Theory of Ungated Suspended Graphene: Interplay of interactions and disorder

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Introduction

The physics of massless Dirac fermions in two spatial dimensions has received renewed attention since their discovery in single-layer graphene. The great interest is not unrelated to the quantum critical nature of the system near the neutrality point, where the Fermi level lies precisely at the (Dirac-like) band crossing. Indeed, absence of any intrinsic long distance length scale sets constraints on the (low) frequency or temperature dependence of any physical quantity. In this regard, electrical conductivity σ plays a special role since in two spatial dimensions it is expected to be proportional to e^2/h; the proportionality constant, which need not be finite, depends only on the nature of the renormalization group (RG) fixed point characterizing the low energy-long distance physics. Electrical conductivity measurements at the neutrality point therefore constitute a direct probe of the non-trivial physics emerging at the end of the RG trajectory.

Results and Discussion

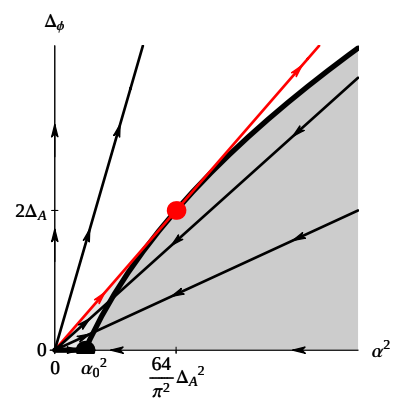
In this work the frequency dependence of the electrical conductivity of Coulomb interacting massless Dirac fermions coupled to random scalar and random vector potentials is found as a function of frequency. The results are asymptotically exact in the regime controlled by a line of fixed points. Such model provides a low energy description of a weakly rippled suspended graphene. The main finding is that at the neutrality point the a.c. conductivity is not frequency independent and may either increase or decrease with decreasing frequency, depending on the values of the disorder variances Δ_ϕ, Δ_A and the Coulomb coupling $\alpha = e^2/(\varepsilon v_F)$. The low frequency behavior

$$\sigma \to \frac{e^2}{h}\left[\frac{\pi}{2} + \frac{\Delta_A}{6} + \frac{(23-6\pi)\pi^2}{96\gamma}\left(1-\sqrt{1-\frac{32}{\pi^2}\gamma\Delta_A}\right)\right]$$

is characterized by the values of two dimensionless parameters $\gamma = \Delta_\phi/\alpha^2$ and Δ_A which are RG invariants, and for small values of which the electron-hole "puddles" are effectively screened making the results asymptotically exact.

Conclusions

The low energy/long distance physics of interacting Coulomb interacting massless Dirac fermions in graphene is characterized by the RG flow diagram shown in the Figure (right). At weak disorder, the trivial fixed point is unstable toward a line of fixed points at finite disorder and interaction. The appearance of such infra-red (locally) stable line of fixed points at finite Coulomb coupling and finite disorder provides a natural theoretical avenue towards the experimentally observed non-universality of the longitudinal electrical conductivity, since the precise position along such line is typically beyond experimental control. Nevertheless, any correlation between the variance of the (independently measurable) strain configurations and the minimal conductivity would provide a good test of the above theory.



References

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