Few-body and many-body physics with magnetic dipolar atoms in ultracold gases

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Ultracold quantum gases provide a pristine platform to study few-body and many-body quantum phenomena with an exquisite degree of control. The achievement of quantum degeneracy in gases of atoms with large magnetic dipole moments in their electronic ground states has opened new avenues of research in which long-range anisotropic dipole-dipole interactions play a crucial role. In this series of two lectures, I will give an overview of experimental progress focusing on few-body and many-body phenomena, respectively.

In the first lecture, I will begin by outlining the peculiar atomic properties of highly magnetic atoms and how this has enabled their cooling. I will then review important aspects of dipolar two-body scattering. I will discuss the intrinsic consequence of the long-range and anisotropic character of the interaction, review important features of both elastic and inelastic dipolar scattering, and present the experimental consequences of these properties. Finally, I will discuss the specificity of short-range scattering and its tunability between magnetic atoms. The complex atomic structure and the large dipolar moments of these atoms lead to a dense spectrum of so-called Feshbach resonances in the s-wave scattering. This reveals chaotic behavior, prevents proper prediction, but enables tunability.

In the second lecture I will focus on many-body effects arising from dipole-dipole interactions in quantum gases of magnetic atoms. I will focus mainly on polarized Bose gases. In this case, the dipolar interactions compete with the conventional short-range contact interactions, the strength of which can be tuned by the Feshbach resonances. I will discuss many-body effects occurring at the mean-field level, including magnetostriction, anisotropy of elementary excitations and superfluid character, and rotonization of the excitation spectrum. I will then discuss the limits of the mean-field regime, i.e. the mean-field instabilities, the potential collapse dynamics, and, specific to the most magnetic atoms, the beyond-mean-field stabilization effect arising from the quantum fluctuations themselves. The latter effect has led to the discovery of novel many-body quantum phases, including liquid-like droplets, droplet crystals, and supersolids, a paradoxical phase of matter that simultaneously exhibits solid and superfluid orders. I will review the experimental observations of such exotic states and their properties. Finally, I will draw a larger picture of other implications of dipolar effects in magnetic quantum systems, including the rich cases of lattice physics, spinfull dipoles, and reduced dimensions.

References:

[1] L. Chomaz, I. Ferrier-Barbut, F. Ferlaino, B. Laburthe-Tolra, B. L. Lev, and T. Pfau, *Dipolar physics: a review of experiments with magnetic quantum gases*, Rep. Prog. Phys. **86**, 026401 (2023).