Non-abelian to abelian transition of the 1/2 fractional quantum Hall state

Siddharth Kumar Singh, Chengyu Wang, Chia-Tse Tai, Casey S. Calhoun, Pranav Thekke Madathil, Kevin A. Villegas Rosales, Adbhut Gupta, Kirk W. Baldwin, Loren N. Pfeiffer and Mansour Shayegan *Department of Electrical and Computer Engineering*
Princeton University

The ground state at $\nu = 1/2$ in the lowest (*N* = 0) Landau level in two-dimensional electrons confined to *wide* GaAs quantum wells transitions from composite fermion Fermi sea to a fractional quantum Hall state (FQHS) and finally to a bilayer Wigner crystal as the density (n) is raised. In wide wells, the electron system has a bilayer charge distribution because of which the nature of the 1/2 FQHS has been a subject of debate. Here, we report the evolution of the 1/2 FQHS in a 72.5 nm wide quantum well as a function of density, from 1.0 to $1.59 \times 10^{11}\ \mathrm{cm}^{-2}$ while keeping the charge distribution symmetric by appropriately biasing the front- and back-gates. The transport energy gap of the 1/2 FQHS shows an upward cusp with a maximum value of about 6 K at $n = 1.37 \times 10^{11}\ \mathrm{cm}^{-2}$ and monotonically decreases to zero as the density is changed in either direction. We find qualitative agreement with theoretical calculations of the energy gap of the 1/2 FQHS where the upward cusp in the energy gap is identified to be due to a transition between the 1-component Pfaffian (Pf) and the 2-component Halperin-331 (Ψ_{331}) states as the density is increased from a small to high value. Interestingly, the Hall plateau at $\nu = 1/2$ remains strongly quantized in this entire range of densities. At $n = 1.37 \times 10^{11}\ \mathrm{cm}^{-2}$ and slightly lower densities, when the 1/2 FQHS is sufficiently strong we also observe the daughter states of the 1/2 FQHS at $\nu = 8/17$ and $7/13$, whose positions are consistent with the daughter states of the Pf state. At higher densities, evidence for the 2-component nature of the electron system can be observed with the emergence of the bilayer Wigner crystal and the destruction of odd-numerator FQHSs. We also show that several of these transitions occur at the same value of interlayer tunneling in units of the Coulomb energy. The continuous transition of the 1/2 FQHS from the non-abelian Pf state to the abelian Ψ_{331} state can potentially be useful for experiments in topological quantum computing and quantum criticality.

References:

1. S. K. Singh et al., *Topological phase transition between Jain states and daughter states of the ν = 1/2 fractional quantum Hall state*, Nat. Phys. (2024).
2. Suen et al., *Correlated states of an electron system in a wide quantum well*, Phys. Rev. Lett. **69**, 3551 (1992).
3. Manoharan et al., *Evidence for bilayer quantum Wigner solid*, Phys. Rev. Lett. **77**, 1813 (1996).
4. Shabani et al., *Phase diagrams for the stability of the ν = 1/2 fractional quantum Hall effect in electron systems confined to symmetric, wide GaAs quantum wells*, Phys. Rev. B **88**, 245413 (2013).
5. K. Nomura and D. Yoshioka, *Gap evolution in the ν = 1/2 bilayer quantum Hall systems*, J. Phys. Soc. Jpn. **73**, 2612 (2004).
6. M. R. Peterson and S. D. Sarma, *Quantum Hall phase diagram of half-filled bilayers in the lowest and the second Landau level: Abelian versus non-Abelian incompressible fractional quantum Hall* states, Phys. Rev. B **81**, 165304 (2010).
7. W. Zhu et al., *Fractional quantum Hall bilayers at half filling: Tunneling-driven non-Abelian phase*, Phys. Rev. B **94**, 245147 (2016).
8. A. Sharma et al., *Composite-fermion pairing at half-filled and quarter-filled lowest Landau level*, Phys. Rev. B **109**, 035306 (2024).