Disorder induced local quantum Hall breakdown on spin-, valley-, and cyclotron-gapped states in graphene

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The Quantum Hall effect (QHE) is known to be stabilized by disorder, thanks to the emergence of bulk localized states that do not participate in quantized transport along the edge. However, disorder also induces the loss of QHE quantization: if a large enough energy (called hopping energy) is provided, charge carriers trapped in a localized state will have the possibility to tunnel from state to state, making the bulk conducting. This phenomenon occurs even at temperatures much lower than the Landau level (LL) spacing, and is usually described in the framework of variable range hopping (VRH) [1], and corresponds to a rich physics governed by universal scalings [2, 3]. The competition between these two antagonistic effects of disorder is set by the interplay between two energy scales (LL spacing and disorder broadening), and two length scales (magnetic length and characteristic disorder length) [4].

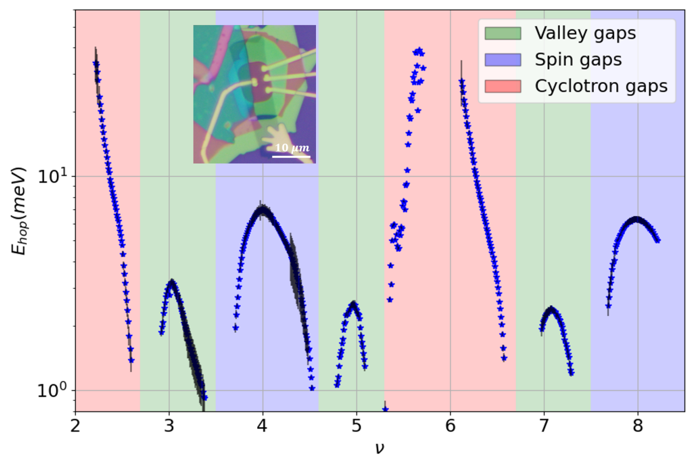

Fig. 1. Extracted hopping energies in the framework of VRH for different types of gaps at $B = 14T$. Inset: Optical micro-graph of the sample.

To explore this interplay, we have probed the temperature dependence of QH states in graphene in a Corbino geometry [5], over three orders of magnitude. The fourfold spin and valley symmetry of graphene is lifted at high magnetic field, providing two well-separated scales for the energy level spacings [6]: cyclotron gap for a fully filled LL, and spin/valley gaps for the symmetry broken states. Tuning the carrier density with an electrostatic gate allows us to probe states with vastly different gaps at otherwise fixed magnetic length and disorder. We observe a difference of two orders of magnitude in the extracted hopping energies between cyclotron gap states and symmetry broken states; we propose a scenario, based on local breakdown of the QHE modifying the effective disorder potential landscape and hence the energy scales involved in the VRH.

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