Numerical Simulation of the Interaction of Charged Particles with Oblique Magnetohydrodynamic Shocks

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The motion of high energy charged particles in ideal oblique MHD shocks, characteristic of the interplanetary medium, has been studied extensively. The shock is treated as a plane surface across which the tangential component of magnetic field changes discontinuously. The orbits of charged particles can be solved exactly from Lorentz force equation and initial conditions of particles in each region, pre- and post-shock, separately. The essential procedure is to determine the crossings and that has been achieved by solving numerically for the times when the particle meets the shock. The position and velocity vectors are continuous across the shock. An ensemble of 1972 monoenergetic particles distributed isotropically in the shock frame are chosen to obtain collective results.

A charged particle may cross the shock front many times before it leaves the shock. During the crossings, it is accelerated by an effective "grad B" drift in the induced electric field. The number of crossings can be as large as fifty. The final energy increases as the number of crossings and the interacting time increase. The most energetic particles are those with initial pitch and phase near the boundary between crossing and reflected particles. Hence, the most energetic reflected and passing particles have about the same pitches. The reflected particles, however, cross the shock about twice as many times as the passing particles do, and therefore the energy gain of reflected particles is about twice that of passing particles. After interaction, the upstream energy spectrum is harder than that downstream. Also, the anisotropy is larger upstream.

The energy gain increases for larger values of shock strength, η; it decreases for larger field inclination angles (B_x/B_1). The probability of reflection increases as η increases; it goes down as B_x/B_1 increases. For small values of B_x/B_1, the shock can be considered as a perpendicular shock. All particles penetrate through such shocks.

Magnetic irregularities near shocks that elastically scatter the particles may increase the number of crossings for some particles and, consequently, cause a few high energy particles. Extensive scattering by irregularities reduces the anisotropy. The average energy gain with scattering is about the same as that of non-scattering cases. Finally, some theoretical results calculated from other papers are shown to be consistent with the numerical results obtained from the computer program runs.