Analytical theory of a magnetopause with an arbitrary energy distribution of particles and a shear of magnetic field lines

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A new class of the models of a magnetopause formed by the solar (stellar) wind is presented. The models are based on the exact solutions to the Vlasov–Maxwell equations in the form of a superposition of arbitrary isotropic distribution functions of particle energy, each multiplied by a Heaviside step function of one of the projections of the generalized momentum of particles. The analytical solutions can represent the distributed complicated current sheets separating two regions of anisotropic collisionless plasma with different values of magnetization and different effective temperatures of the energy distributions of electrons and ions. The developed theory does not rely on a magnetohydrodynamic approach and gives the consistent kinetic description of the inhomogeneous anisotropic distribution functions of electrons and ions with different effective temperatures and an inhomogeneous magnetic field.

Possible profiles of the current density and consistent magnetic field are analyzed in detail and their stability or slow evolution is shown for typical plasma parameters by means of the particle-in-cell simulations. In particular, the stable solutions admit a shear of magnetic field lines and may include several ion components with different effective temperatures and localized countercurrents with various densities and spatial shifts. Magnetopause layers containing several fractions of particles with countercurrents, shifted relative to each other in space and having different scales, allow multiple non-monotonic changes in the magnetic field, while the magnetic field and the total plasma concentration can grow in the same direction. The total thickness of a layer is determined by the values of the shifts between the currents of the fractions with the highest energy content and the typical gyroradii of the particles of these fractions (e.g., fig. 1).

A number of analytical examples for the shifted Maxwell, kappa and other particle distributions with different anisotropy degrees are given and employed for a qualitative comparison of the predicted and observed spatial current profiles in the Earth's magnetopause. These solutions are relevant also to the interpretation of modern data of satellite observations of multicomponent current sheets in the solar wind magnetic clouds and high coronal magnetic structures. The previously-known models of a magnetopause and their limitations as compared to the newly suggested models with an arbitrary energy distribution of particles are discussed as well.

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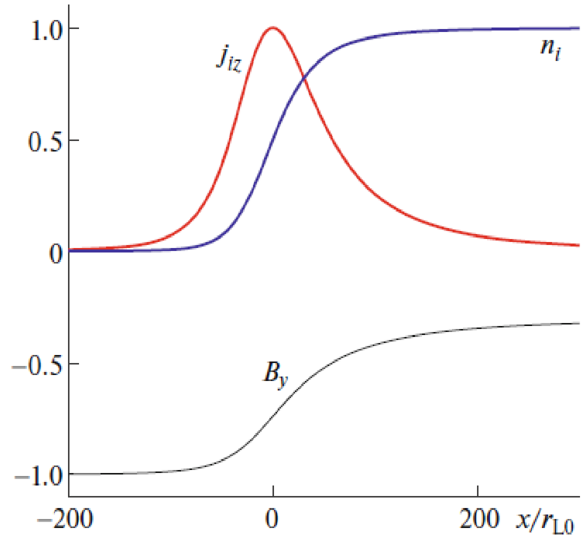

Figure 1. Typical simple asymmetric current sheet with a single anisotropic fraction of protons (when the current of electrons is negligible) with kappa-distribution of energies (κ = 3). The values of the magnetic field, *B*, current density, *j*, and concentration of protons, *n*, are normalized to their maximum values; the coordinate is normalized to the Larmor radius of the electron, which is taken at the value of the magnetic field in the center of the sheet and which, for the parameters used, is approximately two orders of magnitude smaller than the corresponding gyroradius of the proton.

References

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