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Study of shock waves in the National Ignition Facility

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Astrophysical collisionless shocks are ubiquitous in the Universe and are observed to amplify magnetic fields and accelerate electrons and protons to highly relativistic speeds in a variety of places, from supernova remnants to active galactic nuclei. In the well-established model of diffusive shock acceleration, electrons are accelerated by multiple shock front crossings; however, this requires a separate mechanism that pre-accelerates electrons to enable shock crossing. This is known as the injection problem and remains one of the most pressing open questions in shock acceleration, alongside the poorly understood energy partitioning between electrons and ions. Observational limitations in distant astrophysical settings prevent direct access to the microphysics of these shocks, driving the need for complementary approaches. Significant progress in our understanding of collisionless shock physics has been achieved through kinetic and nonlinear numerical approaches, with a primary emphasis on particle-in-cell (PIC) simulations, which describe the plasma from first principles. In recent years, further progress has been attained by synergistically combining PIC codes with laboratory experiments conducted in high-power laser facilities like the National Ignition Facility (NIF), offering a unique avenue to study the microphysics of scaled-down analogues of astrophysical shocks under reproducible and well-diagnosed conditions.

In this work, we conduct fully kinetic one-dimensional PIC simulations under conditions relevant to upcoming NIF experiments, focusing on the formation of magnetized shocks and electron acceleration. Our results demonstrate that the formation of quasi-perpendicular shocks and the onset of non-thermal electron acceleration are achievable within the experimental time and spatial scales. These findings provide valuable insights into the feasibility of addressing the injection problem and advancing our understanding of shock microphysics through laboratory experiments.

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