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Theory of strongly correlated plasmas: phase transitions, transport, quantum and magnetic field effects

Michael Bonitz, Hanno Kählert, Torben Ott, and Tobias Dornheim
ITAP, Kiel University, Germany

We review recent progress in the theory and simulation of strongly correlated charged particle systems. Examples are complex (dusty) plasmas and dense quantum plasmas in warm dense matter. Strong Coulomb correlations are known to cause dramatic consequences for the structural properties of many-particle systems – leading to a departure from the trivial ideal gas behavior, towards liquid-like and crystal-like states [1]. This has been extensively studied in dusty plasmas (Coulomb and Yukawa crystals), and the structure of the phase diagram and the precise location of the phase boundaries is well accessible in simulations and experiments [2]. Also, the time-dependent formation of Coulomb crystals has been studied [3].

Another interesting development is the analysis of magnetic field effects on the structural and dynamic properties of strongly correlated plasmas. An unexpected result is that a strong magnetic field can effectively block crystallization [4]. Aside from structural and thermodynamic properties, excitation and transport behavior is very important for many applications. This can be studied very accurately using molecular dynamics simulations. We will present some results on the interesting interplay of Coulomb correlations and magnetic field effects, on the example of the diffusion coefficient, which shows surprising differences from the behavior of weakly coupled plasmas [5].

While magnetic field effects are omnipresent in many astrophysical plasmas (e.g., neutron stars) and these effects are important for many aspects of the time evolution, in dusty plasmas, it is practically impossible to magnetize the heavy dust particles. Here, an interesting alternative concept has been proposed: the use of a rotating plasma setup which – via the Coriolis force – mimics magnetic field effects [6]. As a result, "effective fields" on the order of several thousand Tesla can be easily generated.

As a final aspect, we will touch upon strong correlation effects in dense quantum plasmas. Here, accurate data for the thermodynamic properties are very difficult to obtain, due to the quantum and spin effects that are of relevance for the electron component. In the absence of small parameters, theoretical approaches face severe problems. Here, we have recently made significant progress in the development of *ab initio* quantum Monte Carlo simulations which avoid the notorious fermion sign problem. This has allowed us to produce highly accurate thermodynamic results for the electron gas in the entire warm dense matter region [7] which will serve as a crucial input for future quantum plasma simulations.

A summary of the presentation and further references will be published in Ref. [8].

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