Isotope mass and charge effects in tokamak plasmas

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The effect of primary ion species of differing charge and mass – specifically, deuterium, hydrogen and helium – on instabilities and transport is studied through gyrokinetic simulations with GYRO [J. Candy and E. Belli, General Atomics Technical Report **GA-A26818** (2010)]. In particular, we performed transport analysis of three balanced neutral beam injection DIII-D discharges which have different main ion species (129135 deuterium, 133778 hydrogen and 138767 helium). We present simulations of a wide range of sophistication; from local linear electrostatic simulations with adiabatic electron response to global non-linear simulations including several ion specii and neoclassical flows.

In linear simulations under imposed similarity of the profiles there is an isomorphism between the linear growth rates of hydrogen isotopes, but the growth rates are higher for $Z > 1$ main ions due to the appearance of the charge in the Poisson equation. Including non-adiabatic electron response leads to the breaking of the perfect similarity of the growth rates between ions with same charge due to the difference in the parallel motion of the nearly adiabatic circulating electrons. The trapped electron (TE) mode growth rates can exhibit qualitatively different behavior for high wave numbers for ions with different charge. On ion scales the most significant effect of the different electron-to-ion mass ratio appears through collisions stabilizing TE modes. In nonlinear simulations we find that the mass scaling of the width of the energy flux spectra compensates the (gyro-Bohm) mass scaling of their magnitude. The presence of any significant (hydrogen isotope or other) impurity species cannot be neglected in a comprehensive simulation of the transport; including carbon impurity in the simulations caused a dramatic reduction of energy fluxes.