Surface state electrons on He-3, and etc.

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Supports

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Outline

- Surface state electrons
- Subband excitation
- DC mobility of the Wigner solid
- Quasiparticle scattering from free surface
- Superfluid He-3
- A phase: I texture
- B phase: Andreev scattering?
- B phase: Gap distortion and n texture
- He films, suspended channels, etc., as supports for electrons
- Conclusion
Image potential

Bulk He

\[-\frac{1}{4} \frac{\varepsilon-1}{\varepsilon+1} \frac{e^2}{z}\]
Microwave absorption

![Graph showing microwave absorption at 500 mK, 200 mK, and 14.6 mK. The graph plots absorption in microvolts against V_{at} in volts.]
Inhomogeneity

Amplitude [arb.]

$V_{DC} [\text{volt}]$

-3
-2
-1
0
1
2
3

Inner

Inner+outer
DC mobility

![Graph showing mobility vs. temperature in mK with a peak at around 100 mK.]
Wigner crystal
Scattering of quasiparticles
Ballistic regime

\[ \frac{e}{\mu_n} = \frac{\hbar k_F^4}{4\pi^2 N} \int ds \, n_x^2 \]

\[ \frac{e}{\mu_s} = \frac{e}{\mu_n} \left\langle \frac{2}{\exp(\Delta(T)/k_B T) + 1} \right\rangle \]

\[ \langle \cdots \rangle = \frac{2}{\pi} \int_0^{2\pi} d\phi_p \int_0^{\pi/2} d\theta_p \sin \theta_p \cos^3 \theta_p \cdots \]
A-B phases

A diagram showing the phase diagram of helium-3 ($^3$He) with regions labeled as 'Solid', 'Superfluid', and 'Liquid (Normal)' in a pressure-temperature (P-T) plot.
Triplet Superfluid

Normal:

\[ G = \text{SO}_3^{(L)} \times \text{SO}_3^{(S)} \times P \times (T \times U(1)) \]

A-phase:

\[ H(A) = (O_z^{(S)} \times O_{x, \pi}^{(S)} U_{\pi/2}) \times (O_z^{(L-(1/2)N)} \times O_{x, \pi}^{(L)} T) \times PU_{\pi/2} \]

\[ \psi_{\alpha\beta}(k) \propto g\sigma_3(n_x + in_y), \quad (g = i\sigma_2) \]

\[ |\Delta|^2 = |\psi_A|^2 \sin^2 \theta \]

B-phase:

\[ H(B) = (\text{SO}_3^{(L+S)} \times T) \times PU_{\pi/2} \]

\[ \psi_{\alpha\beta}(k) \propto g\vec{\sigma} \cdot n \]

\[ |\Delta|^2 = |\psi_B|^2 \]
Energy gap
Electrons on He films

- flat
- resist
- dot
- 1D channel with guard
- 1D channel without guard
### Results

<table>
<thead>
<tr>
<th></th>
<th>C (pF)</th>
<th>$C_{cal}$ (pF)</th>
<th>$C/C_{cal}$ (%)</th>
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</thead>
<tbody>
<tr>
<td>flat</td>
<td>0.068</td>
<td>130</td>
<td>0.05</td>
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<tr>
<td>resist</td>
<td>0.30</td>
<td>20</td>
<td>1.5</td>
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<tr>
<td>dot</td>
<td>0.48</td>
<td>5.4</td>
<td>8.9</td>
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<tr>
<td>1D channel</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>without guard</td>
<td>0.094</td>
<td>7.2</td>
<td>1.3</td>
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<tr>
<td>with guard</td>
<td>1.7</td>
<td>7.2</td>
<td>24</td>
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</tbody>
</table>
Quasiparticles are specularly scattered from the free surface.
DC Mobility is sensitive to the distribution of quasiparticles.
Energy gap profile of superfluid He-3 can be detected.
A-phase I texture is perpendicular to the surface.
Where is the Andreev scattering?
B-phase n texture should be elucidated.
Much to do toward the qubits.
Toward a single electron

20nm gold cluster

Offset by 1.5 nA
$\Delta V_g = 150$ mV

4.2K

$V_{DS}$ [mV]

Current [nA]