Roles of Electron in Physical Processes Related to Magnetic Reconnections in the Earth's Magnetosphere

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Abstract

Magnetic reconnection is one of the most important physical processes in the Earth's magnetosphere. This physical process can cause an energy input from the solar wind to the magnetosphere at the magnetopause, and also bring about energy releases in the nightside magnetotail. Recent developments of computational power and improvement of instruments on satellites have led us to a new stage in which we can well investigate electron-driven dynamics around magnetic reconnection. In this thesis, roles of electron in physical processes related to magnetic reconnections in the magnetosphere are studied. First, properties of electron tearing instability in a thin current sheet before magnetospheric substorm onset are investigated by full-particle simulations. Magnetic reconnection developed from the tearing instability is a candidate of the substorm driver. Second, by using Time History of Events and Macroscale Interactions during Substorms (THEMIS) data, electron outflow structure at the magnetospheric side separatrix of the magnetopause reconnection, and plasma waves excited because of distortion of electron velocity distribution function caused by the reconnection are investigated.

In Chapter 1, backgrounds of this thesis are briefly introduced. The regions of interest in the magnetosphere are described first. Physics of magnetic reconnection is explained from various points of view in the next. Basic roles of electron in physical processes related to magnetic reconnection are subsequently reviewed for reference of the studies in this thesis. The purpose and overview of this thesis are stated last.

In Chapter 2, four 2.5-dimensional full-particle simulations with a new initial magnetic-field structure are performed to investigate electron tearing instability in the magnetosphere before substorm onset. The structure is similar to the Earth's dipole magnetic field combined with a stretched field and current sheet on the tailward side. In order to reduce numerical noises, we apply the Quiet-Start method to determine initial particle positions satisfying the magnetohydrostatic condition. In order to quickly induce instabilities in the CS without unwanted electric-field effects in the specific simulation system, we set smaller particle pressures than those of the magnetic field in the current sheet. The first reference simulation with the initial magnetic-field configuration shows that nodes of the magnetic field appear in the current sheet where the growth condition of tearing instability is satisfied. The features of the instability are close to those of the electron tearing mode

reported in previous simulation results. Another three simulations with a local B_z enhancement, as seen in the statistical observations, at various locations in the current sheet are performed to explore its impacts on the evolution of the instability. A relaxation process around the enhancement generates a new node at its tailward edge if its location satisfies the growth condition. The wavelength and dominant mode of the instability can be changed by couplings between the relaxation process and tearing mode, depending on the location of the enhancement. The new properties of the electron tearing instability and dominant magnetic reconnections resulting from these full-particle simulations are discussed in terms of substorm onset.

In Chapter 3, we investigate the distorted electron velocity distribution functions (VDFs) and associated plasma waves in the innermost open boundary layer (IOBL) formed by dayside magnetopause reconnection. The IOBL structure is identified by high-speed electrons from the magnetosheath on the magnetospheric side of the ion outflow from the reconnection site. The IOBL at the magnetospheric side separatrix of the reconnection is first reproduced by a full-particle simulation which is a similar algorithm to that in Chapter 2. Based on the simulation result, the IOBL structure in association with the dayside magnetopause reconnection is found by using THEMIS data. We introduce two cases where different plasma waves are observed in the IOBL: (i) whistler-mode waves propagating toward the reconnection region, and (ii) electrostatic waves close to the local LHR frequency. Quasi-parallel whistler-mode waves propagating toward the reconnection region are observed in association with a partial shortage of magnetospheric electrons moving away from the reconnection region. A direct calculation of the whistler-mode linear growth rate shows that the waves can be excited by the perpendicular electron temperature anisotropy that develops due to the partial shortage of field-aligned magnetospheric electrons. Electrostatic waves around the lower hybrid resonance frequency are observed in the IOBL in the second case, during the main phase of a magnetospheric storm. Magnetospheric electrons are almost completely lost in the event, except at pitch angles close to 90°, yet whistler-mode waves are not observed. An electron beam from the magnetosheath and counter-streaming cold electrons originating from the plasmaspheric plume are observed in association with the electrostatic waves. Growth rate calculation shows that the waves are likely to be ion acoustic waves excited via couplings between the flowing cold electrons and background cold ions. It is suggested that the different solar wind conditions and magnetic reconnection characteristics may control the shapes of electron velocity distribution function and resulting plasma wave properties in the IOBL, based on the solar wind data and analyses of reconnection properties.

In Chapter 4, achievements of this thesis are summarized as concluding remarks.