Dipolar Bose gases in random potentials

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Dipole-Dipole Interaction in Quantum Systems

- dipole-dipole interaction potential

\[ V_{\text{int}}(x) = \frac{C_{\text{dd}}}{4\pi |x|^3} \left( 1 - 3 \cos^2 \vartheta \right) \]
Disorder is everywhere!
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Magnetic and Electric Interactions and BEC´s

- **Magnetic systems:**
  - Interaction strength: $C_{dd}^B = \mu_0 m^2$, with $m \sim 1$ to $10 \mu_B$
  - Realized samples
    - **Boson:** $^{52}\text{Cr}$ Griesmaier *et al.*, PRL **94**, 160401 (2005)
    - **Fermion:** $^{53}\text{Cr}$ Chicireanu *et al.*, PRA **73**, 053406 (2006)
    - **Boson:** $^{87}\text{Rb}$ Vengalattore *et al.*, PRL **100**, 170403 (2008)
    - **Boson:** $^{164}\text{Dy}$ Lu *et al.*, PRL **107**, 190401 (2011)

- **Electric systems:**
  - Interaction strength: $C_{dd}^E = 4\pi d^2$, with $d \sim 1$ Debye
  - Realized samples
    - **Fermion:** $^{40}\text{K}^{87}\text{Rb}$ Ospelkaus *et al.*, Science **32**, 231 (2008)
    - **Boson:** $^{41}\text{K}^{87}\text{Rb}$ Aikawa *et al.*, NJP **11**, 055035 (2009)

- **Ratio:** $C_{dd}^B / C_{dd}^E \approx 10^{-4}$
Semi-classical theory of transport

- electrons are bloch waves
- scattered on impurities, dislocations and phonons
- conductivity in semiclassical theory

\[ \sigma_B = \frac{n e^2 \tau}{m} \]

• Assumption: All types of Collisions redistribute the quasi-momentum and cause the bloch wave to lose phase coherence
Weak and Strong Localization

- **Failure:** Scattering from static impurities does not destroy phase coherence
- right semiclassical limit if the phase coherence between two static scattering events is lost
- otherwise coherent multiple scattering events
- can be described with an elaborate theory of transport
- **Solution:** Higher probability for the wave to return to their starting point $\rightarrow$ localization
- weak localization: $\sigma > 0$  
  Anderson localization: $\sigma = 0$
Experimental evidence


- **no DIRECT observation for electrons**
interplay between interactions and disorder is still not clear

strong repulsive interactions may localize particles

small repulsive interactions may compete with disorder

different quantum states depending on interaction and disorder strength
The Lifshits Regime

- System populates energetically lowest lying states for small kinetic and interaction energy

- Lifshits states are highly localized with small overlap
Quantum-Phase Diagram for Contact Interaction

- LIFSHITS GLASS
- FRAGMENTED BECs (Bose glass)
- BEC (not fragmented)
- Smoothed BEC
- BEC (not smoothed)

Parameters:
- $V_R$
- $\mu$
Lifshits regime and DDI in 1D

- Blockade of the second Lifshits state
- Chemical potential over interaction energy

![Graphs showing density and chemical potential](image)
Highly localized Lifshits states in 2D

Used random potential
Summary

- Coherent multiple scattering leads to increased probability to find a particle at its starting point.
- Anderson localization of wave function if the disorder becomes strong enough.
- Interplay between disorder and interactions is not yet understood.
- Lifshits-, Bose-glass- and BEC-phases for different disorder and interaction strengths.
- Blockade effect due to dipole-dipole interaction.
Outlook

- Blockade and stripe effect in 2D
- Change of the crossover regions between LR-BG and BG-BEC
- Localization of excitations
Thanks for your attention!