Experimental investigations into what open-field line, current-carrying, magnetized plasmas really do

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Abstract

Although magnetohydrodynamics (MHD) is presumed to be a fairly mature subject, experimental investigations continue to reveal remarkable new insights into how MHD really works.

The Caltech experimental research program has demonstrated that certain widely used MHD paradigms are either inappropriate or somewhat misleading. These paradigms date from the early days of fusion research when it was assumed that (i) a plasma could be considered to be in a static MHD equilibrium and (ii) there could be stable or unstable Fourier mode perturbations about this equilibrium. Another paradigm has been to assume that if the plasma has low beta, its behavior can be reasonably described by ignoring pressure gradients.

What has been found is that when electric current flows along open magnetic field lines, the presumed static equilibrium typically does not exist and instead complex non-equilibrium dynamics occur. The plasma progresses through a sequence of non-equilibrium configurations involving strong unbalanced MHD forces causing high-speed plasma flows. These flows convect the frozen-in magnetic flux associated with the magnetic field produced by the electric current. This magnetic field provides a plasma-confining pinch force and so produces substantial pressure gradients. The pinched flow is thus a collimated, MHD-driven plasma jet. The jet is neither static nor in equilibrium

because it is lengthening. Despite not being in static equilibrium, the jet can develop MHD kink instabilities because the kink grows on a faster time-scale than the jet characteristic time. Hence kink instability is not restricted to static equilibria but is also an important feature of dynamically changing, non-equilibrium plasmas.

Most recently, it has been observed that (i) the kink itself can become unstable to a finer-structure, much faster instability (instability of an instability) that suddenly rips the jet apart and (ii) when current flows along a magnetic flux tube bulged at its axial midpoint, MHD forces drive axial plasma jets from both ends towards the axial midpoint. These effects are observed using high-speed imaging systems that capture the plasma evolution on the Alfven time scale.

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