Unconventional features in transport and noise in the second Landau level

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Outline

• Introduction
  • Quantum Hall effect (QHE)
  • Fractional quantum Hall effect
  • Charge density wave (CDW) in the QHE
  • The second Landau level
  • Hall bar and Corbino geometry

• Low frequency noise measurement
  • Noise and transport measurement in the FQHE and CDW
  • The second Landau level
Quantum Hall effect in conventional 2DEG

Landau level (LL) for Schrödinger electrons:

\[ E_N = \hbar \omega_C \left( n + \frac{1}{2} \right) \]

\[ \omega_C = eB/m \]

Landau level filled when there is one electron per flux quanta:
\[ \phi_0 = \hbar/e \ (\phi = B.S) \]

\[ \nu = 1 \]

\[ \nu \] represents the filling factor: the number of filled Landau Level
Fractional quantum Hall effect: the composite fermion picture

$\nu < 1$
Fractional quantum Hall effect: the composite fermion picture

Composite Fermions
\( \nu = 1/2 \)
Fractional quantum Hall effect: the composite particle picture

Composite Fermions
\( \nu = 1/2 \)

\[ \text{1 CF} = 1 \ e^- + 2 \ \phi_0 \]
Fractional quantum Hall effect: the composite fermion picture

Composite Fermions

$1e^- + 2 \phi_0$

$\nu^* = 1 \Rightarrow \nu = 1/3$

$1 \text{CF} = 1 e^- + 2 \phi_0$
Fractional quantum Hall effect: the composite fermion picture

In general:
\[ \nu = \frac{p}{2mp \pm 1} \]
m, p are integer

Composite Fermions
\[ 1e^- + 2 \phi_0 \]
\[ \nu^* = 2 \Rightarrow \nu = 2/5 \]
Charge density wave at higher Landau Level

Landau Level mixing:

\[ \kappa = \frac{e^2}{\epsilon l} \frac{1}{\hbar \omega_C} \]

(\(l\) is the distance between electron and \(\omega_C = eB/m\))

Ratio of the Coulomb interaction to the cyclotron energy

Charge density wave (CDW) measured in stripe and bubble phases

Stripe phase observed in anisotropy of transport
The second Landau Level: competition between phases

Observation of a transition from a topologically ordered to a spontaneously broken symmetry phase

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Insulating and Fractional Quantum Hall States in the First Excited Landau Level

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Hall Bar vs Corbino

Access to $R_{xx}$ and $R_{xy} = R_{Hall}$

Giving access to conductivities:

$$\sigma_{xx} = \frac{\rho_{xx}}{\rho_{xx}^2 + \rho_{xy}^2} \quad \sigma_{xy} = \frac{\rho_{xy}}{\rho_{xx}^2 + \rho_{xy}^2}$$

$$V = \frac{I}{2\pi \sigma_{xx}} \ln \frac{r_0}{r_1}$$

• Access to $\sigma_{xx}$ without aspect ratio factor
• Bulk measurement, edges states don't participate to transport.
Quantum Hall effect in Corbino geometry

Noise and transport measurements in Corbino

3 Corbins in a sample with distance between contact:

ΔR1 = 550 µm
ΔR2 = 40 µm
ΔR3 = 100 µm

Base T = 7 mK
Electron T ~ 15-20 mK
Current noise

\[ S_I(\omega) = \langle \delta I(\omega)^2 \rangle = \langle \delta I(\omega)^2 \rangle_{\text{sample}} + \frac{\langle \delta V(\omega)^2 \rangle_{\text{amp}}}{(Z(\omega) + R_{\text{amp}})^2} + \langle \delta I(\omega)^2 \rangle_{\text{amp}} \]

\[ Z(\omega) = R_{\text{ech}}//C_{\text{coax}} \]

Ampli NF, gain $1^7$

\[
\sqrt{\langle \delta V^2 \rangle} \approx 2.6 \text{nV/\sqrt{Hz}}
\]

\[
\sqrt{\langle \delta I^2 \rangle} \approx 335 \text{fA/\sqrt{Hz}}
\]
Noise in Crystal phase

\[ \nu = 6 \]
\[ \nu = 5 \]
\[ \nu = 4 \]

\[ \frac{1}{2} = \text{stripe phase} \]
\[ \frac{1}{4} = \text{bubble phase} \]

\[ V_{bias} = 40 \, \mu V \]
Noise in Crystal phase

\[ \nu = 5 \]

\[ \nu = 4 \]

\[ \nu = 6 \]

\[ \nu = \frac{1}{2} \]

\[ \nu = \frac{3}{4} \]

\[ \nu = \frac{1}{4} \]

\[ V_{bias} = 220 \mu V \]

\[ V_{bias} = 40 \mu V \]

1/2 = stripe phase
1/4 = bubble phase
Transport and noise in the second Landau level

\[ \nu = \frac{5}{2}, \frac{7}{3}, \frac{8}{3} \]

RIQHE?
Non linear transport in the second Landau level

Differential conductance ($\frac{\partial I}{\partial V}$)

$v = \frac{5}{2}$
$v = \frac{7}{3}$
$v = \frac{8}{3}$
Non linear transport in the 5/2 state

Differential conductance ($\partial I / \partial V$)
Non linear transport in the 5/2 state

Differential conductance ($\partial I / \partial V$)
Non linear transport in the 5/2 state

Differential conductance ($\partial I / \partial V$)
Non linear transport in the 5/2 state

Differential conductance ($\frac{\partial I}{\partial V}$)
Noise in the 5/2 state
Noise in the 5/2 state
Noise in the 5/2 state
Summary

\( F = \text{fano factor} \)

- **N=2**
  - \( F \sim -50 \)
  - Stripe phase
  - \( \nu = 3 \)
  - Hopping Noise
  - Avalanche Noise

- **N=1**
  - \( F \sim 7/3 \)
  - \( \nu = 7/2 \)
  - \( \nu = 8/3 \)
  - \( \nu = 5/2 \)
  - \( \nu = 7/3 \)

- **CDW**
  - \( \nu = 5 \)

- **CDW and FQH**
  - \( F \sim 1 \)
  - \( F \sim 100 \)

- **CDW and FQH**
  - \( F \sim -200 \)
Conclusion

• First differential conductance and noise measured in FQHE in Corbino geometry
• Crystal phases have a special signature in noise
• Evidence that there is a cohabitation between crystal phases and fractional phases in the SLL from the differential conductance and noise measurements

Thank you for your attention!
Second Landau level at different temperatures

\[ S_j \left( A^2 / Hz \right) \times 10^{-24} \]
Second Landau level at different temperatures
Second Landau level at different temperatures

\[ S_f \left( \frac{A^2}{H^2} \right) \times 10^{-24} \]

Temperature Levels:
- 20mK
- 30mK
- 75mK

Graph showing the behavior of \( S_f \left( \frac{A^2}{H^2} \right) \) at different magnetic fields \( B(T) \) for various temperatures.