

The terrestrial magnetosphere for zero interplanetary magnetic field

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The solar wind energy is transported to the magnetosphere-ionosphere system via energy conversion. In particular, the interplanetary magnetic field (IMF) has a large effect on the solar wind-magnetosphere interaction. If the magnetosphere is totally closed in terms of magnetic field topology, in ideal magnetohydrodynamics, there is no solar wind energy flowing into the magnetosphere. One important element determining the energy inflow rate is the connectivity of the geomagnetic field and the IMF, namely, magnetic reconnection between the two fields. For southward IMF, reconnection occurs on the nose of the magnetosphere. The solar wind energy enters the magnetosphere effectively, producing magnetic storms, auroral substorms, and so forth. Meanwhile, for northward IMF, reconnection occurs on the high-latitude magnetopause. Though not so effective as for southward IMF, the solar wind energy also enters the magnetosphere, producing phenomena specific to northward IMF periods such as theta auroras. Thus, it is expected in the real magnetosphere that the energy inflow is minimized when the IMF is northward and extremely small (say $B=0.1$ nT). However, prolonged periods of such IMF are of very rare occurrence, and consequently observational studies are virtually impossible. In this study, therefore, we performed a numerical simulation using the Reproduce Plasma Universe (REPPU) code (Tanaka, 2015) and reproduced a magnetosphere under northward and extremely small IMF conditions. We set the IMF magnitude to 0.1 nT and the IMF clock angle (measured from due north) to 30° in the simulation. The conclusions of this study are summarized as follows.

(i) Reconnection occurs on the high-latitude magnetopause near the cusp. Although the IMF is northward, this reconnection is Dungey-type reconnection for southward IMF that converts the closed magnetic flux to open magnetic flux. We also found so-called merging cells in the ionosphere resulting from Dungey-type reconnection. However, the contribution of the merging cells to the cross polar cap potential is very small (a few kilovolts).

(ii) Ionospheric convection exhibits the normal twin-cell pattern. The cross polar cap potential (a few tens of kilovolts) is contributed mostly by the convection cells circulation exclusively in the closed field line region (so-called "viscous cells").

(iii) The main energy flow route from the solar wind to the ionosphere is similar to that for southward IMF conditions. The solar wind flow energy is first converted to the thermal energy in the magnetosheath. The thermal energy is then converted to the motional energy of a flow toward the cusp (mainly field-aligned), and then to the thermal energy of the cusp. At the high-latitude boundary layer behind the cusp, the thermal energy finally transmutes into the electromagnetic energy driving the R1 FAC system. Thus, the convection cells that appear in the closed field line region of the ionosphere are not the consequences of the viscous-like interaction in the low-latitude boundary layer between the solar wind and the magnetosphere, as conventionally thought to be the origin of the "viscous cells" (Axford & Hines, 1961). Instead, the energy supply mechanism for the "viscous cells" is basically the same as that for the merging cells for southward IMF. The role of reconnection is to make the magnetosphere topologically open to enable the entry of the solar wind energy into the magnetosphere and the subsequent formation

of the cusp. As long as the magnetosphere is topologically open, be it ever small, a closed magnetic flux circulation is formed in the magnetosphere-ionosphere system by the energy supply mechanism through the cusp.

Keywords: northward interplanetary magnetic field, viscous cell, cross polar cap potential