Laboratory plasmas offer a unique opportunity to study the interaction of magnetic fields with plasmas. In particular, the diffusion region of the reconnection problem can be properly modeled since its scale length is much smaller than that of the entire convection region. Whereas in space, it is difficult to locate and analyze the field reversal region, in the laboratory one can perform repeated in situ measurements of fields, particles, and waves with high resolution in time and space. Such experiments are presently being performed at UCLA. Since the major results have been presented in recent publications this extended abstract serves to summarize the findings and to point out the relevant references.

By imposing an X-type neutral magnetic field of increasing strength in time on a large collisionless plasma column we observed the self-consistent formation of a classical neutral sheet [Stenzel and Gekelman 1981]. The associated plasma flow leads to jetting velocities approaching the Alfvén speed [Gekelman et al., 1982]. The plasma is heated and compressed but the energy density $nkT$ maximizes near the outflow regions of the neutral sheet rather than in the central stagnation region [Gekelman and Stenzel, 1981]. Comprehensive measurements of fields, flows, density and temperature were combined in the generalized Ohm's law in order to determine the resistivity which was found to be anomalously large and spatially inhomogeneous [Stenzel et al., 1982]. The complex spatial resistivity profile led some observers to comment on measurement errors [Baum and Bratenahl, 1983] but our subsequent observations of runaway electrons in the current sheet [Stenzel et al., 1983] showed, more fundamentally, that the fluid description of the plasma in the diffusion region is an over simplification and should be replaced by kinetic theory.

In spite of the macroscopic stability of the neutral sheet the diffusion region contains a rich spectrum of microinstabilities. Most extensive investigations have been performed on magnetic fluctuations [Gekelman et al., 1982b; Gekelman and Stenzel, 1984]. From two-probe cross-correlation functions Fourier analyzed in time and space the fluctuation spectrum $S_{\omega_F}$ has been identified to follow the dispersion surfaces of oblique whistler waves. Furthermore, the polarization of individual modes has been confirmed to be right-hand circular. Although the wave intensity decreases from the lower hybrid to the electron gyrofrequency recent higher frequency scans indicated magnetic fluctuations near cyclotron harmonics. These are thought to be associated with electromagnetic cyclotron harmonic waves in high beta plasmas [Khaladze et al., 1972]. Electrostatic wave analysis has revealed ion acoustic turbulence [Stenzel and Gekelman, 1981b] and enhanced microwave emission due to mode conversion from unstable electron plasma waves [Whelan and Stenzel, 1981].

In order to understand the origin of the various microinstabilities the particle distribution functions have been investigated. Using a novel directional velocity analyzer [Stenzel et al., 1983b] the electrons are observed to exhibit tails of runaway electrons accelerated by the electric field along the separator [Stenzel and Gekelman, 1984]. These velocity-space anisotropies are confined to the current sheet and are not observed in the adjacent convection region. They do not only provide a source of free energy for exciting instabilities but are also important for the transport properties. For example, the energetic electron tail makes a major contribution to the neutral sheet current and energy flow along the separator. The plasma resistivity is not determined by the bulk electron temperature but by inertial effects and wave-particle interactions of the spatially varying particle tails.

Particle accelerations, heating and energy transport undoubtedly involve wave-particle interactions in a collisionless plasma. Observations of heat transport have been initiated by studying electron temperature fluctuations with a new array probe [Wild et al., 1983a]. Spatial cross-correlation measurements revealed that electron heating occurs in bursts arising from current bursts. The heat pulses spread out from the current sheet across the magnetic field at an enhanced thermal conductivity.

Using the directional velocity analyzer in conjunction with a high-speed computer for mass data processing it is now possible to map diffusion processes in phase space ($v, T$). Observations indicate that a perturbation of the distribution function in the current sheet by an obstacle (e.g. satellites, moons) relaxes on a spatial scale short compared with interparticle collision lengths in a turbulent plasma [Wild et al., 1983b]. These microscopic kinetic processes have to be further investigated in order to explain the "anomalous" fluid properties.

Macroscopic disruptions of a current sheet are of primary concern for rapid reconnection events such as substorms and flares. By increasing the current density spontaneous impulsive disruptions of the current sheet have been observed [Stenzel et al., 1983c]. These involve a redistribution of the current profile from a sheet to two channels. Magnetic energy is released in this process which manifests itself by an inductive voltage drop inside the plasma at the location of the current disruption. A nonstationary potential double layer is formed during the disruption. Particle beams are generated and the plasma is thinned in the perturbed current layer. Onset and recovery of these spontaneous disruptions are explained by the nonlinear interaction between the global circuit properties and the local plasma behavior.

The location of the magnetic energy storage, the energy transport and its conversion into kinetic energy are crucial aspects of dynamic reconnection processes. New disruption experiments have been initiated where the bulk of the magnetic energy is stored locally inside the plasma and suddenly released by a controlled current disruption [Stenzel and Gekelman, 1983]. Circulating currents corresponding to large amplitude magnetic waves are set up which tear the current sheet, convect and dissipate the excess magnetic energy.

References


Gekelman, W. and R. L. Stenzel, Magnetic field line reconnection experiments

Questions and Answers

Vasyliunas: From the electron parameters shown in one of your figures, it appears that the relative ion-electron drift speed, $v_{de}$, is nearly comparable to the electron thermal speed. In the magnetotail, on the other hand, $v_{de}$ is typically much smaller than the electron thermal speed. Thus it is not clear to what extent features like double layer which may depend on exceeding critical current densities, can be scaled from the laboratory to the magnetotail.

Stenzel: Indeed, the scaling from the laboratory to the magnetotail is a difficult task and the point you raised is important to consider. The threshold condition $v_{de} \geq v_{th}$ for the classical one-dimensional, stationary double layer in unmagnetized plasmas. In the laboratory we observe three-dimensional, impulsive double layers in a high beta plasma with thresholds as low as $v_{de} \approx 0.1$. It is theoretically not clear what the threshold of a possible double layer in the magnetotail might be. This, unfortunately, compounds the difficulties for making predictions, but it does not rule out a qualitative comparison between the laboratory and space.