Symmetry-Broken Quantum Hall States in Bilayer and Trilayer Graphene.

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Owing to the spin, valley, and orbital symmetries, the lowest Landau level in few-layer graphene exhibits multicomponent quantum Hall ferromagnetism. Using transport spectroscopy, we investigate the energy gaps of integer and fractional quantum Hall states in bilayer graphene (BLG) with controlled layer polarization. The state at filling factor ν=1 has two distinct phases that are stabilized by either high electric field or large magnetic field, corresponding to layer polarized state and coherent combination of the two layers, respectively. In contrast, the ν=2/3 quantum Hall state and a feature at ν=1/2 are only resolved at finite electric field and large magnetic field. These results underscore the importance of controlling layer polarization in understanding the competing symmetries in the unusual QH system of BLG[1].

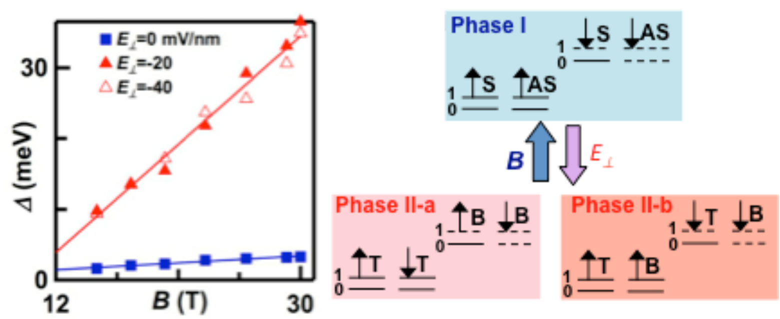

FIG. 1 (left) Measured LL gap *Δ(B)* at E = 0 (Blue) and $E_\perp$ = -20mV/nm and -40mV/nm (Red) respectively. (Right). Schematics of electronic configurations of the different ν=1 phases. T: top layer; B: Bottom layer. S (AS): their symmetric (anti-symmetric) combination. The numbers 0 and 1 are the orbital indices. The solid (dotted) lines represent occupied (empty) levels.

In another FLG system, ABA-stacked trilayer graphene consists of multiple Dirac bands, where crystal symmetry protects the spin degenerate counter-propagating edge modes resulting in $\sigma_{xx} = 4e^2/h$. At even higher magnetic fields, the crystal symmetry is broken in by electron-electron interactions and the ν=0 quantum Hall state develops an antiferromagnetic stability with broken spin rotation symmetry[2]. Our findings indicate the role of crystal and spin symmetry in generation of topological phases in multiple Dirac bands.

[1] Y. Shi et al, submitted (2015).
[2] P. Stepanov et al, in preparation (2015).

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