Coulomb Interaction, Ripples, and the Minimal Conductivity of Graphene

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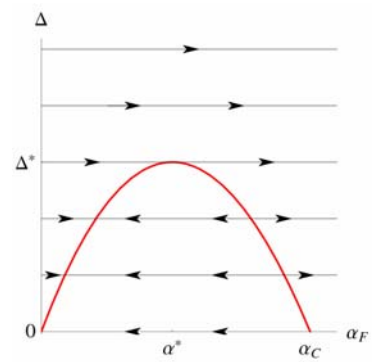
Introduction

Graphene, is an atom-thick layer of graphite, has recently defined a new frontier of condensed matter physics. Its essential electronic property, inherent to the honeycomb lattice formed by the carbon atoms, is that the low-energy quasiparticle excitations can be thought of as being massless Dirac fermions. These fermions propagate with a Fermi velocity of around three thousandths of the speed of light. This pseudo-relativistic nature of the quasiparticle excitations makes the electronic properties of graphene fundamentally new in many respects. When the chemical potential is tuned to the Dirac point graphene provides a rare example of a critical two-dimensional fermionic system. All sufficiently weak interactions between electrons, including the long-ranged Coulomb, are then irrelevant perturbations in the renormalization group sense. One important consequence of this "infrared freedom" is that the zero-temperature dc conductivity of clean graphene is finite and universal, and simply determined by its Gaussian value of $\sigma=(\pi/2)e^2/h$. Including scattering of impurities in a self-consistent Born approach yields another, similar in magnitude and still universal, value of $\sigma=(4/\pi)e^2/h$. Localization corrections are also expected to set in at very low temperatures and thus further diminish the conductivity. The actual measurements of graphene's conductivity, however, are in significant discord with these results: experimentally, $\sigma\cong 4e^2/h$, and thus significantly larger than all the theoretical values. The origin of this discrepancy is unclear at the moment, with several recent works focusing on the role played by the extrinsic charged impurities.

Results and Discussion



In the work cited below we show that the long-range Coulomb interactions between electrons in graphene provides the leading correction to the Gaussian value of conductivity, which is positive and only logarithmically slowly vanishing when frequency approaches zero. This suggests that the origin of the observed unusually large conductivity at the Dirac point may be intrinsic, and originate from the Coulomb correction which is then effectively cut off by finite disorder effects. We consider a specific mechanism of such cutoff which invokes a non-trivial interplay between long-range interactions and disorder, the latter being presently provided by the apparently unavoidable wrinkling of the graphene sheet. The combination of the Coulomb interaction, parameterized by α_F, and the random vector potential, with variance Δ, that may be used to represent such ripples in graphene leads to a line of stable fixed points shown in the Figure. The finite zero-temperature dc conductivity, varies continuously along the line and, most importantly, increases with the increasing disorder strength according to $\sigma=(\pi/2+(4-\pi))e^2/h$. We provide the symmetry arguments for the existence of the line of stable fixed points. A crude estimate of the typical parameters in graphene gives a sizable correction to the Gaussian value already to the lowest order in our calculation and significantly narrows the gap that presently exists between the theory and the experiment.

Conclusions

To summarize, our main finding is that the lowest order combined effect of electron interactions and rippling in graphene is to increase its minimal dc conductivity in a non-universal, disorder-dependent fashion. A testable prediction of our theory would be a decrease of minimal conductivity in graphene with the suppression of wrinkling, which, incidentally, should also bring back the usual localization behavior at finite density.

Acknowledgements

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References

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