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Laboratory astrophysics using differential rotation of unmagnetized plasma at large magnetic Reynolds number

DAVID WEISBERG, UW Madison (currently ORAU)

Differentially rotating plasma flow has been measured in the Madison Plasma Dynamo Experiment (MPDX). Spherical cusp-confined plasmas have been stirred both from the plasma boundary using electrostatic stirring in the magnetized edge *and* in the plasma core using weak global fields and cross-field currents to impose a body-force torque. Laminar velocity profiles conducive to shear-driven MHD instabilities like the dynamo and the MRI are now being generated and controlled with magnetic Reynolds numbers of $Rm < 250$ and fluid Reynolds numbers of $Re < 200$. The measured plasma confinement contradicts existing theories for magnetic cusp confinement, and a new quasi-1D ambipolar diffusion model is presented to explain measurements of cusp loss widths that do not fit the classic hybrid gyroradius theory. Emissive electrode discharge is shown to be an efficient method for plasma heating, but limits on input heating power have been observed (believed to be caused by the formation of double-layers at anodes). These confinement studies have culminated in large ($R = 1.4\,\mathrm{m}$), warm ($T_e < 20\,\mathrm{eV}$), dense ($n_e < 5 \times 10^{18}\,\mathrm{m}^{-3}$), unmagnetized ($M_A > 1$), steady-state plasmas. Results of the ambipolar transport model are good fits to measurements of pressure gradients and fluid drifts in the cusp, and offer a predictive tool for future cusp-confined devices. Hydrodynamic modeling is shown to be a good description for measured plasma flows, where ion viscosity proves to be an efficient mechanism for transporting momentum from the magnetized edge into the unmagnetized core. In addition, the body-force stirring technique produces velocity profiles conducive to MRI experiments where $d\Omega/dr < 0$. Measured values of Rm and Re are significantly higher than previous flow experiments in cusp-confined plasmas, setting the stage for future progress in laboratory research of flow-driven astrophysical MHD instabilities.