Japan Geoscience Union Meeting 2010
(May 23-28 2010 at Makuhari, Chiba, Japan)

PEM031-P05 Room: Convention Hall Time: May 23 17:15-18:45

Magnetic-field-aligned electric field and particle acceleration in nonlinear magnetosonic waves

Seiichi Takahashi[1*], Hiromasa Kawai[1], Yukiharu Ohsawa[1], Shunsuke Usami[2], Charles Chiu[3], Wendell Horton[3]

[1]Department of Physics, Nagoya University, [2]National Institute for Fusion Science, [3]IFS, Univ. Texas

The electric field component parallel to the magnetic field, $E_{\parallel}$, in nonlinear magnetosonic waves is studied with theory and electromagnetic particle simulations [1,2]. Its results are then applied to three different acceleration mechanisms in oblique shock waves [3]: acceleration of trapped electrons [4], positron acceleration along the magnetic field in an electron-positron-ion (e-p-i) plasma [5], and incessant acceleration of relativistic ions [6]; the first two mechanisms are discussed in this paper.

In the ideal MHD, the parallel electric field is zero, and it was generally thought that $E_{\parallel}$was quite weak in low-frequency phenomena in collisionless plasmas. Our recent studies on the parallel electric field, however, show that it can be strong in nonlinear magnetosonic waves. In electron-ion (e-i) plasmas [1], the integral of $E_{\parallel}$along the magnetic field (parallel pseudo potential) is proportional to the electron temperature in small-amplitude pulses in a warm plasma. In a cold plasma (low beta plasma), it is proportional to the magnetic pressure. In e-p-i plasmas [2], the parallel pseudo potential decreases with increasing positron-to-electron density ratio. These theoretical predictions have been verified with particle simulations. Furthermore, we have found an expression for the parallel pseudo potential in shock waves that explains the simulation results for e-i plasmas and for e-p-i plasmas.

We then examined the effect of parallel electric field on particle acceleration in shock waves with particle simulations and test particle calculations: In this method, we first obtain the data of electromagnetic fields of a shock wave from a particle simulation, and then, using these field data, we carry out test particle calculations in two different manners; in one method, the total electric field E is used in the relativistic equation of motion, while in the other $E_{\parallel}$is omitted. We compare these results to analyze the effect of $E_{\parallel}$.

In these simulations, the shock speed is taken to be close to c cos theta, where theta is the propagation angle. In this condition, some electrons can be reflected near the end of the main pulse of a shock wave, which are then accelerated and trapped in the main pulse region [4]. Furthermore, positrons can be accelerated along the magnetic field in the shock transition region [5]. In the test particle calculations with $E_{\parallel}$omitted, neither the electrons nor the positrons are accelerated, indicating that $E_{\parallel}$plays an essential role in these acceleration mechanisms [3].

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Keywords: parallel electric field, shock wave, particle acceleration, electron-ion plasma, electron-positron-ion plasma, trapped electron