Physical consequences of electron-electron interactions in graphene Landau levels

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The relative role of electron-electron interactions in graphene can be triggered via the magnetic field. Whereas in the absence of such quantising field, the relative strength of the interactions is given in terms of the "graphene fine-structure constant", the latter is relevant in graphene in a magnetic field only in the integer quantum Hall effect, i.e. when an an integer number of Landau levels is completely filled. In this case, a perturbative treatment of the electron-electron interactions provides valuable insight into the collective excitations of graphene in a magnetic field. In comparison with non-relativistic 2D electron systems, graphene displays a similar upper-hybrid mode (the magnetic-field descendant of the 2D plasmon), but also linear magneto-plasmons (see figure) that are an original feature of Dirac fermions in monolayer graphene [1,2].

However, because of the large Landau-level degeneracy, the situation is drastically different when the levels are only partially filled. In this case, inter-Landau-level excitations constitute high-energy degrees of freedom, due to the level separation, whereas the low-energy physical properties are governed by intra-Landau-level excitations [3]. Since these excitations do not alter the kinetic energy, the latter does not play any dynamical role and may be omitted, such that the remaining energy scale is set by the Coulomb interaction. One therefore obtains the regime of the fractional quantum Hall effect, or generally speaking that of strong electronic correlations. The observed fractional quantum Hall effect in graphene [4] displays the large internal symmetry [SU(4)] due to the fourfold spin-valley degeneracy of the relativistic Landau levels. The SU(4) picture of the fractional quantum Hall effect [5,6] has very recently found an experimental proof in four-terminal measurements on an h-BN substrate [7]. Most saliently, the family of 1/3 states may be stabilised in the case of even very small symmetry-breaking fields, such as the Zeeman effect, and displays novel collective spin-flip excitations beyond the Laughlin state [8].

References

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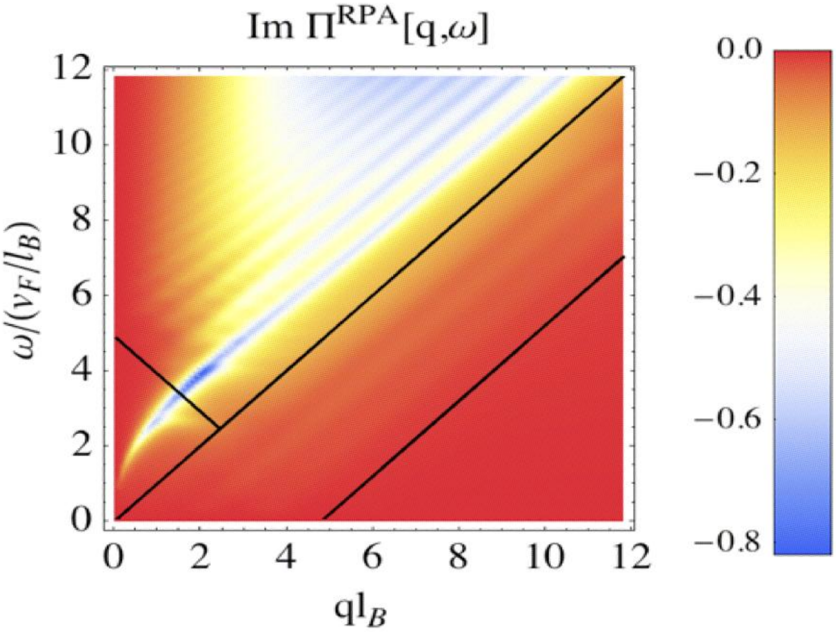
Figures



Imaginary part of the particle-hole excitation spectrum for graphene in the integer quantum Hall regime, calculated within the random-phase approximation. In addition to the upper-hybrid mode, which disperses as the square root of the wave vector at small values of the latter, one obtains linear magneto-plasmons that disperse roughly linearly parallel to the central diagonal.