Chen *et al.* reply — We reported[1] that irradiation-induced vacancies in graphene have local moments that couple to conduction electrons through the Kondo effect, with a resistivity increasing logarithmically with decreasing temperature and saturating at low temperature. The local moment of graphene vacancies has since been verified in susceptibility measurements[2]; however, that experiment was agnostic on the Kondo effect, which would be difficult to probe magnetically as vacancies significantly outnumbered carriers. Weber *et al.* comment that our resistivity data might be confounded by Altshuler–Aronov corrections[3], recently measured in graphene on SiO_2 (ref. 4) and SiC (refs 5–7). The Altshuler–Aronov effect gives graphene's resistivity as:

$$\rho_{xx} = \rho_{xx,0}\left[1+A\,\frac{\rho_{xx,0}e^2}{2\pi^2\hbar}(\mu^2B^2-1)\,\mathrm{ln}\left(\frac{k_BT\tau_{\mathrm{tr}}}{\hbar}\right)\right] \qquad (1)$$

where $\rho_{xx,0}$ is the uncorrected longitudinal resistivity, $A \leq 1$ a constant, e the elemental charge, T temperature, μ the charge carrier mobility, B the magnetic field, and τ_{tr} the transport momentum relaxation time. Here we show that equation (1) cannot explain the magnitude of the logarithmic resistivity and magnetoresistance, or the saturation of the resistivity at low temperature for our devices.

Figure 1a shows fits of equation (1) to our $\rho_{xx}(B)$ for $1\ \mathrm{T} < B < 6\ \mathrm{T}$ at $T = 300$ mK, for four different gate voltages (V_g); the global fit parameter is $A = 0.32$ (A is systematically smaller, and magnetoresistance overestimated, for small $V_g - V_{g,\mathrm{min}}$). Our devices are etched Hall bars with an aspect ratio exceeding three; geometric errors in ρ_{xx} are at most a few per cent. $A = 0.32$ is reasonably consistent with other experiments; Kozikov *et al.*[4] analysed $\rho_{xx}(T)$ and found $0.35 < A < 1.05$ for graphene on SiO_2, and Jobst *et al.*[7] found that $0.35 < A < 0.92$ for graphene on SiC. The Kondo effect itself also produces negative magnetoresistance, so we consider $A = 0.32$ to be an upper bound. Figure 1b shows $\rho_{xx}(T)$ for the same four V_g and the Altshuler–Aronov correction from equation (1) with $A = 0.32$. The Altshuler–Aronov effect accounts for at most 12–16% of the logarithmic divergence of the resistivity in our data. Likewise, had we had fit $\rho_{xx}(T)$, we would find $1.9 < A < 2.5$, and would drastically overestimate the observed magnetoresistance. $A > 1$ is unphysical and *a priori* rules out the Altshuler–Aronov effect as the sole source of logarithmic $\rho_{xx}(T)$.

Now we discuss the saturation of $\rho_{xx}(T)$. The Thouless length L_T sets the scale for Altshuler–Aronov corrections, which become T independent for $L_T > l_{\mathrm{sample}}$ (l_{sample} is the shortest sample dimension)[8]. Assuming[9]

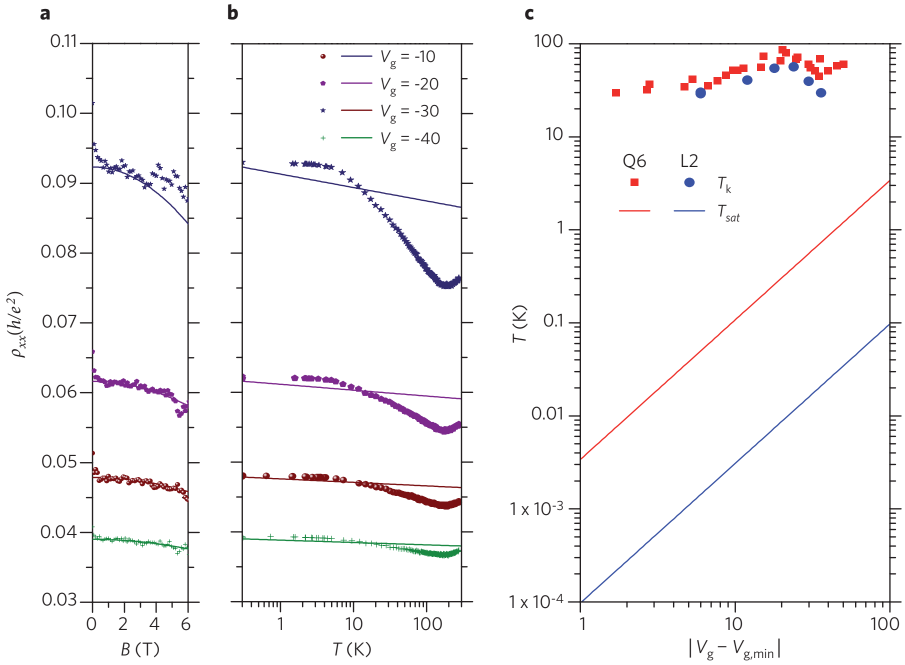

Figure 1 | Temperature and magnetic-field dependent resistivity of graphene with defects. **a**, Magnetoresistance of graphene sample Q6 with defects at a temperature $T = 300$ mK and at gate voltages $V_g - V_{g,\mathrm{min}} = -15.3$ V (blue stars), -25.3 V (purple triangles), -35.3 V (red circles) and -45.3 V (green crosses); $V_{g,\mathrm{min}} = 5.3$ V is the gate voltage of minimum conductivity. **b**, Temperature-dependent resistivity of graphene under 1 T of transverse magnetic field and at the same four V_g values in **a**. In **a** and **b** the solid lines are equation (1) with $A = 0.32$, chosen to fit the data in **a**. **c**, Experimentally determined Kondo temperatures (T_K) for sample Q6 (red squares) and L2 (blue circles). The solid lines are the expected T_{sat} from the Altshuler–Aronov effect for samples Q6 (red) and L2 (blue). Data taken from ref. 1.

$$L_T \approx \frac{\mu}{v_{\mathrm{F}}e}\sqrt{\frac{E_{\mathrm{F}}{}^3}{k_{\mathrm{B}}T}}$$

the saturation temperature (T_{sat}) is

$$k_{\mathrm{B}}T_{\mathrm{sat}} \approx \frac{\mu^2E_{\mathrm{F}}{}^3}{v_{\mathrm{F}}{}^2e^2l_{\mathrm{sample}}{}^2}$$

where v_{F} is the Fermi velocity and E_{F} is the Fermi energy. We reported data for two samples: Q6 ($\mu = 2{,}000\ \mathrm{cm^2\,Vs^{-1}}$ and $l_{\mathrm{sample}} = 2.0\ \mu$m) and L2 ($\mu = 1{,}100\ \mathrm{cm^2\,Vs^{-1}}$ and $l_{\mathrm{sample}} = 6.5\ \mu$m). Figure 1c plots the experimentally determined Kondo temperature and the T_{sat} predicted by Altshuler–Aronov theory as a function of gate voltage $V_g \propto E_{\mathrm{F}}{}^2$. Altshuler–Aronov theory predicts these two samples should show T_{sat} differing by a factor of 35 and strongly V_g dependent; neither is observed. Notably, saturation of $\rho_{xx}(T)$ is not observed down to $T = 0.2$ K in exfoliated graphene on SiO_2 (ref. 4) or 1.5 K in graphene with $l_{\mathrm{sample}} = 5\ \mu$m on SiC (ref. 5). Thus the observed resistivity saturation is novel, and strong evidence for the Kondo effect in graphene with lattice defects. Other saturation mechanisms (such as coherence length $l_\Phi = l_{\mathrm{sample}}$ as in weak localization) are also inconsistent with the data. ❒

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