§13. Effects of Electron Parallel Motion and Ion Finite Larmor Radius in Collisionless Magnetic Reconnection

Motohiko Tanaka

Abstract

Fast collisionless reconnection of magnetized flux loops by the macro-particle simulation shows remarkable asymmetry of the plasma flow. The parallel motion of electrons induced by the reconnection electric field produces significant density and toroidal magnetic field inhomogeneities of a quadrupole shape unlike the m=1 mode, hence, resulting in a thick current layer. The reconnection rate becomes an increasing function of the ion mass and an inverse of the toroidal magnetic field, whereas it decreases drastically for the ion Larmor radius exceeding the ion skin depth.

§1. Electron Effects

The high-temperature plasmas that we are interested in are quite often collisionless, that is, electrical resistivity is virtually zero. Thus, the physics of magnetic reconnection, especially that at the reconnection X-point needs to be treated by non-MHD method such as particle simulations [1].

It was shown by the macro-particle simulation that electron inertia provides equivalent resistivity in the collisionless reconnection [2]. Following up the previous study, it has been clarified here [3] that the observed asymmetry of the plasma flow [2] is due to the parallel motion of electrons. Surprisingly, because of this motion, the flow is locally compressible even under the presence of the ambient magnetic field,

$$\nabla \cdot \nabla^{(s)} \neq 0 \text{ (for } s = e, i).$$

Substantial density inhomogeneity of quadrupole form, $\delta n/n_0 \sim 0.3$, is produced by the flow divergence, unlike most of the previous MHD studies which assume incompressibility. The internal structure makes thickness $D$ of the current layer broad, thus the reconnection rate depending on both the ion and electron inertias, as $d\Psi/dt \sim v_AD/L$.

§2. Ion Effects

The reconnection rate has been measured varying mass and Larmor radius of ions (Fig.1). The rate becomes a smoothly increasing function of ion mass. When the ion Larmor radius $\rho_i$ becomes comparable to the ion skin depth $c/\omega_{pi}$, the rate is greatly reduced as shown in Fig.1(b). The deduced reconnection rate from all the simulation results shown in Fig.1 is,

$$d\Psi/dt = F\left((\rho_i/c/\omega_{pi}) \times (m_i/m_e)^{(1-\nu)/2}\right).$$

with $\nu \sim 2.7$ and the $F(x)$ profile is given by Fig.1(b) [3].

References