Interacting electrons in a strong magnetic field

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Collective excitations of graphene in a magnetic field

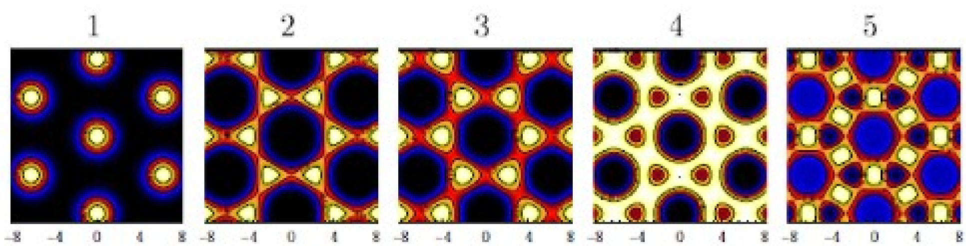
As a consequence of the quantisation of the high-field electrons' kinetic energy into highly degenerate Landau levels, one needs to distinguish two regimes. The first regime is that of completely filled Landau levels, a situation encountered in the integer quantum Hall effect. The relevant Coulomb interaction in this regime does not alter fundamentally the ground state of the electronic system and it manifests itself in collective excitations above the ground state that may be treated within standard perturbative calculations. These collective excitations of graphene electrons in a strong magnetic field have been extensively studied in the LPS theory group (see highlight 10), in comparison with the usual two-dimensional electron gas with parabolic bands, realised for example in GaAs heterostructures. In addition to plasmon-type charge excitations, one expects a violation of Kohn's theorem and thus a renormalisation of the cyclotron frequency at zero wave vector due to interaction effects.

Fractional quantum Hall effect in grapheme

Another interaction regime that has to be distinguished from the one described above is that of partially filled Landau levels, in which case the low-energy excitations are those within the same Landau level. The kinetic energy is thus effectively quenched by the magnetic field, and the Coulomb interaction remains as the relevant energy scale, such that the electrons are strongly correlated. The most prominent phenomenon of these high-field correlated electrons is the fractional quantum Hall effect, which has been investigated theoretically at LPS (mainly in collaboration with N. Regnault from Laboratoire Pierre Aigrain, ENS-Paris) both in graphene and in other 2D electron systems. The spin-valley degeneracy in graphene provides the fractional quantum Hall effect with a particular multi-component structure [deGail, 2008; Papic, 2010] that has been shown to be at the origin of recently observed anomalies in the so-called 1/3 family.

High-field electron crystals

In addition to the fractional quantum Hall effect, the Coulomb interaction between electrons in the same partially filled Landau level gives rise to electron-crystalline phases. Such phases have been investigated in graphene Landau levels. In contrast to two-dimensional electron systems in semiconductor heterostructures, these phases are situated at the graphene surface and thus directly accessible by spectroscopic means, such as scanning-tunneling spectroscopy. Measurable features (the local density of states, see figure below) have been calculated for these electron-crystalline phases [Poplavskyy, 2009].



Calculated local density of states of a Wigner crystal in the n=0 graphene Landau level at low filling, for different energies corresponding to large spectral weight.

Key publications

Z. Papicć, M.O. Goerbig, N. Regnault, . "Atypical Fractional Quantum Hall Effect in Graphene at Filling Factor 1/3", Phys. Rev. Lett. **105**, 176802 (2010)

M.O. Goerbig, "Electronic properties of graphene in a strong magnetic field", Rev. Mod. Phys. **83**, 1193 (2011)