Unraveling the spin polarization of the $\nu=5/2$ fractional quantum Hall state

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Why spin polarization?

• Quantized charge $e/4$ cannot discern the nonabelian state
• Nonabelian states are polarized
• Abelian states are unpolarized

→ Measurement of spin polarization
Measurement

100 mikron wide Hall bar
27nm wide 2DES in a back gated GaAs QW
$\mu = 580 \, \text{m}^2/\text{Vs}$
$0.5 \times 10^{15} \, \text{m}^{-2} < n$
$< 4.2 \times 10^{15} \, \text{m}^{-2}$

5/2 is well visible as well as 7/3 and 8/3.

Polarized electrons induce a local magnetic field around the nuclei $\rightarrow$ Knightshift (shifting of the nuclear resonance frequency)

Measurement of the spin polarization shows the hyperfine interaction between nuclear spins and the electrons of the 2DES.

Resistively detected nuclear magnetic resonance (RD-NMR)
1. Dynamical nuclear polarization @ $v_{\text{read}}$ (4 min) driving a 45 nA $\rightarrow$ reading $R_{xx}$
2. rf irradiation @ $v$ for 0.3 – 10 s
3. Readout @ $v_{\text{read}}$ (10 s - 20 s)

Signal: $\Delta R_{xx} = R_{xx1} - R_{xx3}$

- rf excitations and change in nuclear polarization $\langle l_z \rangle$ are detected as $\Delta R_{xx}$
- originates from the coupling between $\langle l_z \rangle$ and electron Zeeman energy $E_Z \propto (B + b_0 \cdot \langle l_z \rangle)$ mediated by the hyperfine interaction ($b_0$: constant)
RD-NMR

- P from NMR spectra
  - Proportionality factor between P and $K_s$
  - Measurement of states with known spin polarization ($v=2, 5/3$)

But $R_{xx}=0$!

$\rightarrow$ Switch to $v_{read}$ for $R_{xx}$ (most sensitive $v=0.59-0.65$)

Compared to $v=2$ a resonance shift is observed for 5/2
Determining P

- Comparison to a state with known polarization like 5/3
  - Like $\nu = 1/3$ Laughlin state maximally polarized
- Change of $\nu$ over $e$- density →
- $K_{5/2} = 1.5K_{5/3}$ is observed
- Both states are fully polarized.
- Fit $K_s = \alpha_{\nu} \cdot |\Psi_{\nu}(z)|^2$ for each nucleus and integrate over all.
- $P$ from the ratio $\alpha_{5/2}/\alpha_{5/3} = 1.56 \Rightarrow P_{5/2}/P_{5/3} = 1.04$
$E_z$ dependence of P

- $\alpha$ linear with B shows constant polarization
- Independent of $E_z$
  @ 4 T - 7 T

- Fully polarized 5/2
  → Possible states are all nonabelian
Optical Measurements?

- Optical probing indicates an unpolarized 5/2 state.
- Depolarization at low magnetic fields due to Skyrmions?
- No indications here
- Probing of excitations above the ground state?
- Difference between edge and bulk?
- Here the bulk is probed.
Other FQH states

- $\alpha$ in comparison to the full polarization value
- Linear increase for $\nu > 2.2 \rightarrow$ fully polarized $N=1$ LL.
- Static magnetic field thus difference between $N=1$ and $N=0$ due to different CF interaction
- $N=0$ strong repulsion at short distances - compressible Fermi sea of CFs $\rightarrow$ partial P
- $N=1$ weak repulsion $\rightarrow$ full P and CF pairing at $5/2$
T-dependence

- Properties of unpaired 5/2 CFs occur @ higher T?
- FQH 5/2 vanishes @ 150 mK

- Full P @ 5/2 remains up to 200mK
T-dependence

• Robust P is observed for the whole N=1 LL

• Fit of $m_{\text{eff}}$ gives $2.68m_e(5/2)$ and $0.71m_e(3/2)$

• Large $m_{\text{eff}}$ essential for CF pairing?
Summary

• Maximal spin polarization @ FQH state 5/2

• First direct measurement

• Consistent with nonabelian states

• Different character of CF interaction @ N=1 LL