Discussion: Effect of disorder on the minimal conductivity of graphene

August 5, 2009

During the morning session, on wednesday 29th, a discussion came up on the value of the minimal conductivity of monolayer graphene in the presence of disorder. The point under discussion was the existence of an exact universal result for the value of this minimum. The problem being considered was the conductivity of a disordered graphene sample of size L between two leads, at temperature T. The system was assumed to be non-interacting. Within the different types of disorder, the case considered was that of a random vector potential.

A. Mirlin

To obtain the dc conductivity of the system in the presence of disorder, the limit considered is that of a frequency ω *and* temperature T both much smaller than the relevant scales of the problem set by the system size L. In the case of a clean system this limit is $\omega \ll v_F/L$, with v_F the Fermi velocity and L, the system size. In the presence of disorder the relevant scale is the mean free time τ, then $\omega \ll 1/\tau$. For a clean system, the dc conductivity is just $\sigma \sim e^2/h$.

The speaker showed that for any long-ranged random vector potential, the dc conductivity is given by an exact expression [1]

$$\sigma = \frac{1}{\pi}\frac{e^2}{h} \times 4. \tag{1}$$

The speaker also mentioned three other cases of disorder: a random scalar potential V where the dc conductivity is proportional to $ln(L)$, the case of a random mass m term where σ is given by Eq.(1), and the case of generic disorder where the system flows to a quantum Hall point ($\sigma*$). The speaker made the point that, due symmetry reasons, either only one type of disorder or all of them have to be considered. See details in Ref.[1].

O. Vafek

The speaker pointed out that the conductivity is in general a function of the system size L, the external frequency ω, temperature T, disorder and coupling constants, as well as the arbitrary broadening parameter η which the previous speaker used. If only the random vector potential is considered then

$$\sigma = \sigma(\omega, T, L, \eta; \Delta_A)).$$

In the thermodynamic limit $L \to \infty$ and taking $\eta \to 0$ the above has the scaling form [2]

$$\sigma(\omega, T, L \to \infty, \eta \to 0; \Delta_A) = \frac{e^2}{h} f\left(\frac{\omega}{T}, \Delta_A\right), \tag{2}$$

where $f\left(\frac{\omega}{T}, \Delta_A\right)$ is some universal function characterizing the fixed point or fixed line. More details can be found in the review[2].

There are two limits of f which must be distinguished:
I. Collision dominated limit $\hbar\omega \gg k_B T$ which was treated in [3]. In this limit there is a finite correction to $\sigma_0 = \frac{e^2}{h}\frac{\pi}{2}$ which is linear in Δ_A for small Δ_A.
II. Collision dominated limit $\hbar\omega \ll k_B T$, which, in teh presence of Coulomb interactions, remains an open problem.

References

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[2] S. L. Sondhi, S. M. Girvin, J. P. Carini, and D Shahar, Rev. Mod. Phys. **69**, 315 (1997).

[3] I. F. Herbut, V. Juricic, O. Vafek, Phys. Rev. Lett. **100**, 046403 (2008).