Dipolar quantum gases: From rotons to supersolids to vortices

Manfred J. Mark[1, 2, *]

[1] *Institut für Experimentalphysik, Universität Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria*
[2] *Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstr. 21A, 6020 Innsbruck, Austria*

The field of ultracold atomic gases has seen a tremendous evolution over the past 25 years since the first successful creation of a Bose-Einstein condensate in 1995. Such systems offer an unprecedented control over essentially all degrees of freedom, making them an ideal platform for what is now called quantum simulation. The advent of quantum gases made from lanthanide atoms 12 years ago opened up the new field of strongly dipolar systems, as they feature a strong magnetic dipole moment, giving rise to long-range and anisotropic interactions between the atoms. This type of interaction has proven to be a rich source of new and fascinating many-body phenomena.

In this colloquium i will recap some of the most recent discoveries, starting with the observation of the rotonized excitation spectrum. This effect, first proposed from Landau for liquid helium, was predicted to occur also in strongly dipolar quantum gases, and finally got observed recently in our lab [1]. This triggered the interest of many groups, as it was believed that the roton mode is a precursor for crystallization, opening up the possibility to have spontaneous density modulations while being superfluid - a so-called supersolid state. Already a year later, three groups showed the existence of this long-sought state, including two realizations in our group [2]. Our comparatively long lifetimes allowed us to investigate this state in terms of its dynamical response to phase excitations, where we observed rapid dephasing/rephasing of the system [3]. We were also able to study the lifecycle of the state, from its initial forming directly out of a thermal cloud until its decay to a Bose-Einstein condensate due to particle loss [4]. Finally we studied its dependence on the trap geometry and managed to observe supersolidity where the translational symmetry is broken along two directions in a pancake-shaped trap [5]. Most recently we implemented a novel technique to induce rotation into our system called magnetostirring. This allowed us to create quantized vortices in a dipolar gas for the first time, where we observed first signatures of vortex stripes, a peculiar arrangements of the vortices driven by dipole-dipole interactions [6].

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[5] Two-dimensional supersolidity in a dipolar quantum gas, M. A. Norcia et al., Nature **596**, 357-361 (2021)
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* manfred.mark@uibk.ac.at