



# Electronic phase transition in graphene in a magnetic field

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Graphene is comprised of a single layer of C atoms in a hexagonal lattice array. The electronic state of graphene is of great interest because the electron energy increases linearly with momentum, just like for photons and neutrinos. This is called a massless, Dirac dispersion. The nature of the electronic state at zero energy (the “Dirac point”) in a strong magnetic field  $H$  is currently the subject of theoretical debate. Some theories predict that graphene remains metallic with a low resistance even in very large  $H$ , while others predict that it becomes an insulator. Recent experiments by Checkelsky, Li and Ong at Princeton provide direct evidence for a phase transition induced by  $H$ . When  $H$  exceeds a critical value  $H_c$ , graphene undergoes a transition from a metallic state to an insulating state. The figure shows the resistance  $R_0$  at the Dirac point increasing abruptly by over 3 decades from 10 k $\Omega$  to 40 M $\Omega$ . Two competing theories describing the high-field insulating state are shown in the insets. In the charge-density-wave (CDW) model (top inset), electrons preferentially occupy every other site (red circles). In the “Kekule” model (lower inset), the bonds linking adjacent C atoms (blue ovals) shorten slightly in an alternating pattern reminiscent of benzene. Which of these models (or future ones) is correct is being actively researched.

1. J. G. Checkelsky, Lu Li, and N. P. Ong, Phys. Rev. Lett. 100, 206801 (2008); *ibid.* Phys. Rev. B 79, 115434 (2009).

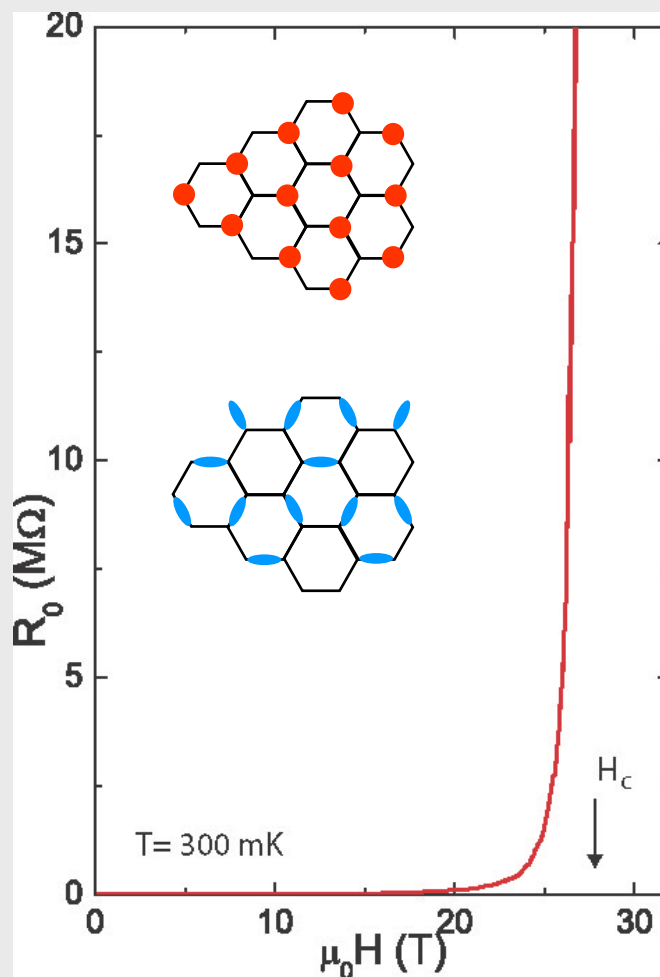


Figure 1 Plot of the resistance  $R_0$  at the Dirac point (red curve) vs. applied magnetic field  $H$  at temperature 0.3 K. The step increase to 40 M $\Omega$  signals a phase transition to an insulating state at the critical field  $H_c$ . The sketches show the CDW (upper inset) and Kekule models (lower).