Density wave instabilities of tilted fermionic dipoles in a multilayer geometry

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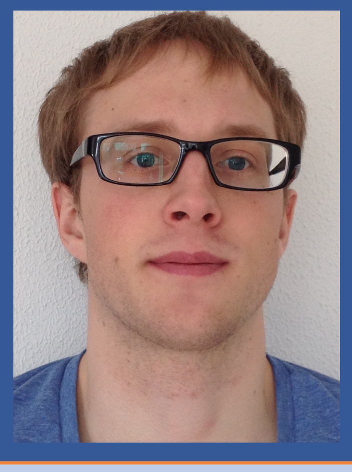


Introduction

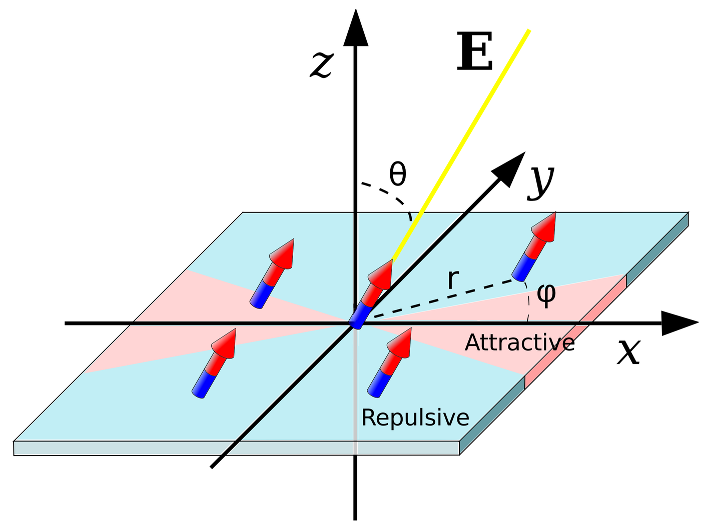
- The density wave instability is the onset of a periodic modulation of the density, which is caused by repulsive interactions.
- Fermionic dipoles are aligned by an external field and confined to in equidistant quasi 2D layers at zero temperature.
- In a conserving Hartree-Fock approximation, we calculate the critical coupling strength for the formation of density waves as a function of the dipole orientation and the distance between layers.

Dipole-dipole Interaction

The interaction between dipoles with dipole moment p is anisotropic when the external field is tilted.
The intralayer interaction,

$$V_{2D}(\mathbf{r}) = D^2 \frac{1 - 3\sin^2\theta\cos^2\varphi}{r^3},$$

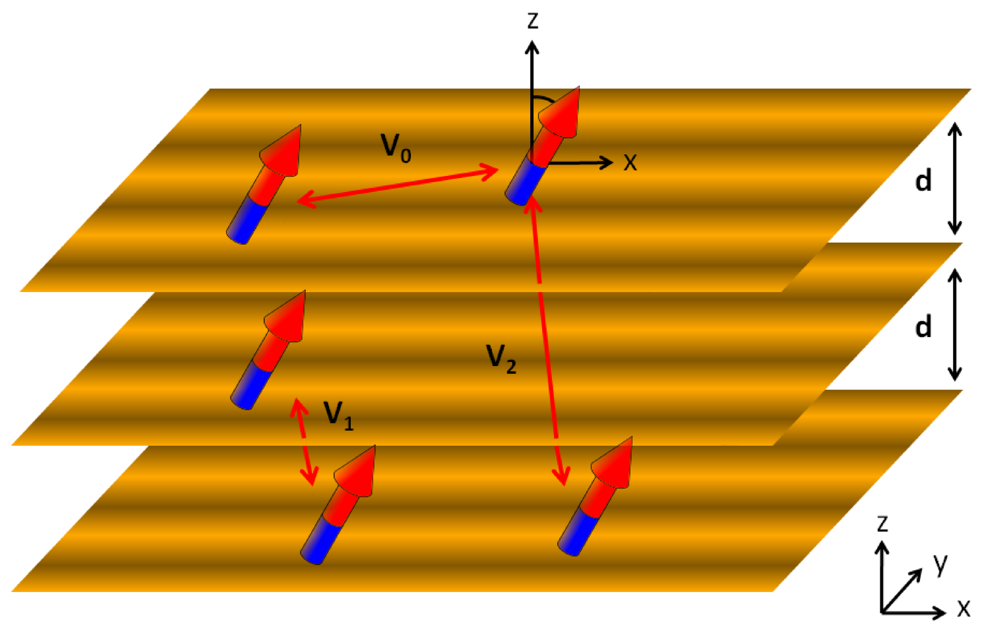
where $D = \frac{p^2}{4\pi\varepsilon_0}$, is illustrated in the figure on the right.



Intralayer interaction. Image: [1]

System

- The dipolar molecules are confined to quasi two dimensional layers by means of a deep one dimensional optical lattice.



- Quasi 2D single particle states

$$\psi_{l\mathbf{k}}(\vec{r}) \propto e^{-(z-ld)^2/(2w^2)} \cdot e^{i\mathbf{r}\cdot\mathbf{k}}$$

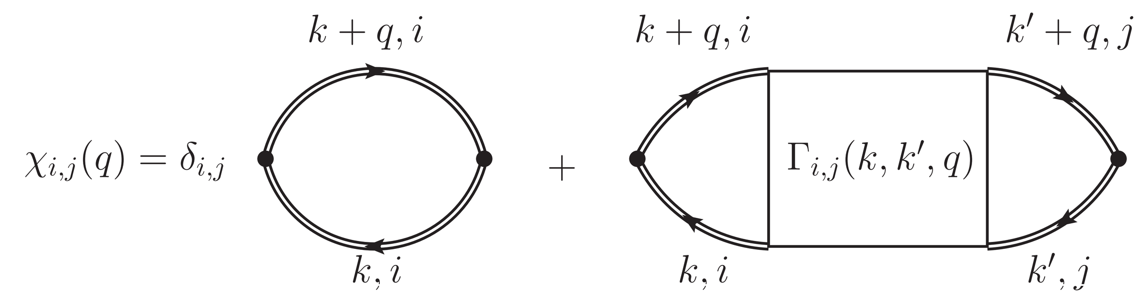
- Hopping suppressed in deep lattice

$$\mathcal{H} = \sum_{\mathbf{k},l}\left(\frac{k^2}{2m} - \mu\right)\hat{c}^\dagger_{\mathbf{k},l}\hat{c}_{\mathbf{k},l} + \frac{1}{2A}\sum_{l,l'}\sum_{\mathbf{k},\mathbf{k}',\mathbf{q}} V_{l-l'}(\mathbf{q})\hat{c}^\dagger_{\mathbf{k}+\mathbf{q},l}\hat{c}^\dagger_{\mathbf{k}'-\mathbf{q},l'}\hat{c}_{\mathbf{k}',l'}\hat{c}_{\mathbf{k},l}$$

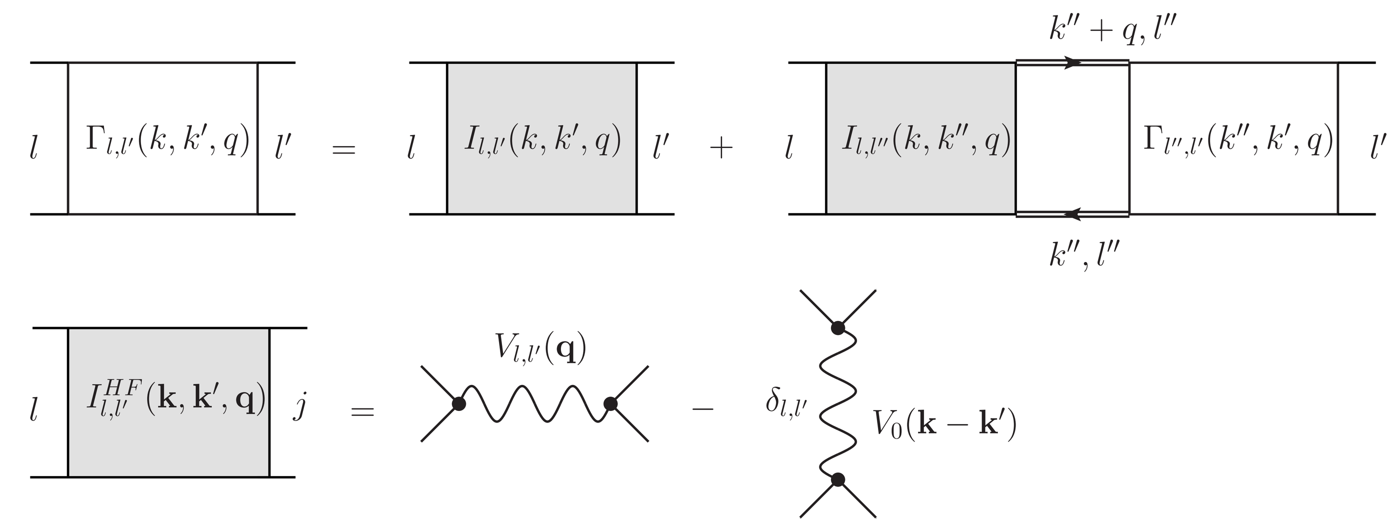
- Dimensionless coupling strength $g \equiv \frac{4mD^2k_F}{3\pi\hbar^2}$

Methods

- A divergence in the static density-density response function at a momentum **q** signifies spontaneous fluctuations in the density with this wave vector.
- The divergences of response function are found in mean field theory using a conserving Hartree-Fock approximation(HFA).

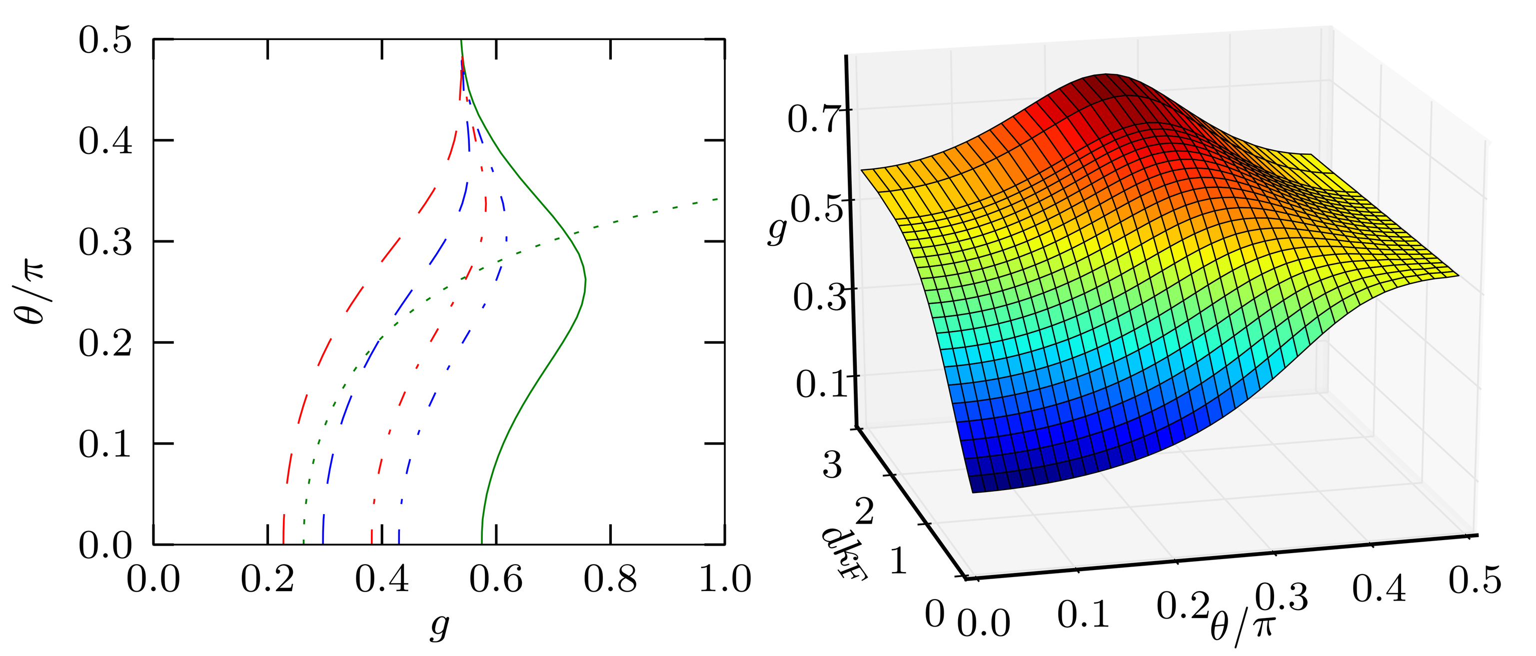


The Bethe-Salpeter equation for the particle-hole scattering matrix



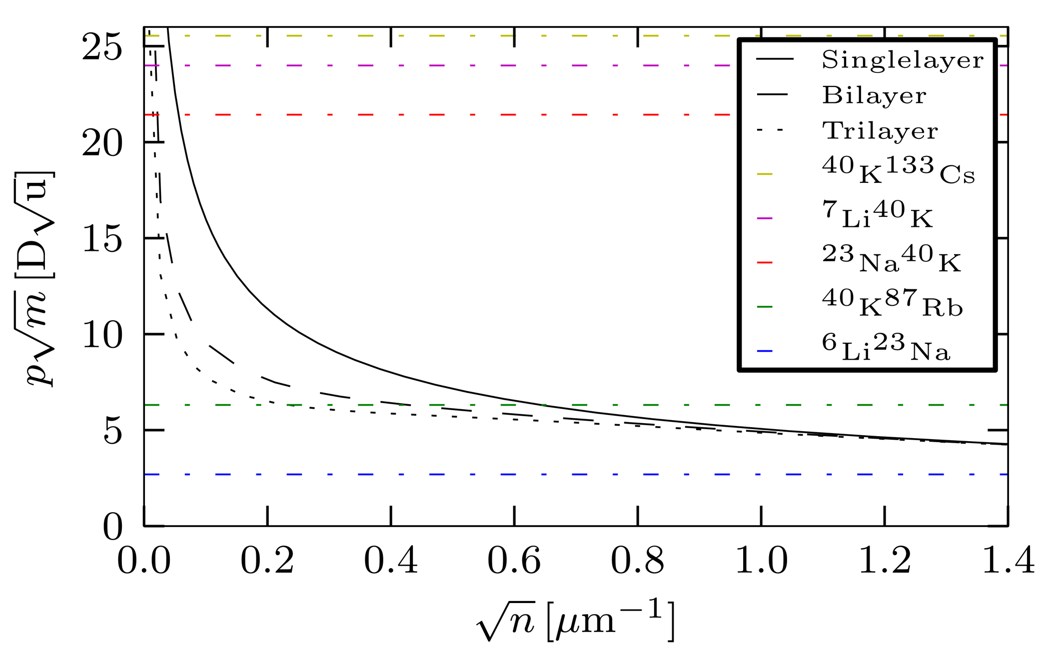
HFA for the irreducible particle-hole interaction. Intralayer: Direct and exchange interactions, interlayer: Only direct interactions (destinguishable)

Results



(a) The phase boundary between the normal (left) and the striped phase (right) in the (g, θ) plane. Singlelayer HFA (full) and RPA (dotted). Bi- and trilayer: The dashed lines are for $dk_F = 0.5$, while the dash-dotted $(- \cdot -)$ are for $dk_F = 1$.
(b) The full dk_F and θ dependency for a bilayer system

Comparison to Experimental Values



For a typical layer separation $d = 1064\,\mathrm{nm}/2$ and perpendicular polarization $\theta = 0$, the critical value of dipole moment times the square root of the mass, $p\sqrt{m}$, as a function of the square root of the density. Vertical lines: Permanent dipole moments for five dipolar fermionic molecules of alkali metals

Conclusions

- Exchange correlations within each layer suppress the density wave instability significantly.
- Conversely, interactions between dipoles in different layers enhance the density wave instability. This effect, which is strongest when the dipoles are oriented perpendicular to the planes, also causes the density waves in neighboring layers to be in-phase for all orientations of the dipoles.
- For several fermionic molecules of alkali metals, the density wave instability is expected to lie in the regime of experimentally realisable densities, where the multilayer effects are significant.

References

Published in: Block J K, Zinner N T and Bruun G M 2012 *New J. Phys.* **14** 105006
[1] Image adapted from: Bruun G M and Taylor E 2008 *Phys. Rev. Lett.* **101** 245301