Metal-insulator transitions in graphene.

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In this work we show the metal-insulator (MI) quantum phase transitions that appear in the quantum Hall effect in graphene, namely the plateau-insulator (PI) and plateau-plateau (PP) transitions. For this purpose we have performed magneto-transport experiments with the magnetic field (up to 28 T) as the driving parameter in the temperature range from 4 K up to 230 K.

The Hall (ρ_{xy}) and longitudinal (ρ_{xx}) resistivities were measured by the standard 4-probe low frequency AC lock-in technique while the graphene sample was obtained by mechanical exfoliation over a Si/SIO_2 wafer with subsequent e-Beam lithography and the evaporation of Au/Ti contacts. The charge neutrality point (CNP) appeared at 3.8 V.

When the gate voltage was placed in the vicinity of the charge neutrality point we have observed a transition from the last plateau υ=-2 to an insulating phase. The transient between delocalized to localized states occurs through a T-independent crossing point where, at low temperatures, the isotherms converge as seen the left panel of **Fig.1** where we show ρ_{xx} isotherms as a function of B for V_G = 2 V where a T-independent crossing point appears at a critical magnetic field B_C = 16.05 T. For temperatures above tents of Kelvin, the PI T-independent crossing point disappears, confirming the robustness of the MI transition as pointed out by Zhang *et al.* [1].

For the PI transition we have calculated the associated critical exponent by calculating the value of υ_0 (υ_0 should not be confused with the Landau level filling factor) in from the equation $\rho_{xx} = \exp[(1/B\text{-}1/B_C)/\upsilon_0]$ applied in the vicinity of the T-independent crossing point [2,3] as shown in the right panel of **Fig.1** Then, extracting υ_0 at every temperature we could calculate the associated critical exponent from $\upsilon_0 \sim T^{\kappa}$. We have obtained a value for κ=0.58±0.01 away from the CNP, in agreement with the expected value for two-dimensional electron gasses (2DEGs) while closer to the CNP the obtained value has been found to match with the one expected in the full percolation limit κ=0.697±0.005. This difference could be attributed to the effect of the disorder present in the sample, dominant the alloy one (Anderson type) for higher densities in contrast with the short-range disorder, that would be dominant at lower densities. What we can firmly question from these results is the universality of the critical exponent associated to the PI transition.

In order to study the PP transition have we tuned the gate voltage tents of volts away from the CNP. We have calculated the critical exponent for the transitions υ = -10→ υ = -6 and υ = -6→ υ = -2 in a range of temperatures from 4.2 to 230 K as seen in **Fig.2**. The PP transition remained clearly observable almost up to the maximum temperature we reached as observed by Giesbers *et al.* [4]. We have extracted the critical exponents both from the temperature dependence of the full width at half maximum (FWHM) of the Shubnikov-de Haas peak in the transition υ = -6→ υ = -2 and from the temperature dependence of the maximum slope for ρ_{xy} between adjacent plateaus in both transitions. The value extracted obtained κ=0.25±0.02 does not match with the expected universal value for 2DEGs κ = 0.42 recently reported also in graphene [4].

With the values obtained for the critical exponents of the MI transitions in graphene we question the universality of such critical exponents in this novel material. We attribute this anomalous behaviour to the effect of the disorder in our samples. Thus, further studies are necessary in order to throw light upon the role of the impurities and disorder in the QPTs in graphene with controlled disordered samples.

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References

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Figures

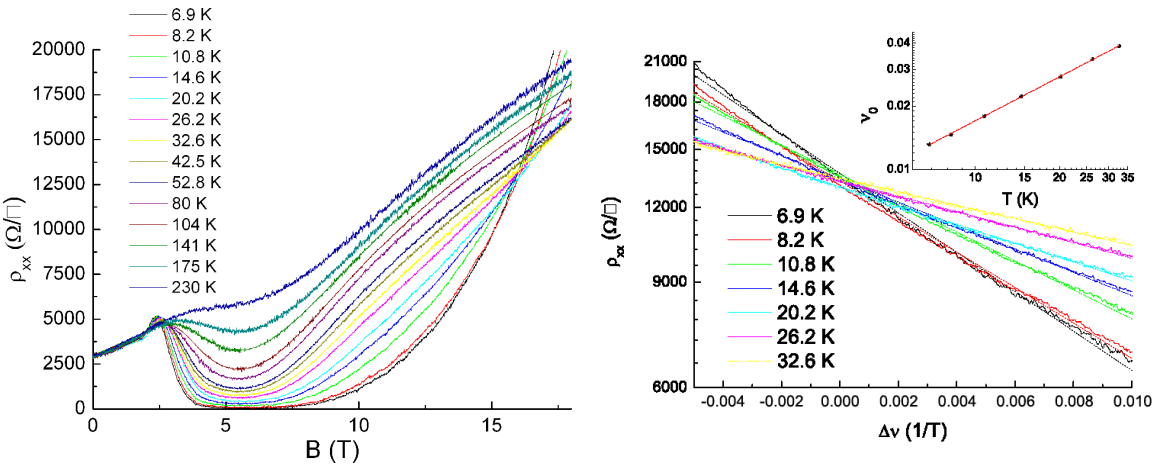

Fig.1. In the left panel we show ρ_{xx} isotherms as a function of B at V_G = 2 V. The T-independent crossing point disappears when B > 32.6 K that confirms the existence of a possible deactivation temperature of the PI transition. In the right panel we show the renormalization of ρ_{xx} close to the T-independent crossing point following the standard procedure [2,3] for the same density of carriers. The associated critical exponent derived from the fit to $\upsilon_0 \sim T^{\kappa}$ is κ = 0.697 ± 0.005, in contrast with the expected value 0.58.

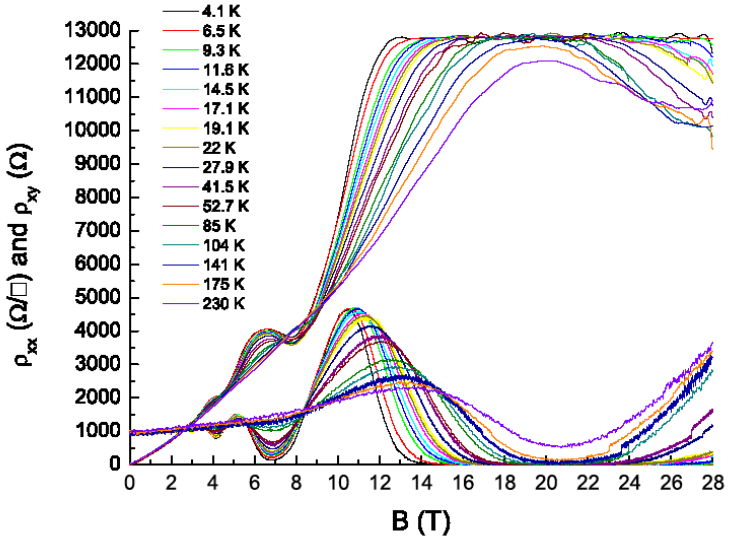

Fig.2. ρ_{xx} and ρ_{xy} isotherms as a function of B for V_G=-8V .Plateaus υ=-10, υ=-6 and υ=-2 and their SdH peaks can be clearly observed up to 230 K.