KINETIC EFFECTS IN THIN CURRENT SHEETS AND SUBSTORMS: GEOTAIL OBSERVATIONS

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The formation of a thin current sheet, in which particle inertial effects are significant, is believed to be essential for initiation of magnetic reconnection in collisionless plasmas. In this paper we report GEOTAIL observations that an extremely thin current sheet is really formed in the Earth's mid-tail region during substorms. In order to study kinetic effects and the current carrier in the thin current sheet, the current density is estimated by the number density multiplied by the velocity difference between electrons and ions. This is not a trivial work, since low-energy electron data are contaminated by spurious effects due to due to spacecraft photoelectrons and the spacecraft potential, and their elimination is very hard and notoriously unreliable. However, we have succeeded (though not always) in obtaining reasonable results of the electron moments with very careful examination of the electron distribution functions. Then the thickness is estimated using the Ampere's law, $h/2 = \alpha B_L/m_0 J_y$, where B_L is the magnitude of the lobe magnetic field and J_y is the cross-tail current density. B_L is estimated by the locally measured total pressure with assumption of pressure balance. α is a factor to represent the effective thickness of the current sheet embedded in the thicker plasma sheet, and it is set to be 0.6 according to the observed results.

We have found that the cross-tail current density is significantly intensified in the mid-tail plasma sheet in the late growth phase to expansion onset of a substorm, and the estimated thickness becomes several hundreds of km, comparable to the ion inertial length. It is worth stressing that the current is carried mainly by electrons drifting dawnward, which indicates that the electric field is directed toward the neutral sheet. The corresponding ion distribution functions show that low-energy electrons are convecting with nearly the same speed and direction as those of the electrons, while energetic ions are non-gyrotropic and moving toward the opposite (duskward) direction to that of low-energy ions. Therefore the currents due to low-energy and higher-energy ions are cancelled out, and the electrons become a dominant carrier of the current. The Ez magnitude is significantly greater than the ordinary convection electric field (Ey), and hence the Hall term is the most significant in the generalized Ohm's law.

The intense current sheet is highly variable and embedded in the thicker plasma sheet, but it should be noted that the region of the most intense current density is not necessarily in the neutral sheet. It appears rather in an off-neutral sheet region. Statistical study of the thin current sheet around the substorm onset shows that in the growth phase the current sheet becomes thin on the earthward side of the initial near-earth neutral line (NENL) position, while the thinning of the current sheet is not clear on the tailward side. This result implies that the NENL is formed at or near the tailward edge of the thin current sheet. The current sheet on the tailward side becomes thinner after the onset.

We have also found the direct evidence of collisionless magnetic reconnection with identification of the Hall current loop and the associated magnetic field deflection. Here the current is again estimated from the velocity difference between electrons and ions. The characteristic features in the electron distribution functions show the presence of the field-aligned electron beams flowing into the magnetic diffusion region, which constitute the outermost current in the Hall current loop.

We discuss electron and ion dynamics in terms of the formation of the thin current sheet and the occurrence of magnetic reconnection.