Pseudopotentials for an ultracold dipolar gas

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Experimental background
Ultracold molecular gases combine many-body effects with fine control over interactions. They present a cleaner system than the solid state, allowing access to effects due to the combination of many-body interactions and quantum mechanics.

Experiments now allow the condensation of molecules that carry dipole moments, which interact via the long-range anisotropic dipolar interaction. For example, the Zwierlein group [2] uses fermionic \(^{23}\)Na\(^{40}\)K molecules with a large tunable electric dipole moment \(d\).

A particularly appealing geometry is a single component quantum-degenerate gas in 2D, with all the dipole moments aligned normal to the 2D plane. This arrangement is now within experimental reach [2,3].

Theoretical problems
Analytical models of this isotropic 2D dipolar gas have predicted a rich phase diagram, including an inhomogeneous density wave phase [4]. However, numerical studies of the system do not observe such a stable stripe phase [5].

In order to resolve this disagreement we improve the modelling of the dipolar potential, to increase the accuracy of numerical simulations. We propose the pseudopotential [6] shown in Figure 1, which captures the essential physics of the real dipolar interaction, as well as being easier to work with numerically [1]. The smoother pseudopotential means we can run simulations of the dipolar gas >450 times quicker than using the real dipolar potential, as shown in Figure 2.

Results
In Figure 3 we show the equation of state calculated using our pseudopotential and using the real dipolar potential, demonstrating high agreement between the simulations. The pseudopotential formalism developed here is now being used to investigate the stripe phase, and could be used for the rest of the dipolar gas phase diagram.

Conclusions
● Accurate pseudopotential for dipolar interaction
● >450 times speed up

Tilted dipoles
If the dipoles are tilted away from vertical the dipolar interaction becomes anisotropic. This means that angular momentum is no longer a good quantum number and the scattering problem is more difficult to solve, making the use of pseudopotentials to accelerate numerical calculations even more beneficial in the anisotropic part of the phase diagram.

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