KINETIC EFFECTS IN INERTIAL CONFINEMENT FUSION

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Recent exploding pusher experiments reveal substantial kinetic effects on the implosion performance, that appear as the plasma mean-free-path grows relative to the background scale making standard rad-hydro single-fluid description invalid [1,2]. In particular, gradients associated with the dynamical implosion process can drive the inter-ion-species transport, so the fuel composition no longer remains constant, unlike what the single-fluid codes assume. Furthermore, the mean-free-path of suprathermal particles is much larger than that of their thermal counterparts, so their distribution function may be far from Maxwellian, even if thermal ions are nearly equilibrated. Ironically, it is the suprathermal, or tail, ions that are supposed to fuse at the onset of ignition. Equally important, suprathermal particles are largely responsible for the heat flux. Hence, self-consistent modeling of inertially confined plasmas would appear to require a kinetic component.

A combination of studies has been conducted to clarify the role of such kinetic effects on ICF performance. First, transport formalism applicable to multi-component plasmas has been developed. In particular, a novel "electro-diffusion" [3] mechanism of the ion species separation has been shown to exist. Equally important, in drastic contrast to the classical case of the neutral gas mixture, thermo-diffusion is predicted to be comparable to, or even much larger than, baro-diffusion [4]. By employing the effective potential theory this formalism has then been generalized to the case of a moderately coupled plasma with multiple ion species, making it applicable to a wide class of high energy density (HED) phenomena [5].

Second, distribution function for the suprathermal ions has been found from first principles and the fusion reactivity reduction has been calculated for hot-spot relevant conditions. Moreover, the suprathermal ion distribution has been shown to be self-similar, that allows semi-analytical solution in the 1D case and provides a computationally expedient tool for evaluating kinetic effects in more complicated geometries. By utilizing this feature, interference between the hydro-instabilities and kinetic effects has been assessed quantitatively to find that the instabilities substantially aggravate the fusion reactivity reduction. In addition, the ion tail depletion has been shown to lower the experimentally inferred ion temperature relative to the actual one, a novel kinetic effect that may underlie the discrepancy between the exploding pusher experiments and rad-hydro simulations and partially explain the observation that DD temperature is lower than DT temperature at NIF [6].

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