Hydrodynamic Studies of Dipolar Quantum Gases

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In recent years, dilute quantum degenerate gases interacting through the long-range and anisotropic dipole-dipole interaction have attracted much attention. At first, magnetic dipolar effects have been unambiguously demonstrated in atomic Bose-Einstein condensates of ^{52}Cr, ^{87}Rb, and ^{7}Li. In addition, recently fermionic ^{40}K^{87}Rb molecules with an electric dipole moment of about 0.5 Debye were brought close to quantum degeneracy by using stimulated Raman adiabatic passage to efficiently convert these heteronuclear molecules into their rovibrational ground state. Due to a large electric dipole moment, the dipole-dipole interaction between such molecules might be up to 10, 000 times larger than in magnetic atomic systems. In the talk we review recent theoretical investigations of the static and the dynamic properties of polarized dipolar quantum gases at zero temperature [1]. The first part deals with dipolar Bose-Einstein condensates, while the second part is dedicated to dipolar Fermi gases in the non-superfluid phase.

Concerning dipolar condensates, we calculate beyond-mean-field corrections to the physical quantities of interest for a harmonically trapped system by working out the Bogoliubov-de Gennes theory [2]. To this end we derive the Bogoliubov excitation spectrum analytically within the local density approximation. By calculating the beyond-mean-field correction to the ground-state energy, we determine the corresponding equations of motion for the Thomas-Fermi radii of the condensate. In equilibrium, we obtain from these equations the quantum correction to the mean-field Thomas-Fermi radii. Afterwards, we consider the quantum corrections to the low-lying oscillation frequencies as well as to the time-of-flight expansion of the condensate. Due to the interplay between the dipolar interaction and the condensate geometry, we find that the influence of quantum fluctuations is strongly affected by the trap aspect ratio so that future experiments should be able to detect them.

In order to investigate the physical properties of dipolar Fermi gases in a harmonic trap, we derive a variational time-dependent Hartree-Fock theory within the Wigner representation [3,4]. We focus on the hydrodynamic regime, where collisions assure the equilibrium locally. After deriving the equations of motion for the Thomas-Fermi radii in phase space, we first explore their static solutions and discuss the aspect ratios in both real and momentum space. In the case where the polarization direction coincides with one of the trap axis, we find that the momentum distribution remains cylindrical, even for a triaxial trap. Afterwards, we study the hydrodynamic excitations. Thereby, we show that the corresponding oscillations in momentum space are anisotropic due to the presence of the dipole-dipole interaction. Finally, we study the time-of-flight dynamics and find that the real-space aspect ratios are inverted during the expansion, while the one in momentum space becomes asymptotically unity. All these results could be particularly useful for future experiments with strong dipolar fermionic molecules deep in the quantum degenerate regime.

[1] A.R.P. Lima, PhD thesis, Freie Universität Berlin (2011);
`http://users.physik.fu-berlin.de/~pelster/Theses/lima.pdf`
[2] A.R.P. Lima and A. Pelster, *Quantum Fluctuations in Dipolar Bose Gases*; `arXiv:1103.4128`
[3] A.R.P. Lima and A. Pelster, *Collective Motion of Polarized Dipolar Fermi Gases in the Hydrodynamic Regime;* Phys. Rev. A **81**, 021606(R) (2010)
[4] A.R.P. Lima and A. Pelster, *Dipolar Fermi Gases in Anisotropic Traps*; Phys. Rev. A **81**, 063629 (2010)