Wigner Crystals

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PHY 525

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Wigner's discovery

- Electron-electron interaction:

$$V(r) = \frac{e^2}{r}$$

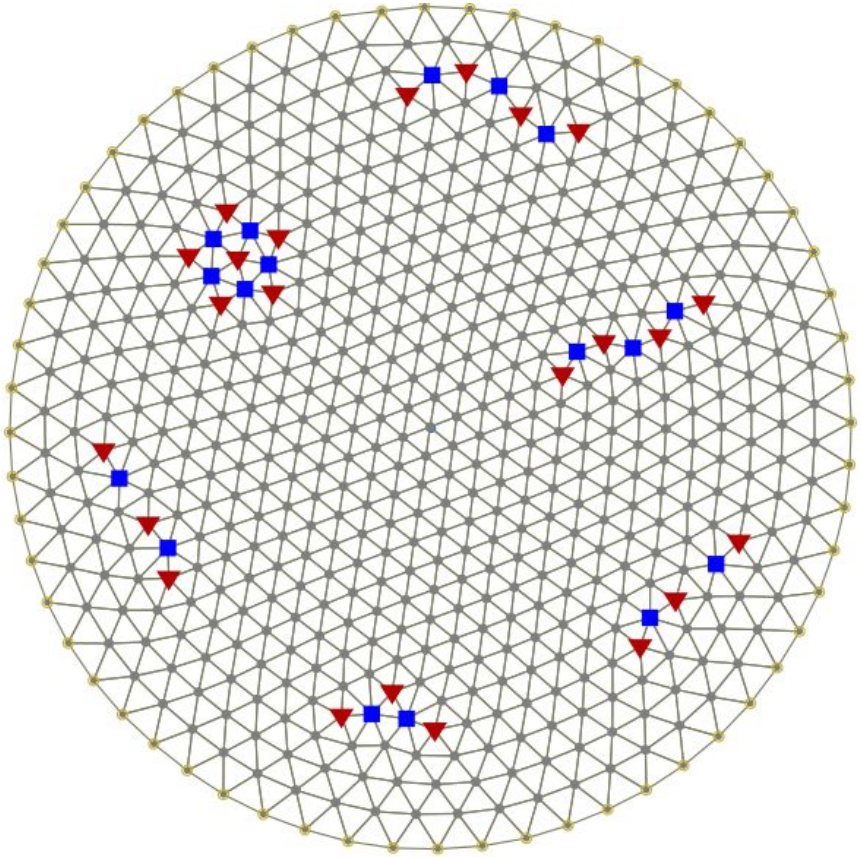
- Minimize energy by maximizing r
- Define:

$$r_s = \frac{E_C}{E_k}$$

Coulomb energy

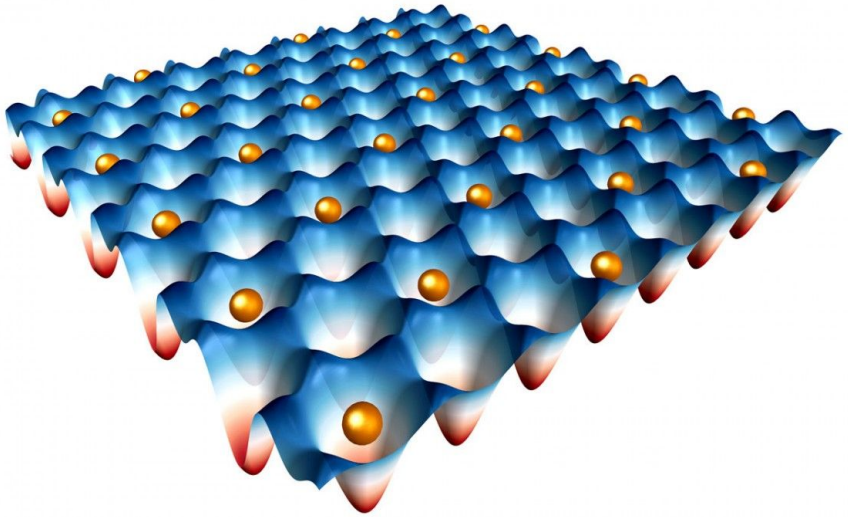
Kinetic energy

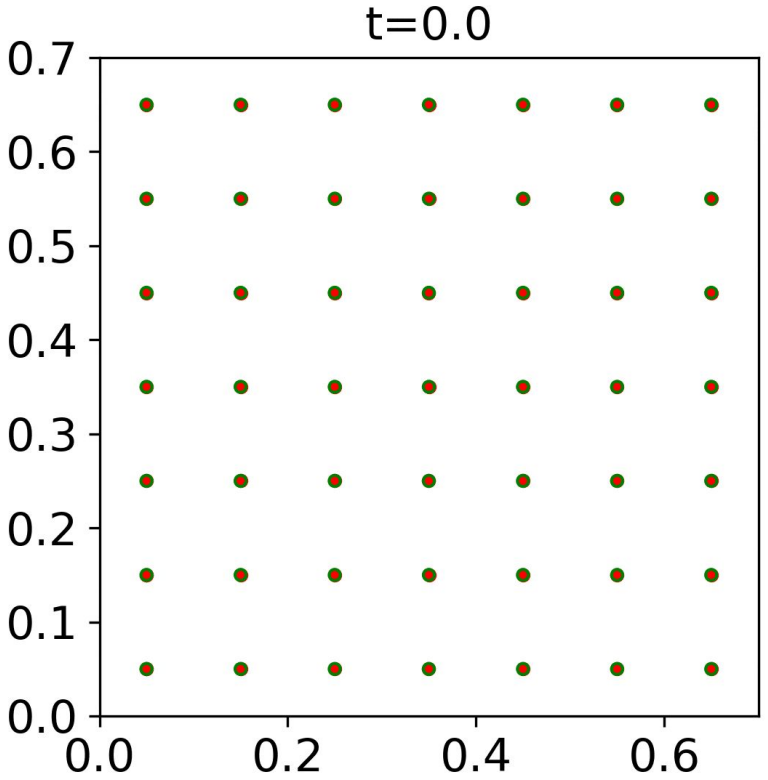
Unitless 'size'



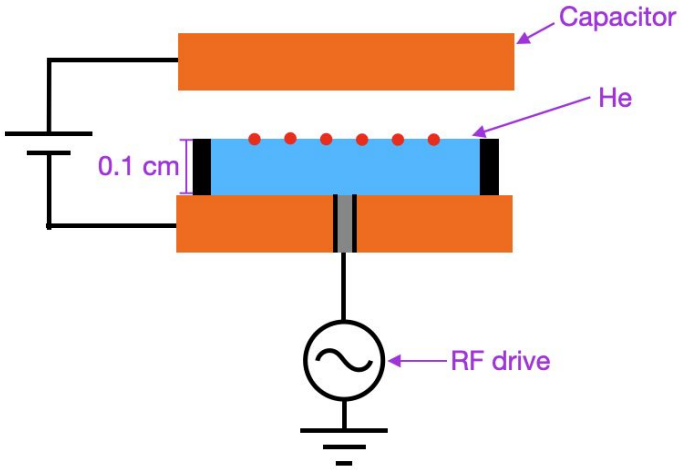
E. Wigner, Phys. Rev. 46, (1934).

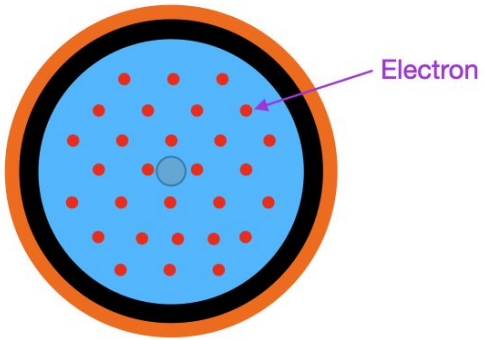
What is a Wigner Crystal?

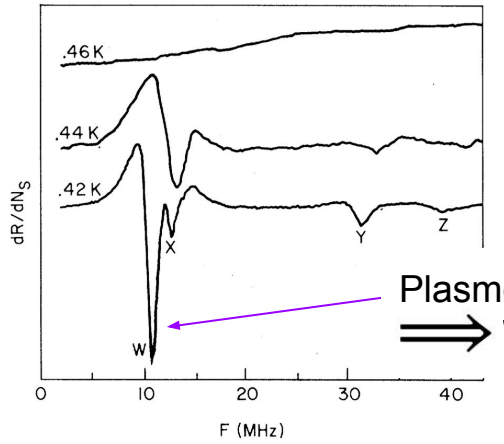




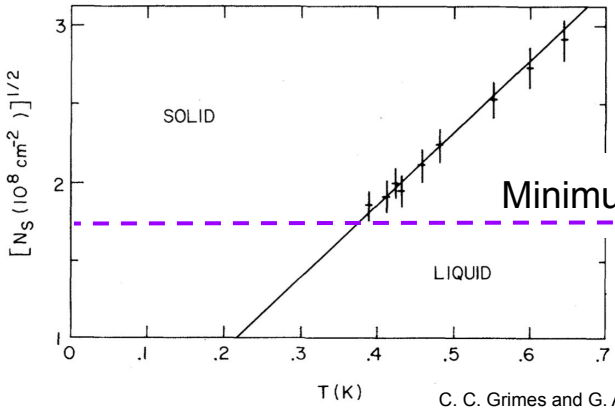
Observations of Wigner crystal on bulk helium







Plasmon-ripplon resonance
⟹ Wigner crystal



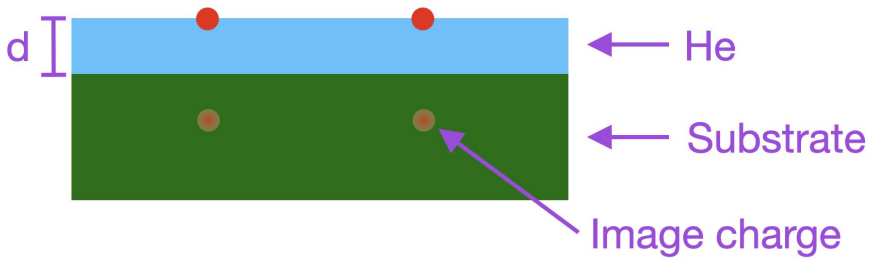
Minimum electron density

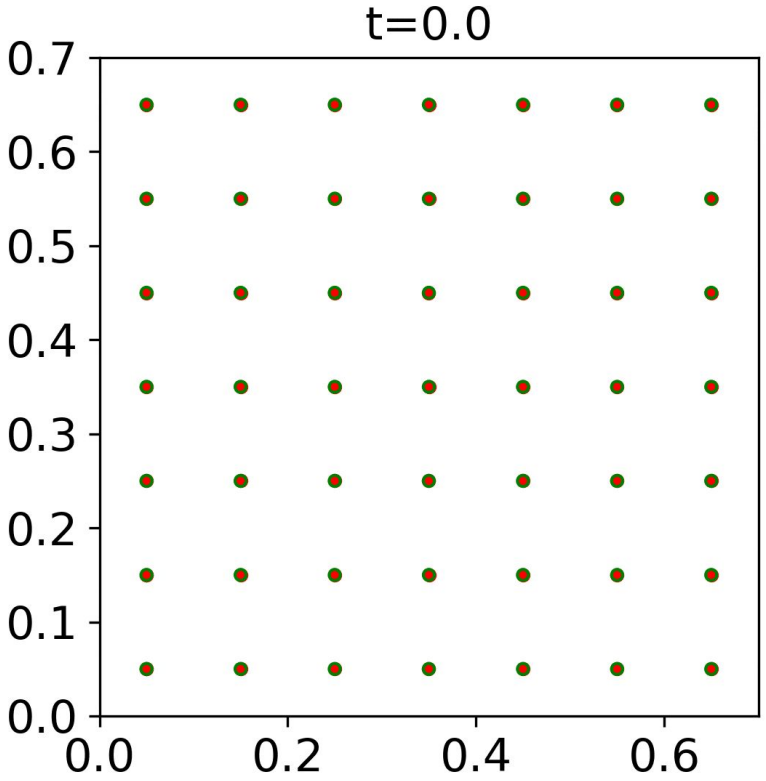
C. C. Grimes and G. Adams, Phys. Rev. Lett. 42 12, (1979).

Extension to thin films

$$V(r) = e^2 \left(\frac{1}{r} - \frac{\delta}{[r^2 + (2d)^2]^{1/2}} \right)$$

$$\delta = \frac{\epsilon + 1}{\epsilon - 1}$$





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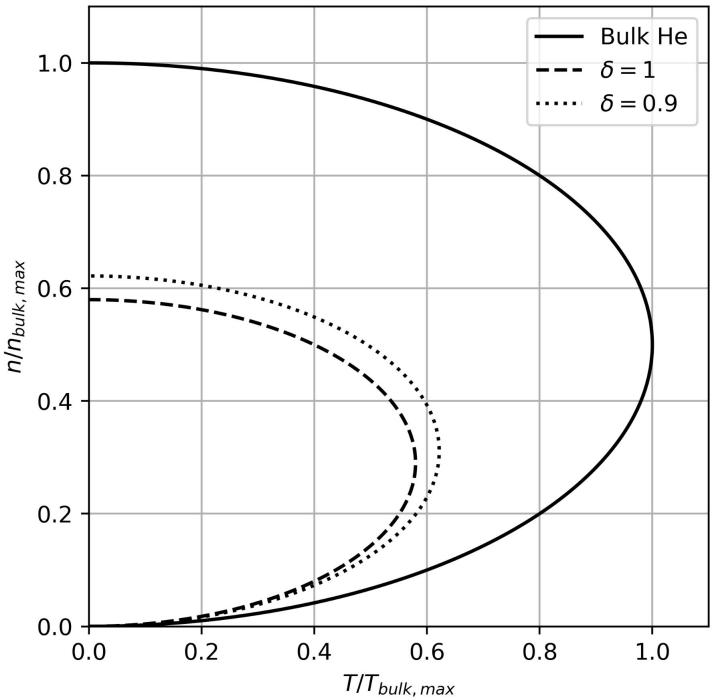
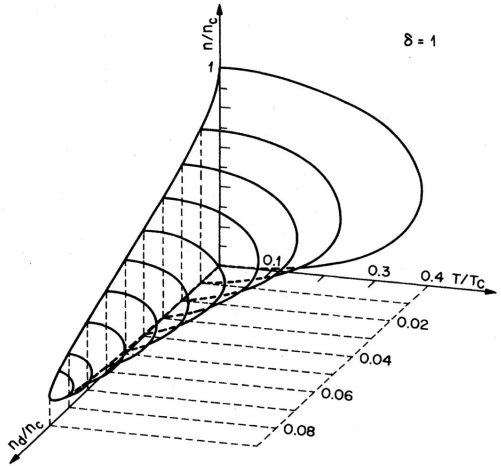
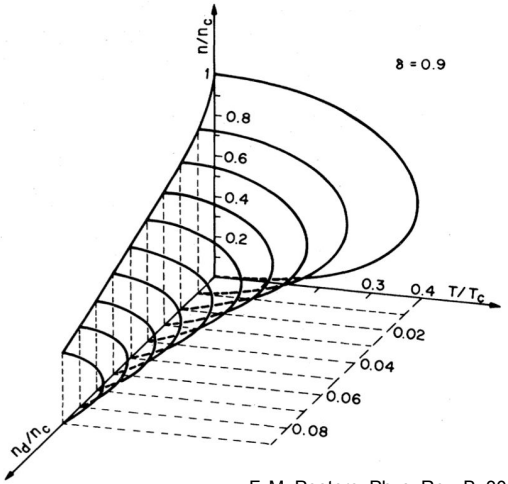
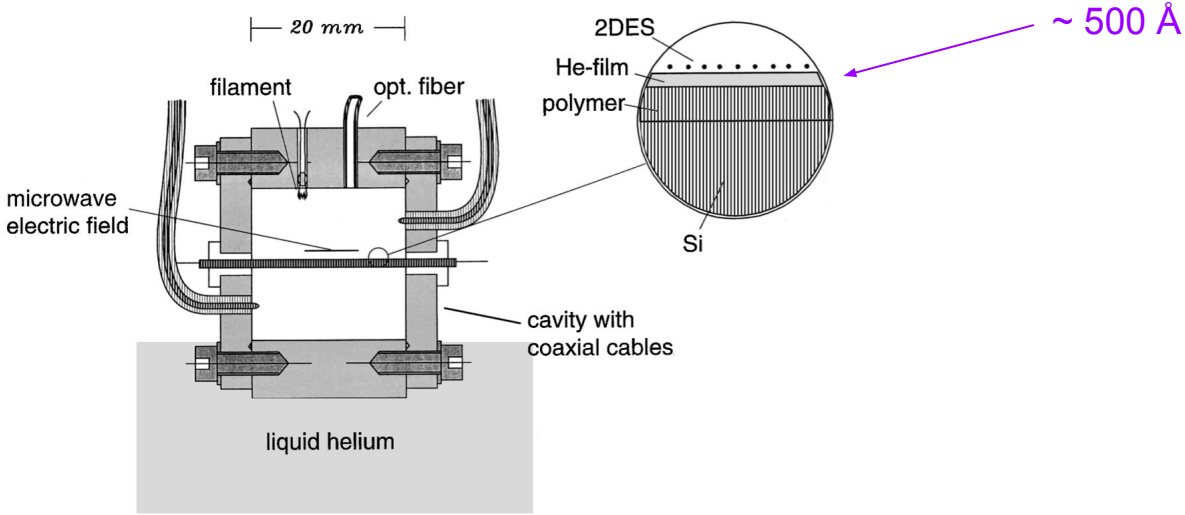






F. M. Peeters, Phys. Rev. B. 30, 1, (1983).

Observation on thin film helium



G. Mistura, S. Neser, and P. Leiderer, Physica B 249-251 (1998) 640-643
G. Mistura et al, Phys. Rev. B., 56 13 (1997).

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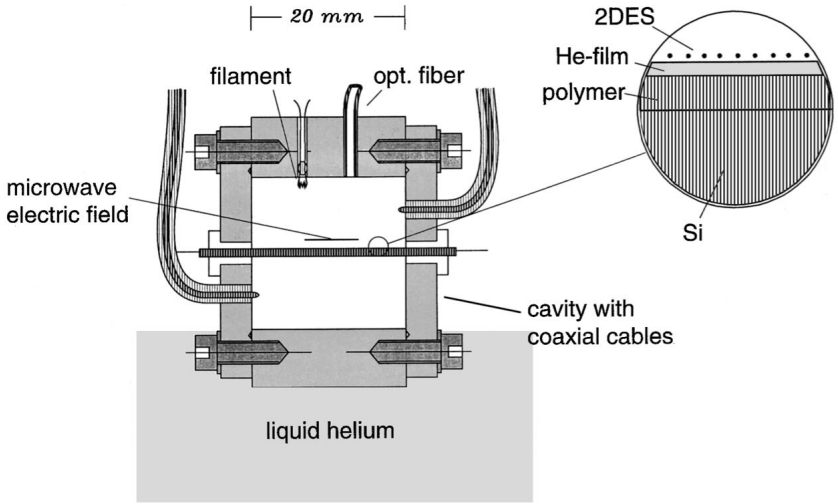

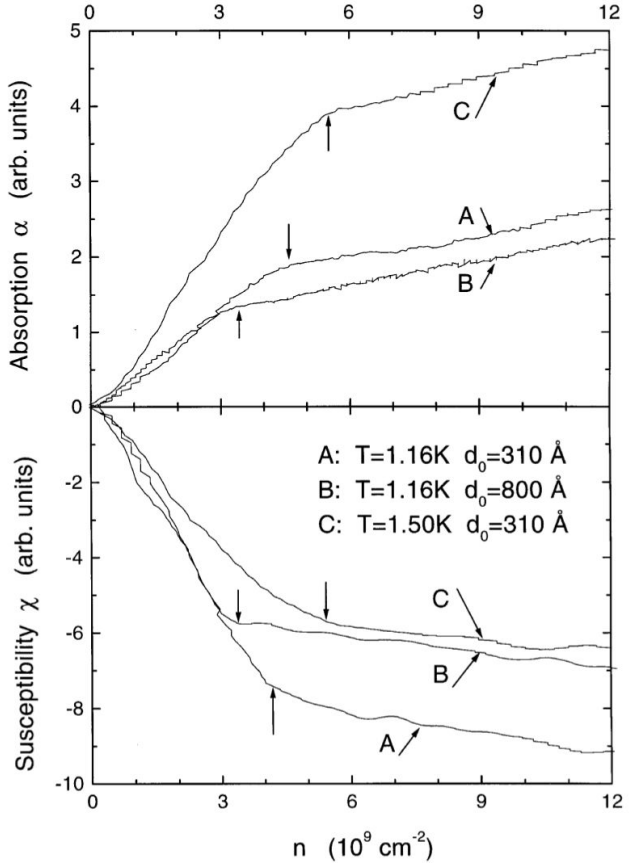

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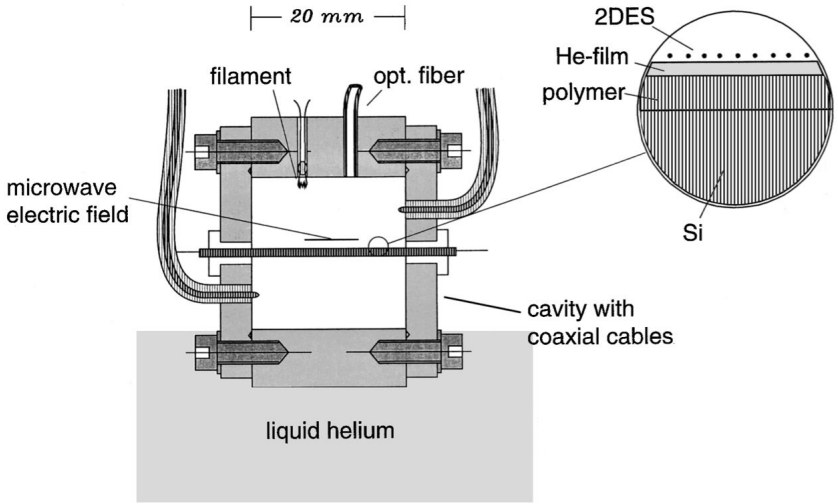

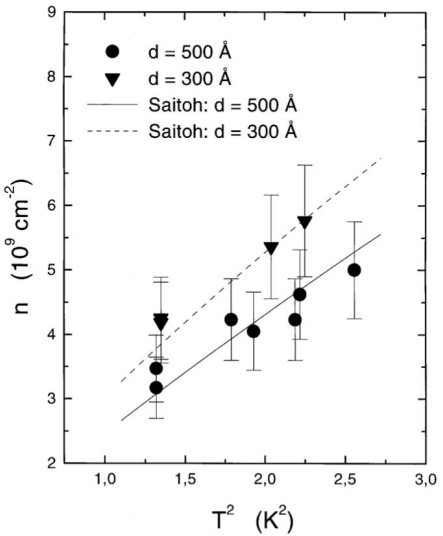

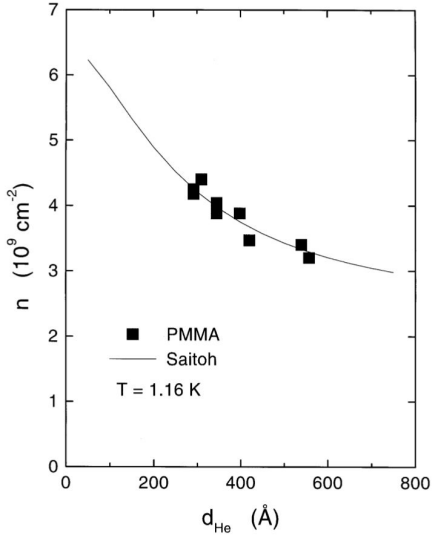

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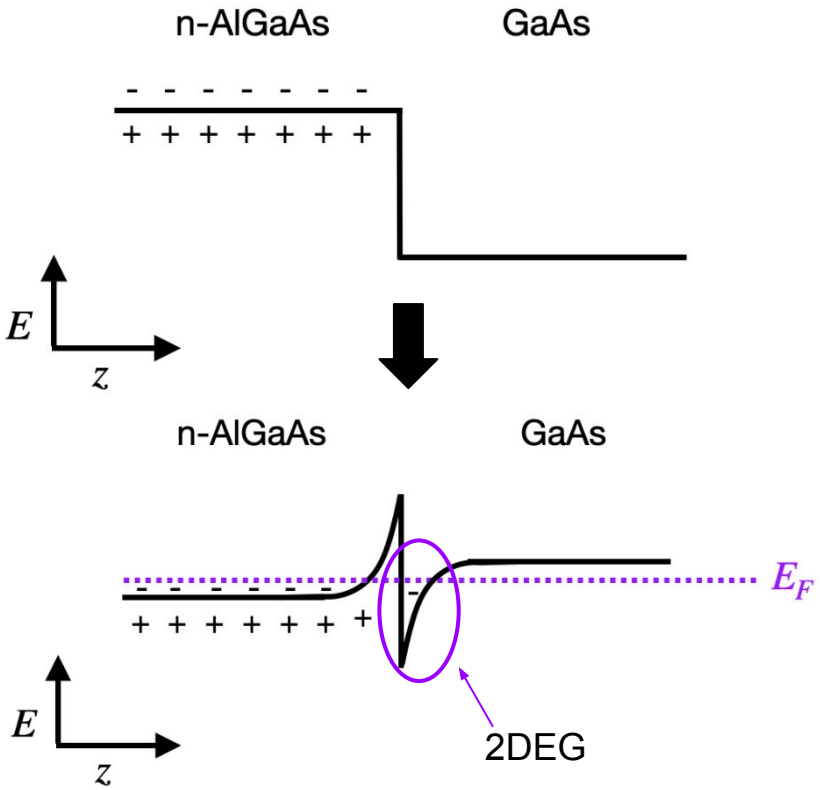
Observations in 2D semiconductor systems



$$r_s = \frac{E_C}{E_F} = \frac{m^*}{\sqrt{n}} \frac{e^2}{4\pi^{3/2}\hbar^2\epsilon\epsilon_0}$$

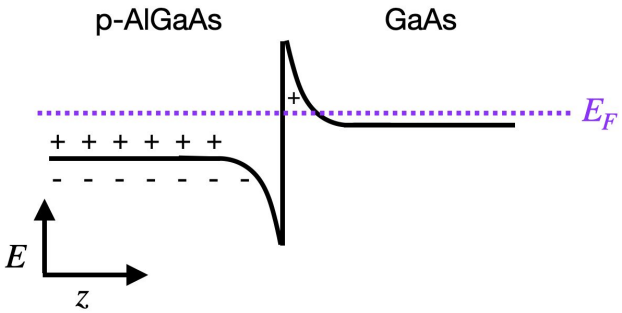
Need:

- Low n
- High m^*
- Low disorder

$$m^*_{e,\mathrm{GaAs}} = 0.067 m_e$$

Observations in 2D semiconductor systems

$$m^*_{h,\mathrm{GaAs}} = 0.37 m_e$$



J. Yoon et al, Phys. Rev. Lett. 82, 8 (1999).

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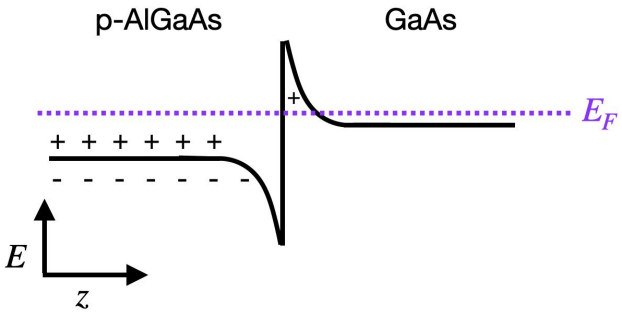
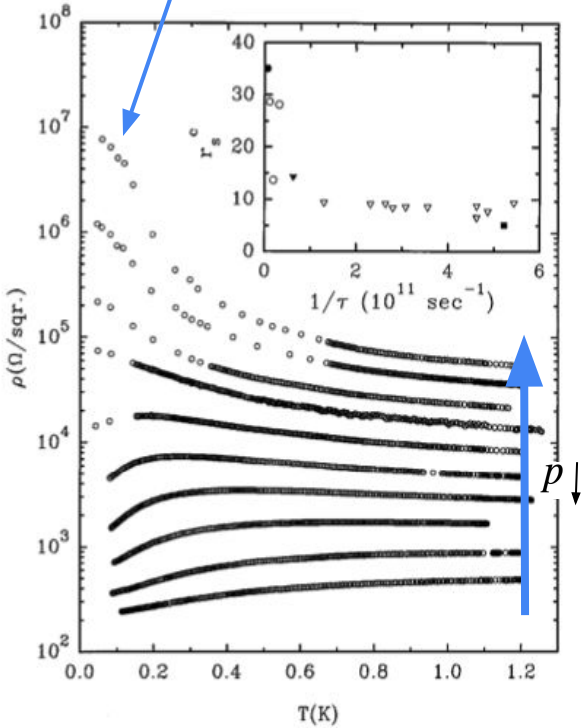


Insulating behavior at low p



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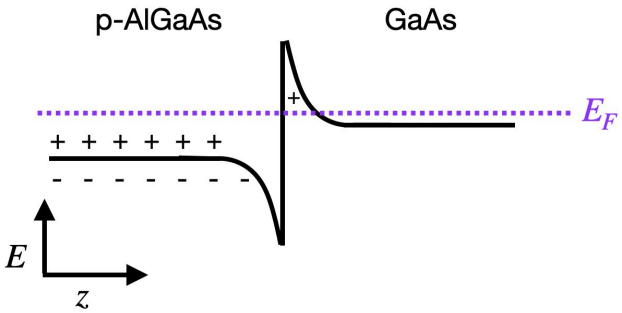

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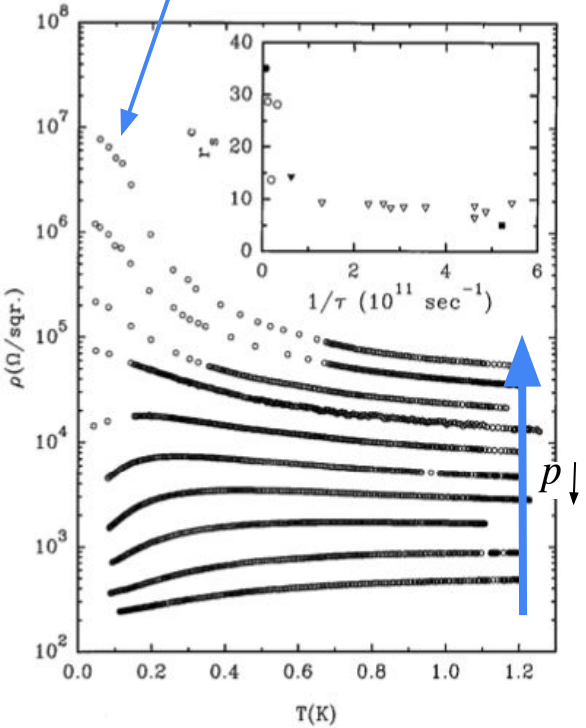
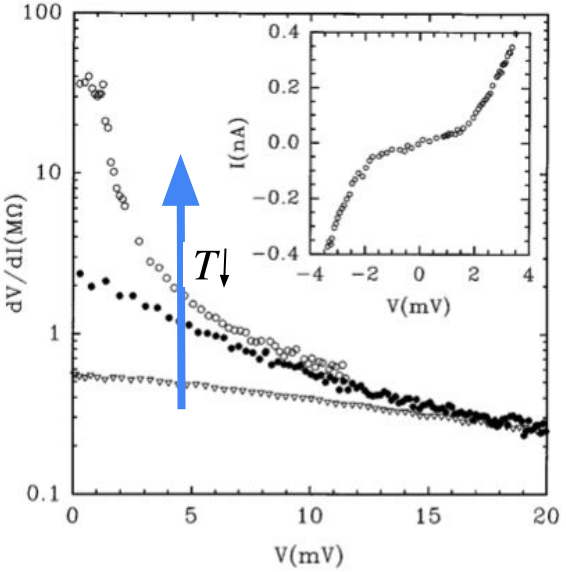


Threshold voltage for insulator



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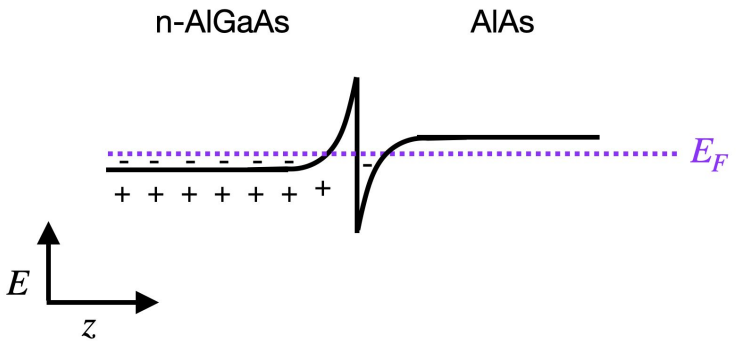
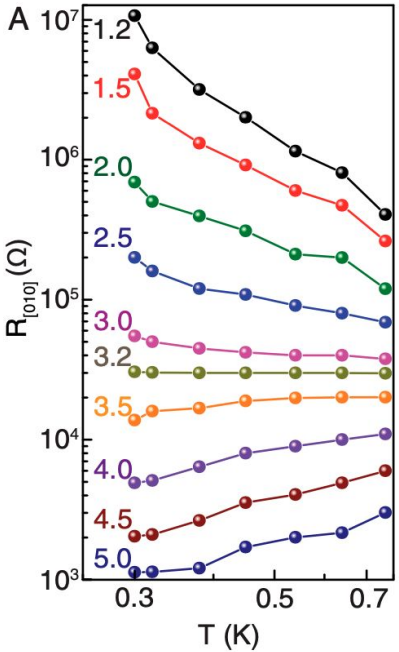
Observations in 2D semiconductor systems

$$m^*_{e,\mathrm{AlAs}} = 0.46 m_e$$





M. S. Hossain, et al, Proc. Natl. Acad. Sci., 117. 51. (2020).

Observations in 2D semiconductor systems

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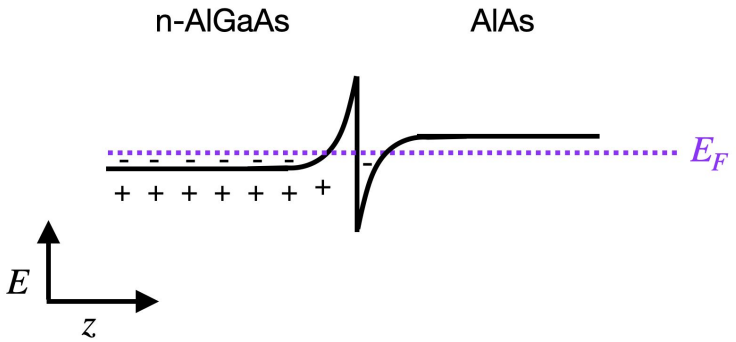

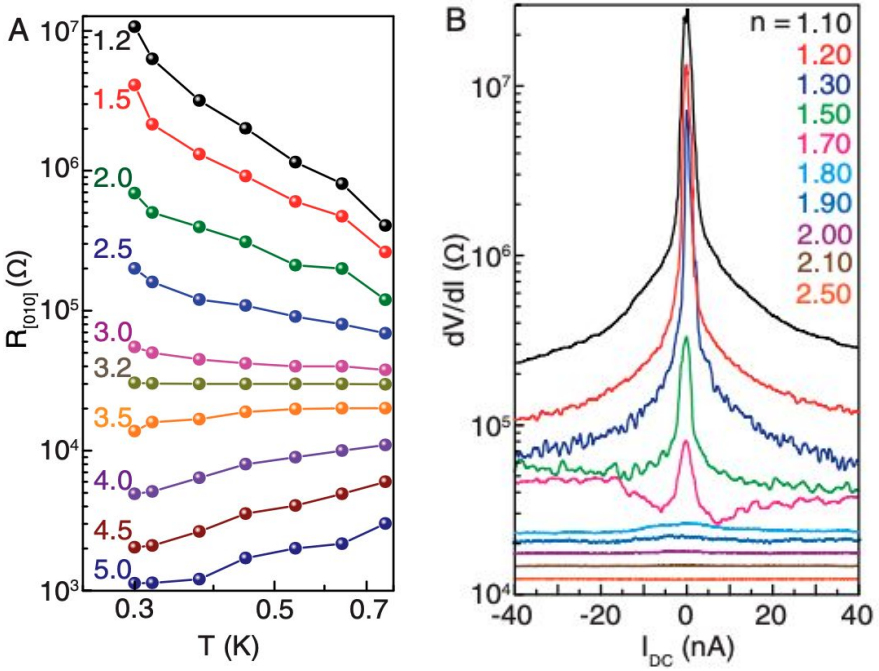

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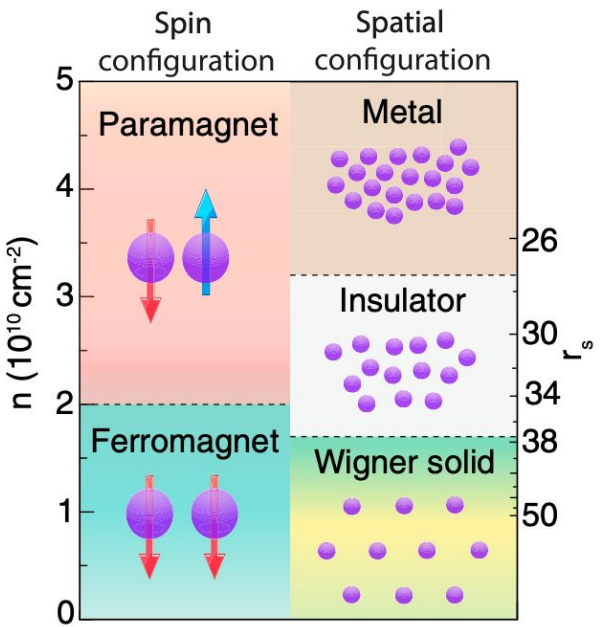

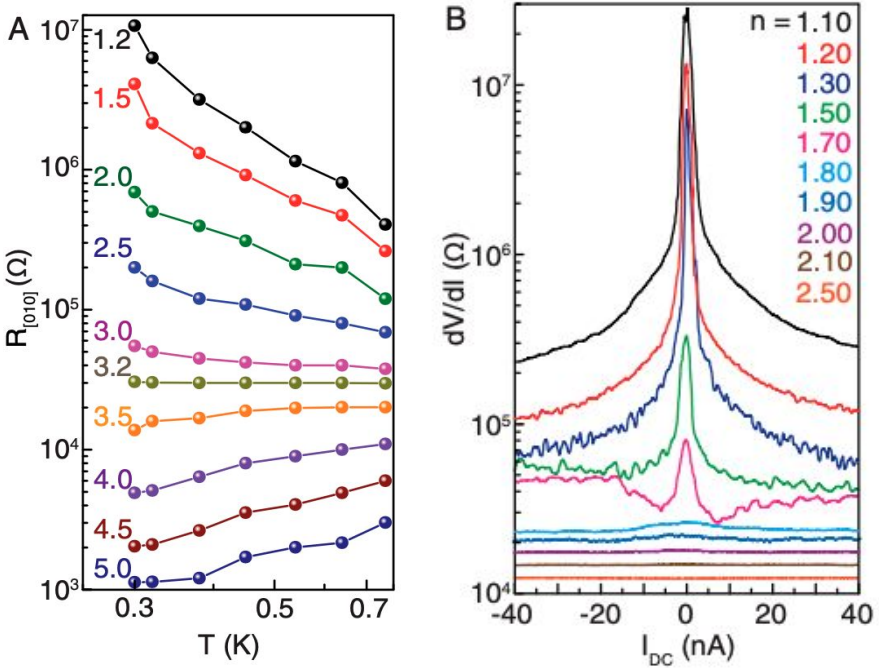

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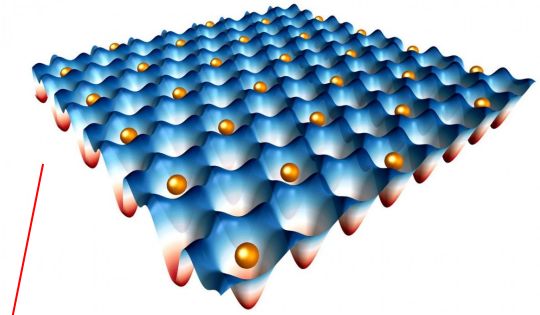
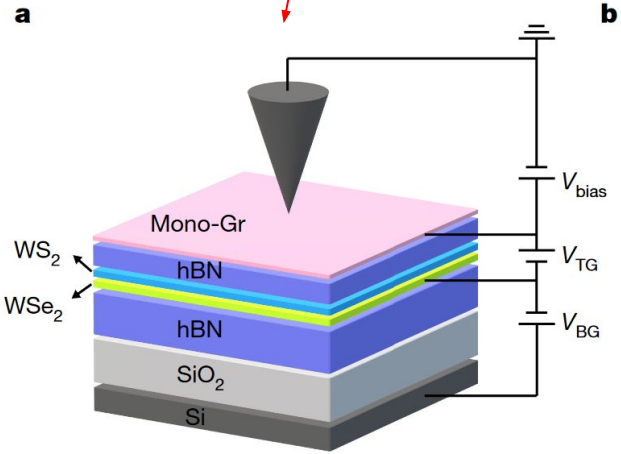
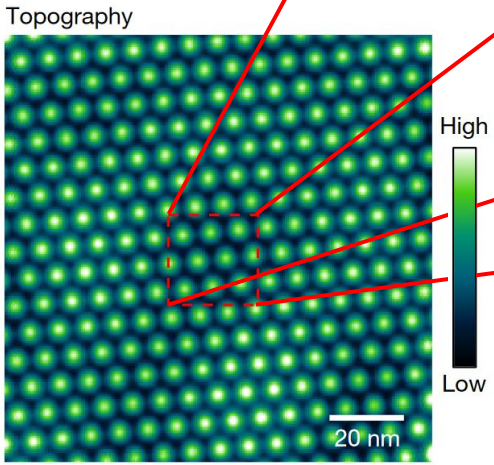
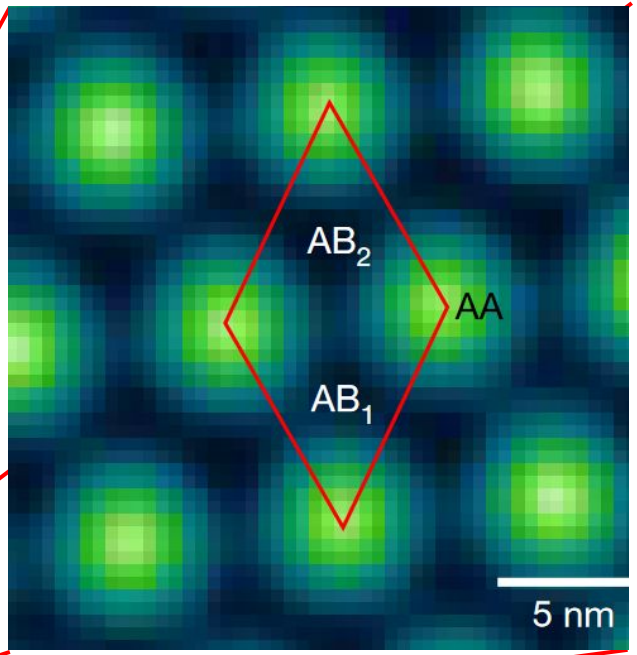
Imaging of crystal in Moiré lattice









H. Li et al, Nature, 597, 650-654, (2021).

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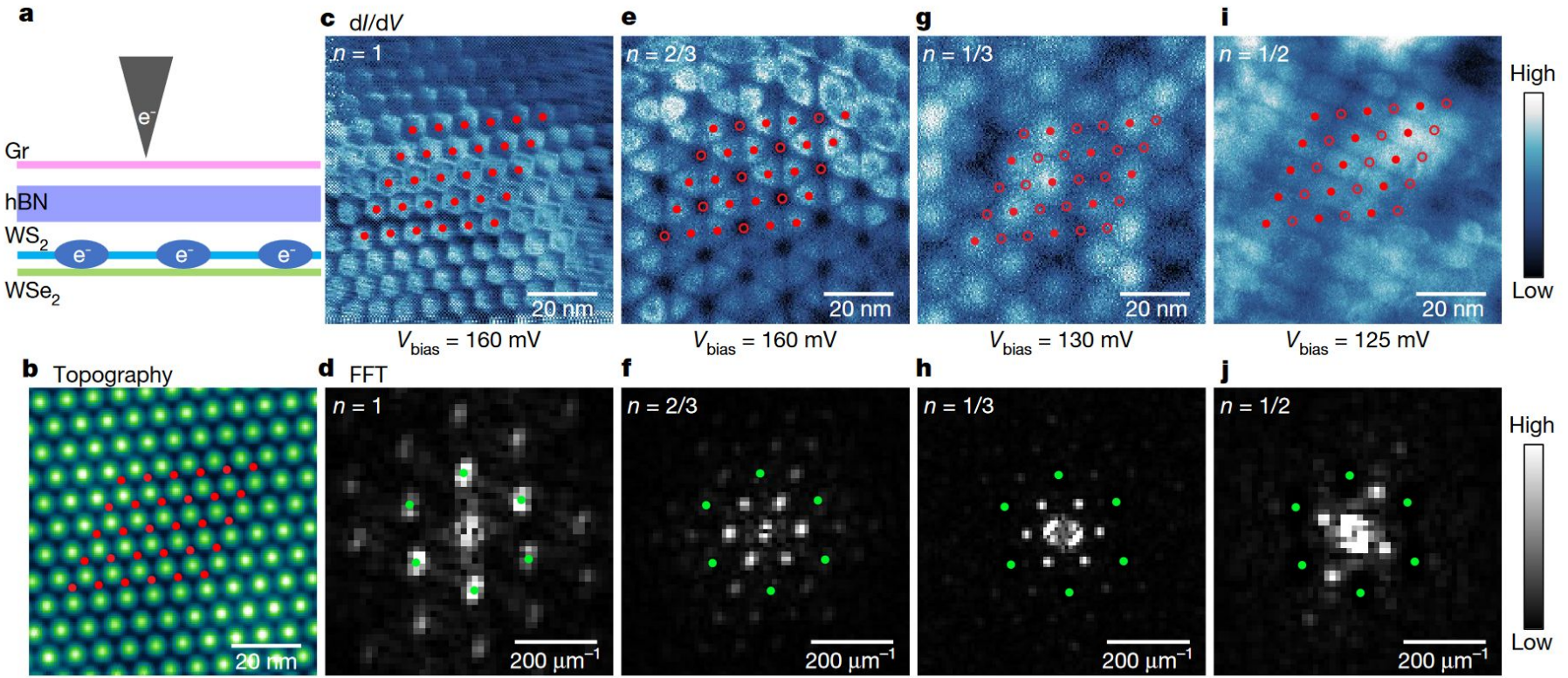

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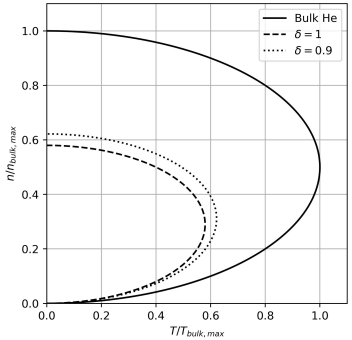
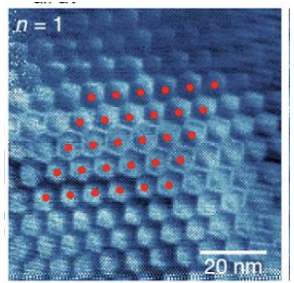
Open questions

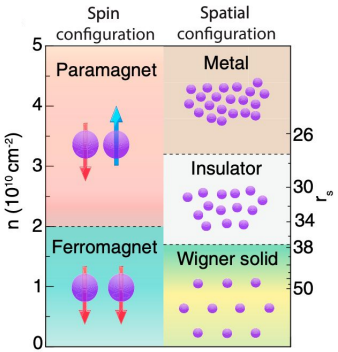
- Observation of low density (“quantum”) melting?



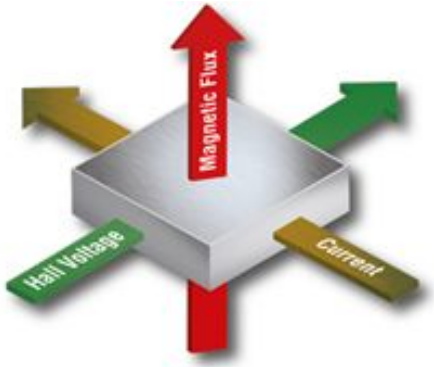
- What determines the lattice shape?
  - Anisotropy? AlAs has m_l^*= 1.1, m_t^*= 0.2

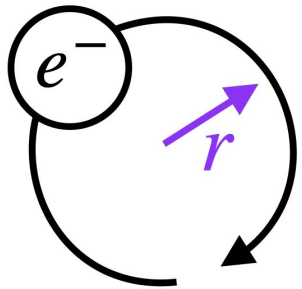


- Transitions to other phases in solid state?
  - FQHE states, insulating phases, magnetization



Other material platforms?

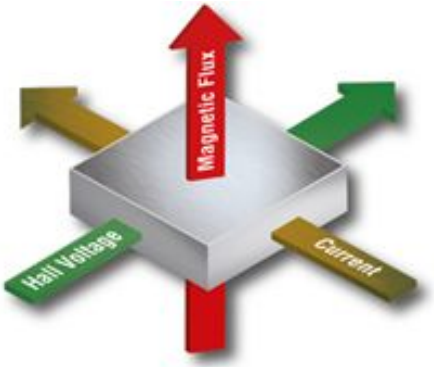


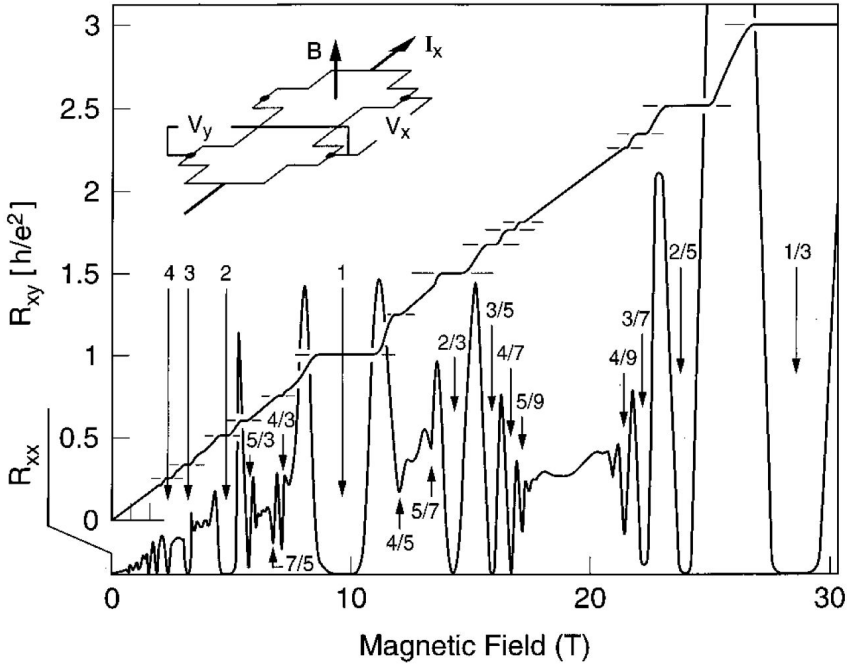


$$r \propto \frac{1}{\sqrt{B}}$$

D. C. Tsui, H. L. Stormer, A. C. Gossard, Phys. Rev. Lett. 48, 22 (1982).

Other material platforms?





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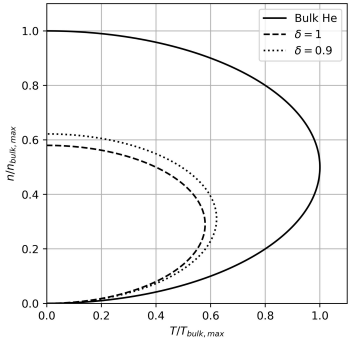
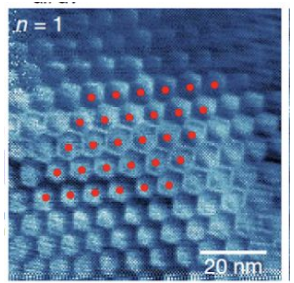
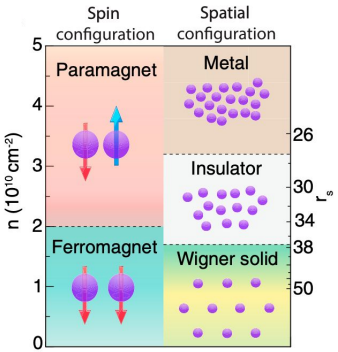


- What determines the lattice shape?
  - Anisotropy? AlAs has m_l^*= 1.1, m_t^*= 0.2



- Transitions to other phases in solid state?
  - FQHE states, insulating phases, magnetization



Questions?