Electric field component parallel to the magnetic field in nonlinear magnetosonic waves

S. Takahashi and Y. Ohsawa

Department of Physics, Nagoya University, Nagoya 464-8602, Japan

takahashi.seiichi@a.nagoya-u.jp

In the ideal MHD, the electric field component parallel to the magnetic field is zero, and it was generally thought that the parallel electric field $E_{\|}$ was quite weak in low-frequency phenomena in collisionless plasmas. In some particle simulations, however, the parallel electric field $E_{\|}$ in magnetosonic shock waves was found to be quite strong [1,2]. This discrepancy prompted us to investigate the structure of parallel electric field in nonlinear magnetosonic waves with theory and particle simulations.

First, we consider two-component plasmas consisting of electrons and ions. Our theory based on the two-fluid model [3] gives the magnitude of the integral of $E_{\|}$ along the magnetic field (parallel pseudo potential), $F = -\int E_{\|} ds$, as $eF \sim \epsilon \Gamma_e T_e$ in small-amplitude pulses in a warm plasma, where ϵ is the wave amplitude, Γ_e is the specific heat ratio, and T_e is the electron temperature, while it is $eF \sim \epsilon^2 m_i v_{\mathrm{A}}^2$ in a cold plasma, where v_{A} is the Alfven speed. These theoretical predictions are consistent with the results of fully kinetic, fully electromagnetic, particle simulations. Furthermore, for shock waves with $\epsilon \sim \mathrm{O}(1)$, the relation $eF \sim \epsilon(m_i v_{\mathrm{A}}^2 + \Gamma_e T_e)$ explains the simulation results for both cold and warm plasmas. These results indicate that the parallel electric field can be strong in nonlinear magnetosonic waves.

Next, we consider three-component plasmas consisting of electrons, positrons, and ions. We also obtain the parallel pseudo potential in small-amplitude pulses with theory and simulations [4]. The comparison confirms that the theory is consistent with the simulation results. Concerning the shock waves, the relation $n_{e0} eF \sim \epsilon(\rho v_A^2 + \Gamma_e p_{e0})(n_{i0}/n_{e0})$ explains the simulation results, where n_{e0} and n_{i0} are, respectively, the electron and ion densities, ρ is the mass density, and p_{e0} is the electron pressure. In the limit of zero positron density, this relation reduces to the one in two-component plasmas. Furthermore, the theory and simulations both show that the parallel pseudo potential decreases as the positron-to-electron density ratio increases, which explains the simulation result that the positron acceleration along the magnetic field [2] is strong when the positron-to-electron density ratio is low.

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