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Experiments on the dynamics and scaling of spontaneous-magnetic-field saturation in laser-produced plasmas[1]

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Saturation of spontaneous magnetic fields in plasmas results from the balancing of various physical processes. Understanding the saturation mechanisms is a challenging undertaking essential to basic plasma physics. In high-energy-density (HED) plasmas produced with high-power lasers, large-scale strong magnetic fields are generated by the Biermann-battery effect when temperature and density gradients are misaligned. Saturation takes place when advection and dissipation balance the field generation. While theoretical and numerical modelling provide useful insight into the saturation mechanisms, experimental demonstration remains elusive. To quantitatively study these dynamical processes, new experiments were performed at the OMEGA laser. Illuminating a plastic foil with a laser of energy $\sim$ kJ in a $\sim$ ns pulse, $\sim$ megagauss Biermann fields were generated, which subsequently advected and dissipated in an expanding plasma plume. With time-resolved proton radiography and Thomson scattering, the evolution of the magnetic field structure and plasma conditions were measured. The experiments and resulting data were modeled with hydrodynamic simulations. For the first time at these conditions, the spatially resolved magnetic fields were reconstructed, leading to a picture of field saturation with a scaling of B $\sim 1/\mathrm{L}_T$ for a convectively dominated plasma, a regime where the temperature gradient scale (L_T) exceeds the ion skin depth (d_i). This work not only quantifies the saturation mechanism and scaling with underlying physics in a typical laser-plasma experimental regime, but also more broadly provides new physical insight into the dynamics of spontaneous magnetic fields in HED plasmas.

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