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Wigner Crystals in Transition Metal Dichalcogenides

- Prelude

Weakly Interacting Electrons $\Leftrightarrow$ Fermi Liquids

electrons

+

Pauli Principle

$\Downarrow$

Fermi surface.

"nearly" free plane waves w/ well-defined momenta and energies

Electron - electron interactions strong

$\Downarrow$

"wave" starting point not so good

- Wigner crystal (WC) ?

Consider electrons at low density (n)

Classically

$n \downarrow \Rightarrow a \sim n^{-1/3} \uparrow \Rightarrow$ Weak interactions

a - e-e separation

Quantum Mechanically

Coulomb Interactions (no screening)

$$E_{pot} \sim \frac{e^2}{a}$$

Kinetic Energy

$$E_{kin} = \frac{p^2}{2m} \sim \frac{p_F^2}{2m}$$

$$p_f \sim \frac{\hbar}{a}$$

(Uncertainty Principle)

$$\Downarrow$$

$$E \sim \frac{\hbar^2}{2m a^2}$$

Low densities ($a > \frac{\hbar^2}{me^2} > a_0$.)

(large a)

Potential energy dominates

Electrons at low densities are

strongly correlated system!

Ground State?

Minimize Potential Energy $\Rightarrow$ periodic arrangement

electrons are localized at sites

- WC breaks translational symmetry without underlying lattice (in contrast to Mott insulators)

- $\exists$ no additional degrees of freedom (e.g. phonons as in CDW instabilities). Therefore localized wavepackets are essentially electrons with small m and strong quantum fluctuations

- "Mixed identity"

"classical" particles are discernible by position

quantum → QFs strong

⇓

quantum crystal

- a controlled by density

$n \uparrow \Rightarrow$ KE $\uparrow \Rightarrow$ Melting

↑

Into what?

How?

- WC can be set in motion by

an E field $\Rightarrow$

Motion $\Rightarrow$ Current

- Embedded in real crystal

Very sensitive to disorder

(pinning)

Why are WCs difficult to observe?

(proposed in 1934..

- Difficult to achieve very low densities

- Very fragile with respect to the environment

Disorder ⇒ electrons prefer to "sit" in local minima

Material must be very clean

How to probe (electronic structure often buried in device)

- Indirect (Direct imaging difficult)
  - Resonance at modes of WC
  - Transport

Prior Experimental Settings

Electrons above surface of Liquid Helium — No Disorder.

Semiconductor Heterostructures

1) Very clean (GaAs)

2) Application of magnetic fields quenches kinetic energy — electrons in Landau orbits