STABILITY OF LUMINOUS DISCHARGES IN STRONG FIELDS

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ABSTRACT. I show that a common thermal instability of conventional plasma discharges does not occur if plasma turbulence impedes current flow. Normally, thermal discharges drain current into a single hotter filament, because classical Coulomb resistance falls as a filament heats. Anomalous resistance reverses this, stabilizing the circuit. Only small levels of turbulence are needed.

Electrodynamic models in strong magnetic fields are vulnerable to disruption. In particular, models of the luminous filaments at galactic center must explain the persistence of features, whether caused by colliding magnetic loops (Heyvaerts et al, 1988) or currents driven by induction from passing molecular clouds (Benford, 1988). A crucial but seldom recognized problem with establishing current systems lies in a simple thermal instability.

Consider a network of strong magnetic field lines, all open to possible currents driven by an external source. This resembles a set of parallel conductors. If normal Coulomb resistivity sets the level of resistance, R, we expect that R scales with $T^{-3/2}$. Suppose a voltage source induces currents along a flock of magnetic paths, heating them and illuminating them, perhaps accelerating electrons in temporary current disruptions so that we can see these features by synchrotron radiation. Now let one single current path heat a bit more, so that its resistance drops. More current than flows in this lesser resistance, drawing current from the other strands. This continues until the entire electrodynamic potential acts solely through one path, a series circuit with very small R since it is now very hot.

Plainly this can occur instrands described by the Bennett pinch condition, for example. For such equilibria, T is proportional to I^2, with I the total current. Since V=IR, dR/dT is negative because dI/dT is positive. Thus any Bennett pinch assembly invoked to explain, for example, the galactic center filaments as in Benford (1988), will be unstable to formation of a single, hotter filament in a time $\sim L/v_A$ if Coulomb collisions set the resistance. For Bennett pinches this requires only minutes!

Averting this catastrophe requires anomalous resistivity. As the

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classical resistance falls, electron speed increases to carry the higher currents. Eventually the electron drift speed exceeds some threshold, roughly a few times the ion thermal speed, and unstable ion waves grow to amplitudes such that they effectively scatter electrons, stabilizing the system. Details do not matter here, since we are only interested in the condition that $dR/dI > 0$ to avoid thermal instability of the circuit; microinstability averts macroinstability. This process begins when the anomalous collision frequency (from electron scattering by fluctuating electric fields) exceeds the Coulomb scattering rate. A plausible expression for the anomalous scattering frequency is $W\,\omega_p$, with ω_p the plasma frequency and $W = \langle E^2 \rangle / 4\pi kT$ is a dimensionless measure of the importance of the fluctuating fields, E. Requiring that this rate exceed the Coulomb scattering demands (for typical estimates of galactic center quantities) $W > 10^{-8}\ (n/10^9\ \mathrm{cm}^{-3})^{1/2}\ (T/100\ \mathrm{eV})^{-3/2}$ Here T is the electron temperature and n is the plasma density. This is a very mild condition on W, one exceeded by the great majority of laboratory turbulence experiments. The electric fields induced by moving molecular clouds near the galactic center should induce fields of about 10^{-8} stat Volt/cm, which quickly accelerates electrons to relativistic speeds if only Coulomb scattering occurs, thus soon provoking plasma waves.

I conclude that resistance dominated by plasma waves is essential to maintaining any luminous discharge for long times, and mild levels of turbulence will do the job. Inverting the argument, when we observe orderly arrays, as at galactic center (and perhaps as well in magnetospheric environments of the planets), we must conclude that plasma waves dominate transport there. This provides a qualitative standard for invoking plasma processes in such environments.

The persistence of even very small current-carrying filaments can be assured, then, by the very turbulence which is so often feared as an enemy of magnetic confinement in the fusion energy program. Recently Blandford (1989) raised the question of whether Alfven turbulence could disrupt small ($\sim 10^4$ km) pinched current paths. While Alfven waves can modify magnetic structures, active features are replenished by the very fact that they are in a circuit. Any modification of a pinch will alter the circuit parameters, and the system will correct or readjust itself to erect some similar current-carrying path to fulfill the macroscopic electrodynamic requirements. Another way of saying this is that a magnetic pinch is rebuilt by the current flow itself in an Alfven time, so turbulent Alfven waves have no longterm effect.

I conclude that turbulence may well be essential in producing large, luminous features in strong magnetic fields. The fields provide the "backbone" which can avoid wriggling and pinch instabilities. Persistence of visible filaments argues that these regions must experience substantial turbulence, providing a qualitative visual signature of microscopic processes. This work was supported by AFOSR.

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