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QED in Graphene[1]

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Electronic properties of materials are commonly described by quasiparticles that behave as non-relativistic electrons with a finite mass and obey the Schrödinger equation. I will describe our experimental studies of graphene (a free-standing single layer of carbon atoms) in which electron transport is essentially governed by Dirac's (relativistic) equation and charge carriers mimic relativistic particles with zero rest mass and an effective "speed of light" of $\approx 10^6$m/s. We have found a variety of unusual quantum phenomena characteristic of two-dimensional Dirac fermions. In particular, we have observed that a) the integer quantum Hall effect in graphene is anomalous in that it occurs at half-integer filling factors; b) graphene's conductivity never falls below a minimum value corresponding to the conductance quantum, even when carrier concentrations tend to zero; c) the cyclotron mass of massless carriers in graphene is described by Einstein's equation $E=mc^2$; and d) Shubnikov-de Haas oscillations in graphene exhibit a phase shift of π due to Berry's phase. I will also explain another, third type of the integer quantum Hall effect that happens in bilayer graphene and accompanied by Berry's phase of 2π.

[1]In collaboration with K. Novoselov.