order to understand the mechanism of the origin of the stationary electric fields found by experiment, researchers resort either to elementary physical estimates or to quasi-neutrality approximations (Schindler and Birn, 2002; Silin et al., 2002; Yoon and Lui, 2004).

In the study of the structure of inhomogeneous configurations of the magnetoactive plasma, efforts have been made to analyze the effects of polarization beyond the boundaries of the quasi-neutrality approximation (Shabansky, 1961; Sestero, 1965). For example, it was shown (Shabansky, 1961) that with an increase of velocity of the plasma flow running into the magnetic wall, the polarization of the plasma boundary layer and the electric field polarization in the area of the reflected particles builds up. Sestero (1965) succeeded in solving numerically the boundary layer equilibrium problem for a conditional electron and ion mass ratio of 1/3 only, whereas for real hydrogen plasma, the ratio is 1/1836.

A sufficiently large number of theoretical studies is devoted to the investigation of the magnetopause structure. So, the paper (Lee and Kan, 1979) offered a self-consistent stationary model of magnetopause based on the solution of Vlasov-Maxwell equations. In this model, there is an electric field normal to the magnetopause. The paper (Lyu and Kan, 1989) describes the magnetopause as a specific Alfvén discontinuty. The paper (Roth et al., 1996) gives a generalization of the investigations of equilibrium states such as tangential discontinuities in the space plasma. Harris's and Sestero's models, owing to their historical importance, were considered. Some conditions for beginning of tiring-instability are also considered. The paper (Mottez, 2003) is concerned with the study of equilibrium of tangential layers in the nonlinear approximation. The paper (Harrison and Neukirch, 2009) studies the magnetoactive-plasma polarization of some equilibrium configurations in quasineutral approximation. The paper (Panov et al., 2011) shows that tangential C-and S-layers can be described through the use analytical balance state.

Research of the instability of a current sheath is contained in the paper (Karimabadi et al., 2011) where kinetic modeling is used to study the problem of dynamics of magnetic islands at the magnetic reconnection.

Magnetopause is being studied intensively by an experimental approach as well. For example, the paper (Plaschke et al., 2009a) reports that within the period between April and September of 2007 the magnetopause boundary layer was crossed more than 6000 times. The conclusion was made of a higher stability of the magnetopause than it was formerly recognized and amplitudes and periods of the fluctuations developing on the border of magnetosphere were determined. The paper (Plaschke et al., 2009b) gives the results of the investigations of Alfven waves in the magnetopause.

However, the problem on polarization of the boundary layers and, the main thing, about the effect of the electric field on their stability remained undetermined. For example, one of the recent experimental studies (Lazutin et al., 2010) raises the question of the need to clarify the nature of slowly varying electric fields observed during geomagnetic storms.

We suggest an approach to investigate the effects of polarization of sharply inhomogeneous magnetoactive plasma structures, such as the magnetopause. The kinetic equation with a self-consistent electromagnetic field for perturbation of the distribution function has been solved. Based on this solution, the permittivity tensor for non-electroneutral plasma in the magnetopause has been calculated and the dispersion equation to study possible modes of its instability obtained. This paper presents the results of the study of the magnetopause instability relating to the tearing perturbation and the effects of plasma polarization on the development of tearing instability.

## 2. Problem statement

First, it is necessary to determine the equilibrium (steady-state) solution for the current plasma sheet, which separates the regions with antiparallel magnetic fields of different magnitudes, and then it is possible to explore the stability of the obtained configuration of the equilibrium boundary.

Papers (Alpers, 1969, 1971) are devoted to theoretical research of the magnetopause in the quasi-neutral approximation. Papers (Amata et al., 2006; Savin et al., 2006; Taktakisvili et al., 2007) throw light on the experimental research of the magnetosphere boundary within a framework of the Cluster Program. These papers show the frequency characteristics of the observed electromagnetic fields. Thus, the stationary components of the electric field are measured to be within the range of 0.3–700 mV/m, and the variable components are within the range of 1–104 mcV/m.

In the first approximation, it may be thought that the magnetopause represents the boundary layer between the solar wind plasma and the magnetic field of Earth. However, the magnetosphere contains a small amount of plasma (much smaller than in the solar wind), and the solar wind contains a weak interplanetary magnetic field (IMF), which has north or south components depending on the solar activity cycle. IMF intensity is much less than the magnetospheric field intensity. Therefore, a more adequate model of the magnetopause should be based on the theory of contact discontinuity; the boundary layer between the two states of space plasma.

The contact discontinuity will be considered to be in the plane yoz (see Fig. 1) and to the left and to the right of the discontinuity there will be a two-component plasma with different sets of characteristics.

The problem is one-dimensional. All the quantities depend on the variable x. The system under study is described by the kinetic equation:

$$\frac{\partial f_\alpha}{\partial t} + \vec{v}\frac{\partial f_\alpha}{\partial \vec{r}} + e_\alpha\{\vec{E} + [\vec{v}\vec{B}]\}\frac{\partial f_\alpha}{\partial \vec{P}_\alpha} = 0, \quad (1)$$

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