§25. Particle Acceleration due to Strong Electromagnetic Fields in Shock Waves

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We have studied 1) electron acceleration caused by small pulses in shock waves in a reversed external magnetic field [1], 2) positron acceleration in a shock wave in an electron-positron-ion plasma [2], 3) acceleration of energetic particles [3], 4) shock formation processes [4], and 5) low frequency electromagnetic fluctuations in a thermal equilibrium, multi-ion-species plasma [5,6]. We have investigated these subjects with particle simulations. Here, we briefly describe the study of the first subject.

It was shown in 2005 that a small pulse generated in a shock wave can cause electron acceleration to ultrarelativistic energies [7]. Unlike the electron acceleration discussed by Bessho and Ohsawa in 1999 [8], this mechanism can work in weak magnetic fields such that $\omega_{ce}/\omega_{pe}<1$ as well as in strong magnetic fields. Further, it does not require the condition that the shock speed v_{sh} is close to $c \cos\theta$, where θ is the angle between the external magnetic field and the wave normal.

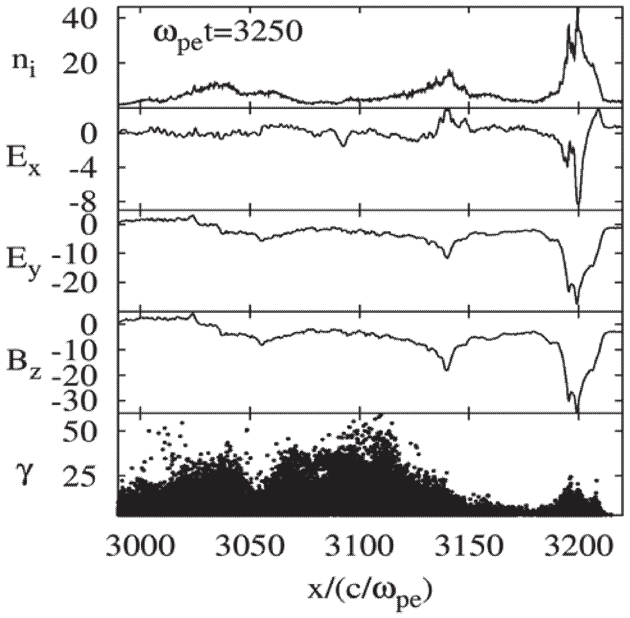

Fig. 1. Snapshot of ion density, fields, and electron phase space (x, γ). At this moment, the front of the secondary shock wave is at $x/(c/\omega_{pe})$=3200, a particle-accelerating compressive small pulse is at $x/(c/\omega_{pe})$=3140, and the field-reversed small pulse is at $x/(c/\omega_{pe})$ =3030.

In the simulations in Ref. [7], the external magnetic fields were uniform. In 2006, we have extended that work to the case in which the external magnetic field is reversed across a neutral sheet. With one-dimensional (one space coordinate and three velocity components), relativistic, electromagnetic particle simulations, we have examined the evolution of shock waves around the field-reversed region and associated electron acceleration.

Specifically, we have considered shock waves propagating in the x direction in an external magnetic field B_{z0} that varies with x in a finite region $a<x<b$ from $B_{z0}(a)$ (>0) to $B_{z0}(b)$=-$B_{z0}(a)$. Simulations show that before a shock wave with positive B_z reaches the position x=a, some electrons are accelerated by a compressive small pulse as was shown in Ref. [7]. After penetrating the inhomogeneous region, the original shock wave is damped. A secondary shock wave with negative B_z is then generated in the region $x>b$. In this wave, some electrons are accelerated to ultrarelativistic energies immediately behind newly created compressive small pulses. Further, after the encounter with the original shock wave, the neutral sheet (B_z=0 sheet) begins to move, and the energization of electrons occurs around this field-reversed small pulse (see Fig.1). Because these pulses are under the influence of the shock wave, electric fields exist around them; electrons can absorb energy from the transverse electric field there. As shown in Fig. 2, electrons accelerated by the field-reversed pulse exhibit meandering motions along the neutral sheet.

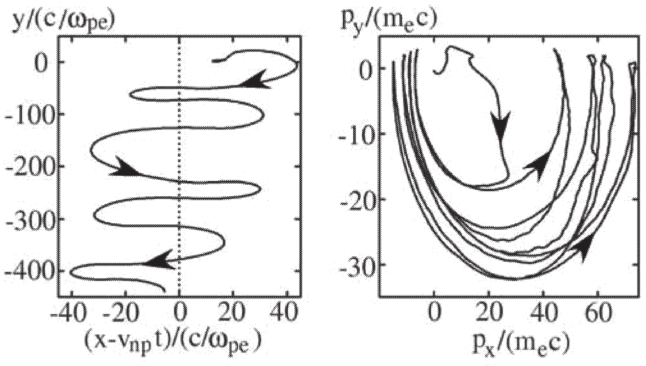

Fig. 2. Orbits of an accelerated electron in the (x-$v_{np}t$,y) and (p_x,p_y) planes. Here, v_{np} denotes the speed of the field-reversed pulse. The dotted vertical line in the left panel indicates the magnetic neutral sheet.

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