The minimum energy state and the minimum angle rotation of the magnetic field in the homogeneous magnetopause current layer

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In the tangential discontinuities at the magnetopause and in the solar-wind, the magnetic field rotates continuously, when the directions of the magnetic fields are different at the both ends of the discontinuity. It is shown that this process of the field rotation is a relaxation process (self-organization process) toward the minimum energy state. By assuming a one-dimensional tangential discontinuity, where the magnetic field strength is constant and the magnetic field is force-free, it is shown that the relaxed state with the minimum ratio of the magnetic energy to the helicity is the state having the minimum angle rotation and the minimum field aligned current density.

It has been observed in the tangential discontinuities at the magnetopause and in the solar wind that the magnetic field rotates continuously in the discontinuities, when the directions of the magnetic field at the boundaries of the discontinuity are different. In the present paper it is shown that such rotation of the magnetic field in the tangential discontinuity can be explained by using the plasma relaxation (self-organization) to the minimum energy state, when the tangential discontinuity is homogeneous. More specifically, the magnetopause current layer is modeled by a one-dimensional planar current layer, which becomes a tangential discontinuity in the force-free state. The total magnetic energy and the magnetic helicity in the rectangular volume in the magnetopause current layer are defined. It is shown that the helicity is gauge-invariant and the total rotational angle of the magnetic field across the magnetopause is proportional to the ratio of the total magnetic energy/helicity in the force-free state. The total rotational angle is also proportional to the field-aligned current density in the magnetopause current layer in the force-free state. By solving the constant coefficient-force-free eigenmode equation it is shown that the force-free field rotates in the magnetopause current layer. By the stability argument it is conjectured that the magnetopause current layer relaxes to the state with the minimum absolute ratio of the energy/helicity and thus to the minimum energy state for a given helicity. Therefore, it is suggested that the field-aligned current intensity in the magnetopause becomes minimum and the total rotational angle of the magnetic field across the magnetopause becomes minimum, i.e., less than 180 degrees. The magnetic field structure and its hodogram in the force-free states for some representative cases are calculated numerically. The relevance of the obtained results to observations of the field rotation across the magnetopause is discussed.