Abstract. The magnetic field and plasma data from the ISEE 1, 2, and 3 spacecraft have greatly increased our knowledge of the quasi-parallel collisionless shock in space. Hybrid-code simulations have provided us with valuable insights into the physics of the quasi-parallel shock. Unfortunately, theoretical understanding of the nonlinear physics of the quasi-parallel shock is still in a qualitative stage of development. Generation of large-amplitude whistler waves and hydromagnetic waves observed in the quasi-parallel shock has been discussed either in terms of linear instabilities or qualitative nonlinear arguments. It appears that the ion reflection, ion heating, and leakage of the shock-heated downstream ions at the quasi-parallel shock can all be explained in terms of nonadiabatic scatterings of ions by the large-amplitude whistler-magnetosonic waves with frequencies near the ion gyrofrequency and wavelength near the ion inertial length. The nonadiabatic scattering is defined by the non-conservation of the magnetic moment. Future study of the quasi-parallel shock should focus on developing quantitative theoretical models for the nonlinear physical processes fundamental to the quasi-parallel shock.

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1. Introduction

Collisionless shocks are shock-like structures in collisionless plasmas. Observations showed that the structure of collisionless fast-mode shocks are quite sensitive to the
shock normal angle $\theta_{bn}$ which is the angle between the upstream magnetic field and the shock normal. Observations of collisionless shocks in space have led to the classification of quasi-parallel (Q-||) and quasi-perpendicular (Q-⊥) shocks defined respectively by $\theta_{bn} \leq 45^\circ$ and $\theta_{bn} > 45^\circ$ (Formisano and Hedgecock, 1973; Greenstadt, 1974; Greenstadt, 1985; Leroy et al., 1981, 1982; Eselevich, 1983). The Q-|| shock is characterized by a highly-structured shock transition region with large amplitude upstream waves, in contrast to the Q-⊥ shock characterized by a well-behaved shock transition region without the upstream waves.

Progress in the collisionless shock research during the last decade has depended mostly on in situ measurements and numerical simulations. Observations by the plasma and field instruments onboard the ISEE 1 and 2 spacecraft contributed greatly to our knowledge of the Q-|| shock. Simulations of Q-|| shocks provided us with the much needed insights into the nonlinear shock physics. Unfortunately, our understanding of the Q-|| shock is still in the qualitative stage. Quantitative understanding cannot be attained until we have successfully formulated theoretical models of the fundamental processes underlying the Q-|| shock.

The purpose of this paper is to review the progress in the Q-|| shock research during the last decade. The main emphasis of this review will be to compare simulation results against observations in an effort to improve our understanding of the Q-|| shock. By assessing our knowledge and improving our understanding of the Q-|| collisionless shock, we hope to gain a better perspective in focusing the future research on this fascinating subject in the nonlinear collisionless plasma physics.

2. Observations of Quasi-Parallel Shocks

Plasma and field structures of Q-|| shocks observed in space have been well documented (e.g., Greenstadt, 1985; Russell and Hope, 1983; Scudder et al., 1984; Gosling et al., 1985; Paschmann et al., 1979; Thomsen et al., 1985; Kennel et al., 1984). The structure of a high Mach number Q-|| shock is rather extended in space. The shock transition is not easy to identify, the scale lengths of the transition region can be difficult to determine. The magnetic transition of a Q-|| shock can extend in excess of 10 $R_E$ (earth radius). The complexity is compounded by the highly turbulent magnetic field structure in the transition region with wave amplitudes often greater than the downstream magnetic field.

2.1. OVERALL STRUCTURES

Figure 1 shows an example of the observed magnetic field profile across a quasi-parallel shock (courtesy of C. T. Russell, 1990). Upstream is on the left, downstream is on the right. The magnetic profile exhibits several large-amplitude pulses across the shock transition region (from 05:57 to 06:00). Upstream waves (from 05:54 to 05:57) are of longer wavelengths and smaller amplitudes than those magnetic pulses in the shock transition region. The principal shock jump or the shock ramp is around 05:58 ± 00:005. The uncertainty in the location of the principal jump is caused by the