Strongly Correlated Plasmas in Penning Ion Traps

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Ions in a trap are a good realization of a one-component plasma (OCP). An OCP consists of a single species of charged particles that are immersed in a uniform, neutralizing background charge. Theoretical calculations predict that a bulk strongly coupled OCP undergoes a first-order liquid-solid phase transition to a body-centered cubic (bcc) lattice at a Coulomb coupling parameter $\Gamma[\equiv q^2 / (4\pi\epsilon_0 a_{WS} k_B T)] \sim 172$. With Doppler laser cooling and ion densities $> 10^8$ cm^{-3} we routinely achieve couplings $\Gamma > 1000$ with up to 10^5 Be^+ ions in a Penning trap. We have used Bragg scattering and real-space imaging techniques to observe the types of crystals that form for $\Gamma >> 172$. For approximately spherical plasmas, 3-D periodic crystals were observed with plasma diameters as small as 30 interparticle spacings. When the plasma diameter was greater than ~60 interparticle spacings we exclusively observed bcc crystals (bulk behavior) [1]. For thin, disc-shaped plasma, we observed a crystal structure that sensitively depended on the plasma thickness [2].

After a brief review of the observations of static correlations mentioned in the previous paragraph, we will discuss a measurement of the equilibration rate of ion cyclotron energy with ion energy parallel to the magnetic field. We observe an equilibration rate that is enhanced by more than 10^{10} over that predicted for uncorrelated ($\Gamma << 1$) plasmas [3]. The enhancement is due to screening of the Coulomb repulsion between colliding ion pairs by the surrounding (correlated) plasma and is closely related to the enhancement of nuclear reactions in dense stellar interiors, first predicted 50 years ago by Salpete and colleagues [4, 5]. This is the first observation of this enhancement in the strongly correlated regime and high energy density plasmas. This is a good example of how a cold atomic system can be used to study the physics of dense matter in a controlled laboratory setting.

If time permits we hope to discuss some of the similarities and differences between cold trapped ions and ultra-cold neutral plasmas, and some studies in strongly coupled plasma physics that can possibly be pursued in these systems.

References

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