Dipolar Supersolids in One Dimension

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Background and Aims

A superfluid is a quantum liquid that flows without dissipation

A solid is a phase of matter characterised by spatial order

A supersolid is a phase of matter in which superfluid and solid-like order coexist

In 2019, researchers independently demonstrated the existence of a possible supersolid phase in strongly-dipolar bosonic quantum gases [1].

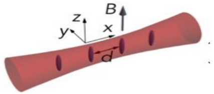
Our Objectives:

1. Understand the different zero-temperature ground states of 1D dipolar condensates
2. Understand the phase diagram of the supersolid system
3. Gain insight into whether superfluidity really coexists with solidity

The Model: Gross-Pitaevskii and Beyond

In line with recent experiments, we consider a gas of ultracold, dilute bosons that are

- Tightly confined in one plane (a *cigar-shaped trap)*
- Polarised perpendicular to the trap axis



[2]

If the confinement is tight enough, our system can then be described by the one-dimensional extended Gross-Pitaevskii equation for the *condensate wavefunction:*

$$i\hbar\frac{\partial\psi}{\partial t}=\left[-\frac{\hbar^2}{2m}\Delta+\underbrace{\frac{g}{2\pi a_\rho^2}|\psi|^2}_{①}+\underbrace{\Phi^{dd}[\psi,\overline{\psi}]}_{②}+\underbrace{\frac{2\gamma_{qf}}{5\pi^{3/2}a_\rho^3}|\psi|^3}_{③}\right]\psi$$ [3]

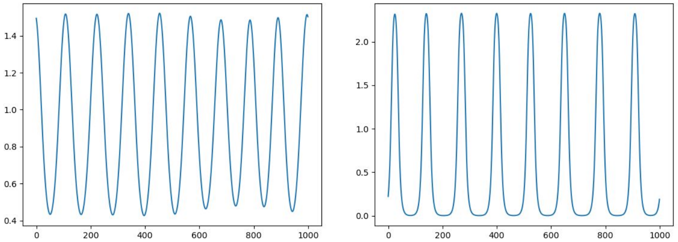
① Van der Waals forces- *short range, isotropic*

② Dipole-dipole forces- *long range, anisotropic*

③ LHY energy- beyond-mean-field correction to the energy

By simulating the evolution of a condensate in imaginary time, we can find all of the properties of the system's ground state at zero temperature.

Preliminary Results



Left: ground state wavefunction just above the phase transition
Right: droplet state far away from the transition.

ε_{dd} parametrises the relative strength of the dipole interactions. By tuning ε_{dd} (among other parameters) we have so far reproduced the profiles for three distinct ground states, one homogeneous (not shown here) and two inhomogeneous. The homogeneous ground state was found for weak dipole interactions. The left figure shows the ground state at ε_{dd} slightly larger than some critical value ε_{dd}^{crit}, while the right figure shows the ground state at $\varepsilon_{dd} >> \varepsilon_{dd}^{crit}$. The left diagram is a candidate for a ground state with supersolid properties.

Further Work

- Determine unambiguously the zero-temperature phase diagram of the dipolar gas, and the role of density in determining the phase diagram
- Test the superfluid properties of the inhomogeneous phase
- Find any other ground states the system may have

References

[1] L. Tanzi et al., April 2019, *Phys. Rev. Letts.*, **122**, 130405
[2] I. Ferrier-Barbut et. al., May 2016, *Phys. Rev. Letts.,* **116**, 215301
[3] M. Edmonds, T. Bland, N. Parker, Dec 2020, *J. Phys. Commun.,* **4,** 125008