# METAL-INSULATOR TRANSITIONS IN GRAPHENE

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The experimental observation of a non standard sequence of integer quantum Hall plateaus in graphene [1,2] has renewed the interest for the study of the quantum phase transitions (QPTs). We have measured the plateau-insulator (PI) QPT in monolayer graphene, observing a $\nu = 0$ plateau and obtaining the value of the critical exponent $k = 0.58 \pm 0.03$ [3]. More recently we extended our study to a wide temperature range and different gate voltage (VG), and the results question the universality of the critical exponents in graphene. Actually, this study can help to clarify the controversy about the nature of $\nu = 0$ state. Indeed, previous experiments have shown that at $\nu \sim 0$ the longitudinal resistivity may either decrease [4] or increase [5] with decreasing temperature, fueling the debate concerning the existence and the origin of an insulator phase at the charge neutrality point (CNP) at high magnetic fields.

Monolayer graphene was obtained by peeling graphite onto a Si wafer with a 300 nm $SiO_2$ top layer. We evaporated 8 metallic contacts made of 500/50 $\AA$ of Au over Ti in a Hall bar geometry with an aspect ratio W/L = 0.48. A dilution fridge and a 4He cryostat with a variable temperature insert allowed us to vary the temperature from 1.4 K to room temperature. A resistive 20 MW magnet from the LNMCI-Grenoble allowed us to obtain magnetic fields up to 28 T. The Hall and longitudinal resistances were measured by the standard 4-probe low frequency AC lock-in method with excitation currents of ∼10 nA.

We first investigated the quantum Hall effect (QHE) in a graphene sample with Hall-bar geometry close to the CNP at magnetic fields up to 28 T and temperature from 1.4 K to 4 K. We observed a PI - QPT passing from the last plateau for the integer QHE in graphene to an insulator regime: $\nu$ = -2 $\rightarrow$ $\nu$ = 0. In particular we observed the PI transition when the magnetic field is tuned across a critical field $B_c$ = 16.7 T. Both the Hall conductivity and the longitudinal resistance remain quantized deep into the insulating phase, suggesting that we are in the same quantized Hall insulator regime observed for the PI transition in low-mobility 2D systems.

Using the standard scaling theory analysis, we have obtained the critical exponent for this transition $k = 0.58 \pm 0.03$, in agreement with the common value observed for this exponent in conventional 2D systems. This evidence supports the identification of $\nu = 0$ in graphene as an insulating phase rather than a QH state. Therefore two distinct PI transitions exist near the Dirac point in graphene, namely a conventional QH-insulator transition as the observed in our experiment and the recently observed KosterlitzThouless (KT) transition found by Checkelsky et al [5].

We also studied to the PI and plateau-plateau (PP) QPTs in a wider temperature range (from 4 K up to 230 K) and at different VG. In the case of the PI $\nu$ = -2 to $\nu = 0$ transition we have observed it up to 45 K, pointing out the robustness of the QPT and of the metal and insulating phases. The critical exponent for this transition is consistent with the accepted universal value for 2DEGs when the sample is doped away from the Dirac point ($k = 0.58 \pm 0.01$) but tends to the classical full percolation limit ($\nu = 0.697 \pm 0.005$) when VG approaches the CNP. No trace of KT transition was found when approaching to the CNP. In the case of the PP transition, we measured it up to 230 K. We obtain a value for the critical exponent $k = 0.25$ far away from the universal value $k = 0.42$ as was recently reported in a similar experiment [6]. Thus the analysis of the temperature dependence of the Hall and longitudinal resistivity reveals the non-universality of the critical exponent for the metal-insulator transition when varying the density of carriers. Further studies with controlled disordered samples are necessary in order to clarify the role of the unintentional doping and disorder in the QPTs in graphene [7].

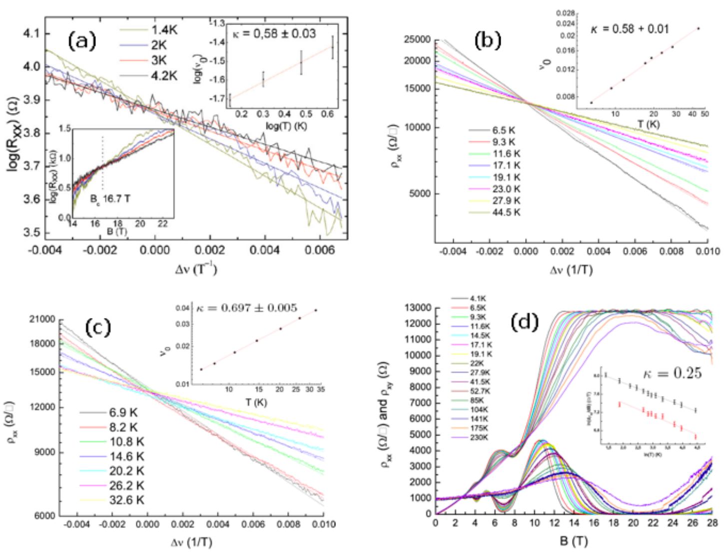


Figure 1: (a) Longitudinal resistance $R_{xx}$ as a function of $\Delta\nu$ with $\Delta\nu = 1/B - 1/B_c$ and $B_c = 16.7$ T, at low temperatures and $V_G = -8$ V; lower inset: $log(R_{xx})$ vs B; upper inset: the parameter $\nu_0$ obtained fitting our data using the standard scaling procedure ($R_{xx} = \exp[-\Delta\nu / \nu_0(T)]$, critical exponent $\nu_0 \propto T^k$)). (b) The analysis described in (a) but at higher T. (c) The analysis described in (a) but at higher T and $V_G = 2$ V. (d) $\rho_{xx}$ and $\rho_{xy}$ as a function of B at $V_G = -8$ V at temperature from 4.1 K to 230 K, showing the plateaus $\nu$ = -2,-6,-10 in $\rho_{xy}$ an their Shubnikov-de Haas peaks.

## References

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