Discontinuities and shocks

Definitions

Shock is a non-linear plasma wave generated by plasma flow (Burgess, 1995). This wave is irreversible (entropy-increasing), and it causes a transition from supersonic (upstream, Mach number M>1) to subsonic (M<1) flow. Shocks are thus places where plasma and field go through dramatic changes in density, temperature, field strength, and/or flow speed. If there is no plasma flow through the surface (Un <> 0) or there is no dissipation and compression across it, we talk about **discontinuity** only, not shock.

Discontinuity/shock types

The problem with space plasma is that there are several "typical" information speeds: for example, there are three different MHD wave types: fast, intermediate, and slow. Furthermore, space plasmas are **collisionless**, which complicates things even more. The following table lists the possible discontinuities and shocks under ideal MHD. The oblique shocks, divided into three categories, corresponds to the MHD waves listed above.

Possible types of discontinuities in ideal MHD		
Contact discontinuity	Un = 0, Bn <> 0	Density jump arbitrary, but pressure and all other quantities are continuous
Tangential discontinuity	Un = 0, Bn = 0	Plasma pressure and field change, maintaining static pressure balance
Rotational discontinuity	Un = Bn/sqrt(mu x ro)	Large-amplitude intermediate wave; in isotropic plasma, field and flow change direction, but not magnitude
Shock waves	Un <> 0	Flow crosses surface of discontinuity accompanied by compression and dissipation
Parallel shock	Bt = 0	Magnetic field unchanged by shock
Perpendicular shock	Bn = 0	Plasma pressure and field strength increase at shock
Oblique shocks	Bt <> 0, Bn <> 0	Fast shock Plasma pressure and field strength increase at shock; magnetic field bends away from normalSlow shock Plasma pressure increases; magnetic field strength decreases; magnetic field bends towards normal Intermediate shock (Alfvén) Magnetic field rotation of 180° in plane of shock; density jump only in anisotropic plasma
U = flow velocity, B = magnetic field; n, t refer to normal and tangential directions, respectively		

Many solar wind discontinuities are tangential. In the absense of reconnection, magnetopause and cross-tail current are also tangential discontinuities. Of the shocks, fast shocks are the most typical in solar system plasmas. For example, Earth's bow shock is a fast shock, as are also most interplanetary shocks in the solar wind.

Shock geometry and strength

An important factor influencing the shock behavior is the shock geometry, i.e., direction of the upstream magnetic field. It is measured using an angle *T* between the field and the shock normal. *T* = 0° gives **parallel** shock, and *T* = 90° **perpendicular** (quasi-parallel and quasi-perpendicular refer to less strict conditions). **Oblique** shock is something in between.

Shock strength tells the amount of energy processed by the shock. It is measured with the Mach number. Higher Mach number shocks are called supercritical as opposed to subcritical shocks. Bow shock is an example of the former type (Alfven Mach number 1.5-10), while interplanetary shocks are of the latter type.

Dissipation processes in shocks

In all shock formations there is, by definition, irreversible dissipation that transforms the ram energy of the plasma flow into thermal energy. For subcritical shocks this can happen because of effective, or anomalous, resistivity and viscosity due to waves (as opposed to collisions). The waves grow due to some instability, which will be driven by departure from equilibrium of the particle distribution function.

However, in supercritical shocks anomalous resistivity cannot provide the required dissipation. Furthermore, ions are heated much more than electrons, which cannot be explained by the current-driven instabilies invoked for anomalous effects. It has been shown that **reflection of ions**

from the shock are important in these cases. In quasi-perpendicular shocks, the shock field spreads out the ion distribution function, which will provide free energy for ion instabilities downstream.

Foreshocks and particle acceleration

Planetary bow shock have upstream regions called foreshocks, created by energetic particles that travel upstream from the bow shock. These regions are full of interesting waves and particles.

Particle acceleration processes are typical at shocks.

References

- Burgess, D., Collisionless shocks, in *Introduction to Space Physics*, eds. by M. G. Kivelson and C. T. Russell, Cambridge University Press, 1993.