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Kinetic Effects in Inertial Confinement Fusion[1]

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Sharp background gradients, inevitably introduced during ICF implosion, are likely responsible for the discrepancy between the predictions of the standard single-fluid rad-hydro codes and the experimental observations. On the one hand, these gradients drive the inter-ion-species transport, so the fuel composition no longer remains constant, unlike what the single-fluid codes assume. On the other hand, once the background scale is comparable to the mean free path, a fluid description becomes invalid. This point takes on special significance in plasmas, where the particle's mean free path scales with the square of this particle's energy. The distribution function of energetic ions may therefore be far from Maxwellian, even if thermal ions are nearly equilibrated. Ironically, it is these energetic, or tail, ions that are supposed to fuse at the onset of ignition. 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" 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. 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 the problem of mix at the shell/fuel interface in ICF implosion. Second, distribution function for the energetic ions has been found from first principles and the fusion reactivity reduction has been calculated for hot-spot relevant conditions. A technique for approximate evaluation of the distribution function has been identified. This finding suggests a path to effectively introducing the tail modification effects into mainline rad-hydro codes, while being in good agreement with the first principle based solution.

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