§49. Collisionless Shock Waves and Particle Acceleration

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The structure of collisionless shock waves and the acceleration of particles in these waves have been studied by means of one- or two-dimensional, relativistic, electromagnetic, particle simulations with full electron and ion dynamics.[1-7] Also, we have studied the energy transport in multi-ion-species plasmas; transport due to current-driven instabilities and that due to ion Bernstein waves.[8-10]

Here, we describe the results of one- dimensional simulations of wave propagation and particle acceleration in a plasma consisting of electrons, ions, and positrons. In a three-fluid cold model, we have three oblique waves in the frequency domain lower than the electron gyrofrequency, $\omega<|\Omega e|$, as shown in Fig. 1. They are the Alfvén wave (line A), the higher-frequency mode (line H) and lower-frequency mode (line M) of the magnetosonic wave. The magnetosonic wave (line M) can evolve into a shock wave. Particle simulations have shown that a magnetosonic shock wave propagating obliquely to an external magnetic field can accelerate some positrons to ultrarelativistic energies (see Fig. 2).

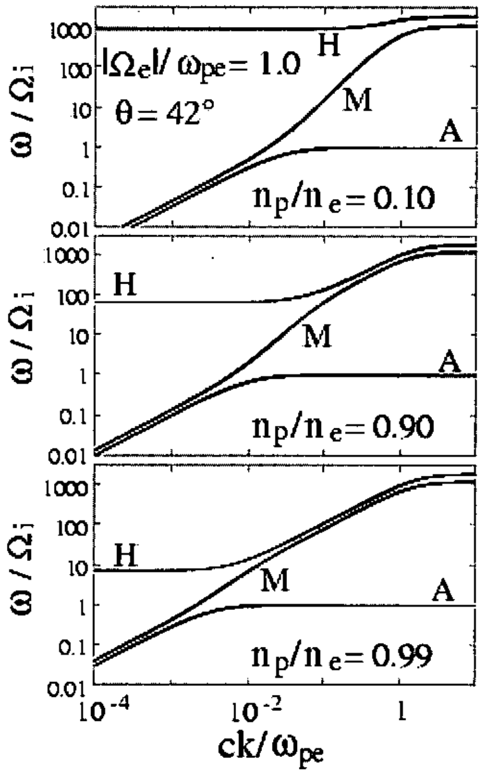

Fig. 1. Dispersion relations for magnetohydrodynamic waves for three different positron densities. Here, n_p and n_e are the positron and electron densities, respectively, and θ is the angle between the external magnetic field and the wave normal.

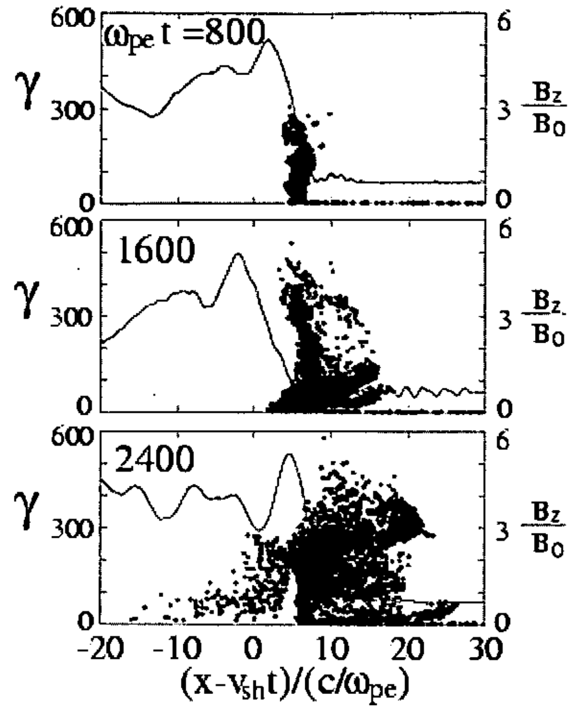

Fig. 2. Phase space plots (x, γ) of positrons. Profiles of Bz are also shown. The shock wave propagates in the x direction with a speed v_{sh} in an external magnetic field $\boldsymbol{B}_0$ that is in the (x,z) plane.

In this mechanism, some positrons are reflected by the electric field parallel to the magnetic field $\boldsymbol{B}$. Then, they move nearly parallel to $\boldsymbol{B}$ for time periods much longer than their relativistic gyroperiods. The theoretically obtained energy increase rate, which is proportional to the inner product of $\boldsymbol{E}$ and $\boldsymbol{B}$, is in good agreement with the simulation result.

Furthermore, we have developed a three dimensional, electromagnetic, particle code. Simulation studies of shock propagation and particle acceleration by use of this code are underway.

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