Fast reconnection in low-density hydrogen and pair plasmas

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Magnetic reconnection is considered to play important roles in converting magnetic energy to kinetic energy in solar flares, magnetic substorms in Earth's magnetosphere, and astrophysical objects such as pulsar winds and extragalactic jets. Many of these environments have background densities significantly lower than is assumed in standard simulations. We have studied Harris current sheets with small background densities and without a guide field, and carried out a comparison study of magnetic reconnection in hydrogen plasmas and electron-positron (pair) plasmas by means of 2 dimensional particle-in-cell simulations. We will present the following new findings: (1) Reconnection rates depend on the background number density in a Harris sheet. Decreasing the background density gives a faster, Alfvénic reconnection rate. (2) Even though there is no Hall effect in pair plasmas, fast reconnection can be mediated by particle acceleration and resulting increase of the inertial and pressure terms in the generalized Ohm's law. (3) As time progresses, the diffusion region is extended in the outflow direction and is also broadened in the inflow direction. The aspect ratio of the diffusion region keeps a small value, and thus fast reconnection becomes possible.

It is known by many simulations that a fast reconnection rate around $0.1 B_0 v_A/c$, where B_0, v_A, and c are the asymptotic magnetic field, the Alfvén speed, and the speed of light, respectively, is possible if the background density of the order of 0.1 of the current sheet density is used. We have demonstrated that much faster reconnection rate of the order of 1 is possible if the background density is much smaller, of the order of 0.01. We will discuss the structure of the diffusion region and compare results in hydrogen plasmas and pair plasmas. In hydrogen plasmas, the reconnection electric field in the electron diffusion region is balanced with the electron pressure term and the inertial term in the generalized Ohm's law. In addition, there is a significant contribution of Hall term to the reconnection electric field in the ion diffusion region until the time of the maximum reconnection rate of the order of 1. As time evolves, the electron diffusion region is extended both in the outflow and inflow directions, and the reconnection rate gradually decreases to of the order of 0.1. In that phase, the Hall term decreases considerably and the inertial term becomes quite large to compensate the reduction of the Hall term. In pair plasmas, where the ion and electron diffusion regions are identical and therefore there is no Hall effect, particle acceleration around the X-line leads to a large contribution of the inertial term to the reconnection electric field in the diffusion region. As time evolves, a significantly broader diffusion region has been observed. We will discuss both similarities and differences between hydrogen and pair plasmas.