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The high-field state at the Dirac Point in graphene[1]

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The discovery of the quantum Hall Effect in graphene has generated considerable interest in the state at the Dirac Point in a magnetic field H. In intense H, the 4-fold degeneracy of the $n = 0$ Landau Level (LL) is lifted by the enhanced exchange energy. Among the broken symmetry states proposed are the quantum Hall ferromagnet, the quantum Hall insulator state, excitonic condensation, and charge-density-wave formation. A subset of these theories propose counter-propagating edge states that remain conducting in large H. We have performed measurements of the resistance R_{xx} and Hall resistance R_{xy} to fields of 33 T at temperatures T from 0.3 to 50 K in ∼6 graphene samples. We find that, as T decreases below 10 K, R_0 (= R_{xx} at the Dirac Point) undergoes a steep increase with a divergence consistent with a field-driven transition to an insulating high-field state. The divergence in R_0 fits well to the Kosterlitz-Thouless (KT) form $\exp(b/\sqrt{h-1})$ with $h = H/H_c$ and $b \sim 1.4$. The critical field H_c is sample dependent (12 T to 33 T), and correlates with the disorder as measured by the offset gate voltage V_0 and the zero-H mobility. The divergence in R_0 is strictly confined to the $n = 0$ LL (bracketed by the sublevels $\nu = \pm 1$). The peaks with $n = \pm 1$ remain near the values h/e^2. Using an ultralow-power (3 fW), voltage-regulated technique, we show that the KT-fit to R_0 is valid over 3 decades (40 kΩ to 40 MΩ). The steepness of the R_0 vs. T curves implies a bulk gap Δ of magnitude 15-20 K that decreases when H falls below H_c. We compare our findings with the various proposed models. We will also report thermopower and Nernst measurements taken to fields of 14 T.

Refs. J. G. Checkelsky, L. Li and N. P. Ong, prl **100**, 206801 (2008); ibid. cond-mat arXiv:0808.0906v1.

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