Hall effect in graphene near the charge neutrality point

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In single layer grapheme, when the carrier concentration through the charge neutrality point (CNP) is varied from hole-type to electron-type, the measured Hall resistivity ρ_{xy} close to the CNP shows a smooth zero crossing for magnetic fields up to 30 T. In contrast, ρ_{xy} diverges in a conventional semiconductor approaching the CNP from both the electron and the hole side. We explain our results in terms of a two-component carrier system where both electrons and holes with finite concentrations are present simultaneously around the CNP. The Hall resistivity is given by (supposing a similar mobility for electrons and holes) :

$$\rho_{xy} = \frac{n-p}{e(n+p)^2} B \qquad (1)$$

with n and p the charge carrier concentrations for electrons and holes, respectively, e is the electron charge and B the applied magnetic field.

Our samples are monolayer graphene devices deposit on Si/SiO_2 substrate using standard methods [1], and the charge carrier concentration is varied with a back gate from highly electron- to highly hole-doped.

Fig. 1(a) shows the low magnetic field data for one of our samples measured at $T = 0.5$ K where the Hall resistance does not yet show the quantum Hall effect (QHE). Knowing the total charge density $q=n-p$ from the back-gate voltage, we have extracted the individual carrier concentrations n and p [Fig. 1(b)] as a function of the total charge with Eq. (1). We find that both types of charge carriers are present both above and below the CNP. For this sample, precisely at the CNP (q=0) we find $n = p = 4.2\cdot10^{14}$ m^{-2} only weakly dependent on the magnetic field in this non-quantized regime. Away from the CNP the system remains two-component and the minority carriers only disappear for $|q| > 2\cdot10^{15}$ m^{-2}.

When we increase the magnetic field into the quantum Hall regime at $T = 4.0$ K [2, 3] [Fig. 2(a)], we still observe a zero-crossing of ρ_{xy} and at the CNP in Fig. 2(b), we find that both n and p are present but their number increases with the magnetic field. Plotting charge carrier concentration as a function of B, n is found to be constant for $B < 5$ T after which it increases linearly as B increases. This behavior is attributed to transport dominated by electron-hole puddles for low magnetic fields evolving into a quantized density of states in high magnetic fields [4].

The observed presence of both electrons and holes near the CNP even deep into the quantized Hall regime may contribute to a better understanding of the nature of electronic states at the lowest Landau level in graphene [5]. In particular, in high magnetic fields it allows to distinguish between different splitting scenarios of the lowest Landau level: valley first where electrons and holes are separated and the Hall resistance is expected to diverge at the CNP, and spin-first where electrons and holes remain present above and below zero-energy and the Hall resistance crosses zero at the CNP [6].

References

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Figures

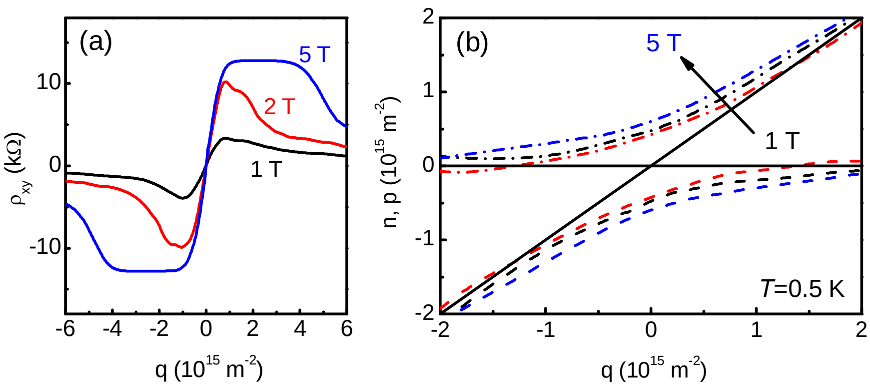

Fig. 1: (a) Low-field Hall resistivity and (b) extracted carrier concentration for electrons n and holes p according to Eq. (1) as a function of total charge q. Both types of charge carriers are present below and above the CNP for $|q| < 2{\cdot}10^{15}$ m^{-2}.

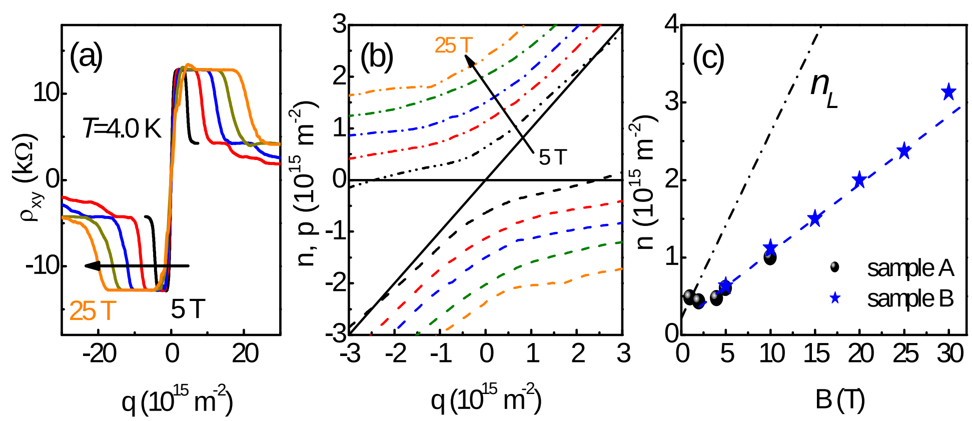

Fig. 2: (a) High-field Hall resistivity in the quantum Hall regime.

(b) Extracted carrier concentration for electrons n and holes p according to Eq. (1) as a function of the total charge q.

(c) Charge carrier concentration increases with B due to a quantized density of states. Most carriers are localized in the tails of the Landau level and only about 1/3 of the total carrier concentration is measured as free charge carriers.