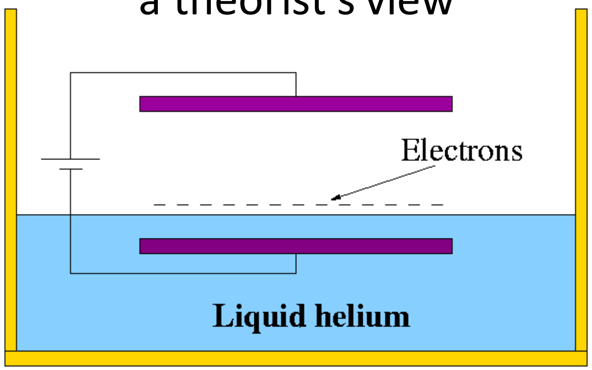
Electrons on Helium

Steve Lyon – docent
Princeton University

- Overview
- Speakers
  - Mark Dykman (presented by SL)
  - Paul Leiderer
  - Dave Schuster
- Discussion

- Generous input from Kimitoshi Kono, Denis Konstantinov, David Rees

Experimental cell:
a theorist's view

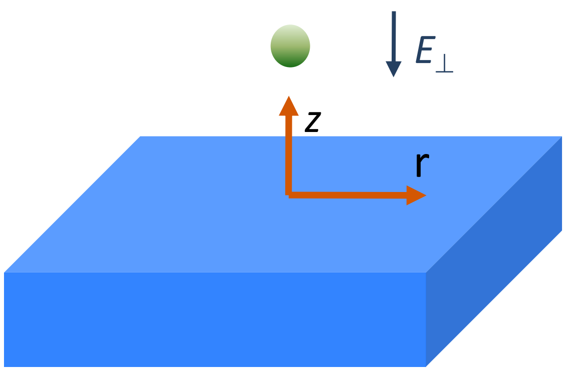


Electrons reside in vacuum. Interelectron distance is ~1μm. The in-plane mobility is the highest known

$$\mu \lesssim 2\times10^{8}\ \mathrm{cm}^2/\mathrm{V}\cdot\mathrm{s}, \qquad \tau \lesssim 10^{-7}\ \mathrm{s}$$

GaAs heterostructures: $\mu \lesssim 3.6\times10^{7}\ \mathrm{cm}^2/\mathrm{V}\cdot\mathrm{s}, \quad \tau \lesssim 10^{-9}\ \mathrm{s}$

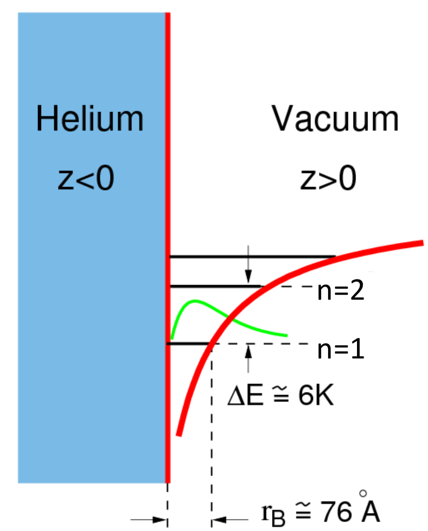
Idealized model: flat surface, infinite barrier, image potential



$$U(z) = -\Lambda/z \quad (z > 0)$$

$$\Lambda = (\varepsilon - 1)\, e^2/4(\varepsilon + 1)$$

$$E_n = -R/n^2, \quad R = m\,\Lambda^2/2\hbar^2$$

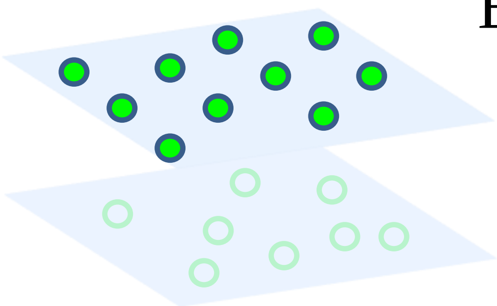


Control: pressing field $E_\perp$, magnetic field, density, temperature

Electrons on Helium – expt'l systems

Confinement

"Bulk" – 2D

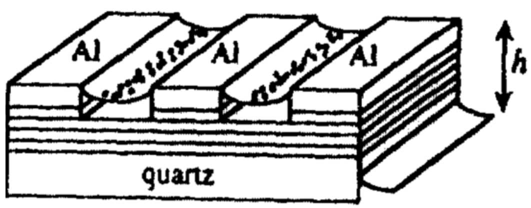


Electrons on surface →

Bubbles/ions below surface →

- Highly correlated electron liquids, Wigner crystal
- Topological properties of ^{3}He

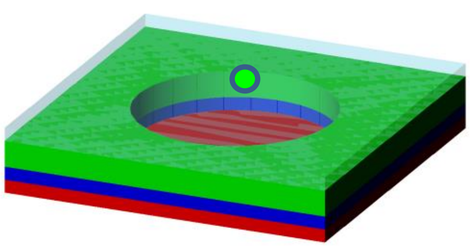
Channels



Quasi-1D to 1D →

- Quasi-1D correlated liquids and solids
- Applications

Quantum Dots

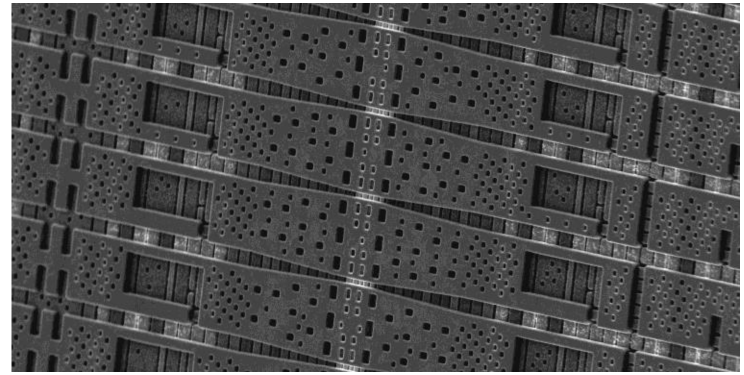


Quasi-0D to 0D →

- Few-body systems
- Applications

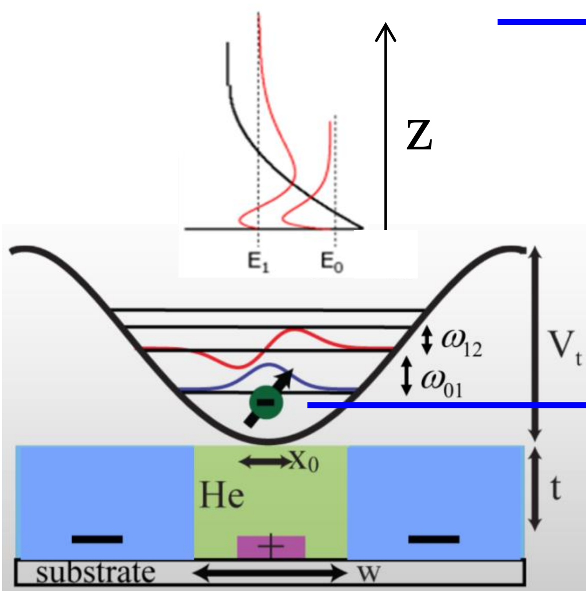
Applications

Moving and manipulating electrons with great precision (Precision available only to theorists in semiconductors)



Electron “atom” for quantum simulation/computing

Qubits

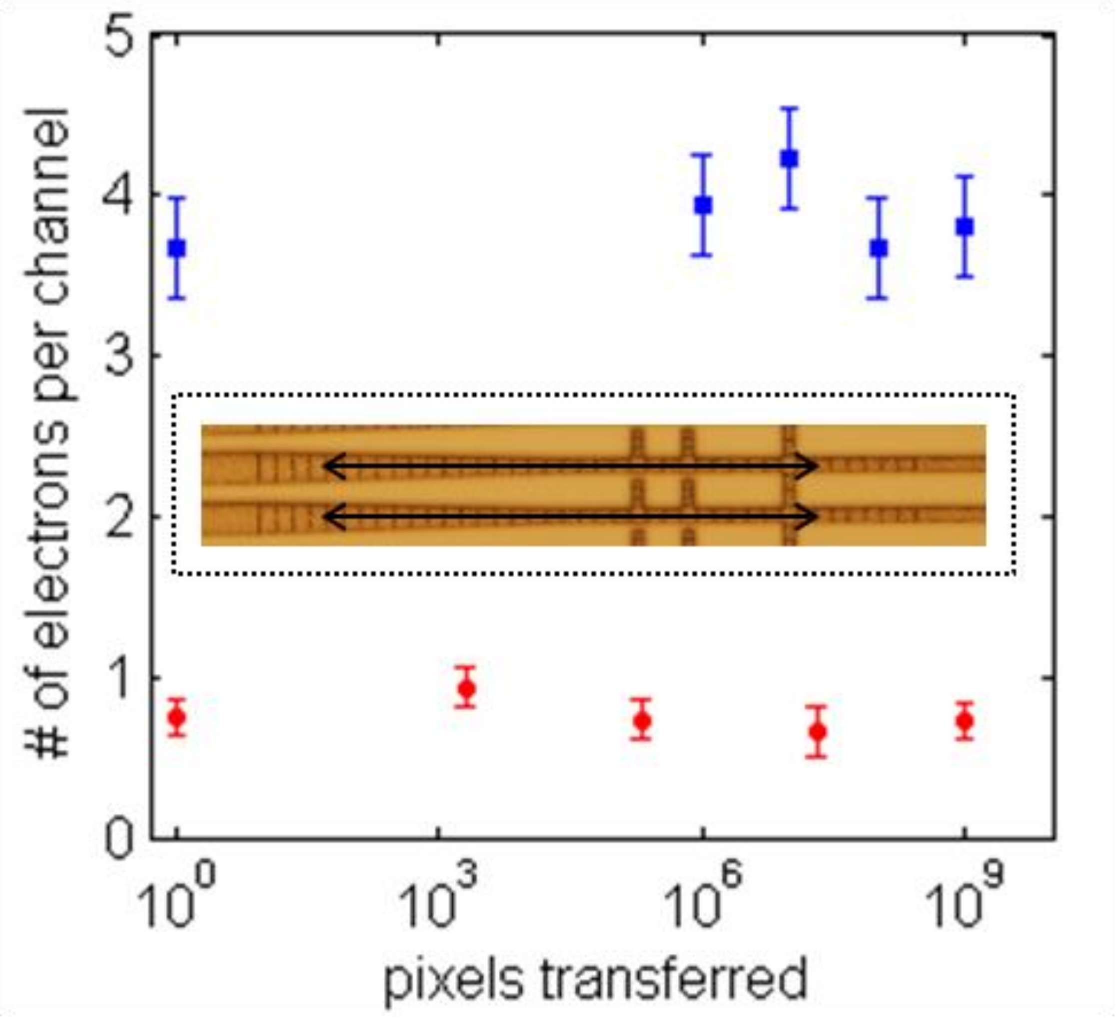


Vertical transition = hydrogenic potential
Platzman and Dykman, Science, **248**, 1967 (1999)

Lateral transition ≈ harmonic potential
Schuster, *et al.*, PRL **105**, 040503 (2010)

Electron spin – expect long coherence for mobile electrons (very small spin-orbit: $\Delta g < 10^{-7}$ in bubbles $\Rightarrow T_2 \geq 10\text{s}$)
Lyon, PRA **74**, 052338 (2006)

CCD on Helium



Bradbury, PRL **107**, 266803 (2011)

Electrons on Helium

Versatile Platform for Physics and Applications of Many Body Phenomena

- Strongly Correlated Electron Systems
  - "Classical" electrons, but coupled to quantum fields; bosonic (ripplons) and fermionic (^3He)
  - Working towards quantum melting of the Wigner crystal
- Quantum Simulation/Computing
  - Several distinct qubit states $\Rightarrow$ hybrid schemes possible
  - Natural match for conventional Si technology
- Topological States of Matter
  - Recent results from Kono's group on ^3He-A and ^3He-B
  - Effects of magnetic field through Wigner crystal

Grand Challenges

- Strongly Correlated Electron Systems
- Quantum Simulation/Computing
- Topological States of Matter

Petit Challenges (key advances within field)

- High-density low-disorder degenerate electrons
  $\Rightarrow$ Quantum melting of the Wigner crystal
- Measuring and controlling single quantum states
  $\Rightarrow$ Single electron ↓ (done by M. Lea & Y. Mukharsky)
  $\Rightarrow$ Single electron spin
  $\Rightarrow$ Single electron in lateral harmonic oscillator
  $\Rightarrow$ Single electron in hydrogenic state
- Many-body polarons?
  $\Rightarrow$ Nature of the nonlinear transport of the Wigner crystal
- Image electrons in Wigner crystal