Origin of logarithmic resistance correction in graphene

To the Editor — Chen *et al.*[1] recently presented data of a logarithmic low-temperature anomaly in the resistance of graphene flakes and attributed this to Kondo physics. The samples were irradiated beforehand with ions, and the appearance of a logarithmic anomaly was linked to the presence of induced defect states with unpaired electrons.

Here, we present evidence that this assignment to Kondo physics is wrong. The observed effect is due to electron–electron interaction (EEI)[2], which in the diffusive regime also gives a logarithmic correction to the resistance (in two dimensions). It is an effect that is based on very general assumptions, and that has been observed in many two-dimensional materials in excellent agreement with theory. It has been pinpointed in graphene recently[3].

The EEI correction to the longitudinal resistivity is quantitatively described by the formula

$$\rho_{\square}(n,T) = \rho_{\square,0} + [(\omega_c\tau_{tr})^2 - 1]\,\frac{e^2\rho^2_{\square,0}}{2\pi^2\hbar}\left[1 + c\left(1 - \frac{\ln(1+F_0^\sigma)}{F_0^\sigma}\right)\right]\ln\left(\frac{k_B T\tau_{tr}}{\hbar}\right)$$

in which all quantities are known: the Fermi liquid constant $F_0^\sigma = -0.10$ from theory, the number of channels was chosen as $c = 3$ as expected for strong intervalley scattering[3], and cyclotron frequency ω_c and transport time τ_{tr} were derived from the experiment[1]. $\rho_{\square,0}$ is the longitudinal Drude resistivity, T is the temperature, e the elementary charge and n the charge density. As the geometry is often not well controlled in a flake, we allowed for a rescaling $\rho_{\square} = g\rho$ of the experimental values. With the geometry correction estimated to be $g = 3$, our quantitative prediction of EEI is plotted together with the experimental data of Chen *et al.*[1] (corrected for g) in Fig. 1. There is excellent quantitative agreement with one consistent parameter set. All those parameters are known and experimentally confirmed for graphene. The saturation of the experimental data at low temperature stems from finite size effects. Note also that after the harsh treatment (ion irradiation and subsequent annealing) the homogeneity of the sample is not guaranteed.

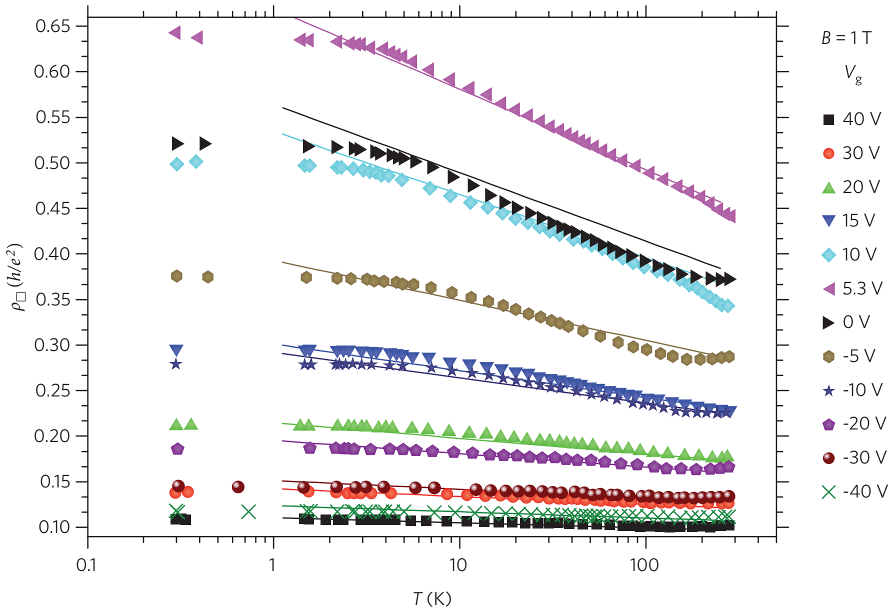

Figure 1 | Comparison between EEI correction[2,3] and experimental data[1]. EEI theory (lines) gives a parameter-free description (charge density and mobility are derived from experiment) of $\rho_{\square}(T)$. When allowing for a geometry correction of $g = 3$, the observed logarithmic slopes (coloured symbols) and the scaling with V_g are quantitatively described. A magnetic field of B = 1T was applied to suppress weak localization[1].

The logarithmic correction $\Delta\rho$ was observed after irradiation, because it was substantially enhanced by two main mechanisms: $\Delta\rho$ increases with ρ_0 quadratically, and c eventually decreases from seven to three because local defects reduce the intervalley scattering time.

Chen *et al.*[1] argue that EEI is absent because no logarithmic correction occurs in the Hall data. Although we are not able to see this in the given (inappropriate) plot, the logarithmic contribution in the Hall data may be obscured by universal conductance fluctuations or unavoidable contributions from non-ideal alignment of the Hall leads.

We conclude that the well-established logarithmic correction to the resistivity due to EEI describes the data excellently without any free parameter (apart from a geometry correction factor), and hence no convincing indication for Kondo physics remains in the data. When, however, the geometry correction is chosen as $g = 1$, then the EEI correction (that depends only on fundamental constants) should be properly subtracted. This would lead to a positive slope at low temperatures, which is incompatible with the argument of Chen *et al.* The remaining effect would still scale with the gate voltage V_g exactly like the EEI correction. ❒

References

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