Dynamical conductivity of graphene: the memory function approach

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Abstract

The frequency and wave-vector-dependent relaxation function in the longitudinal conductivity tensor of weakly interacting electronic systems (usually called the memory function) is calculated by using the current-dipole approach to the quantum transport equations [1]. It is shown, for the first time consistently, that there is a close relation between the exact electron-hole pair self-energy and the memory function [2,3]. It is also shown that in this gauge-invariant approach singular long-range Coulomb interactions, together with other $\mathbf{q} \approx \mathbf{0}$ scattering processes, drop out of both the memory function and the related equations of motion for electron-hole pair propagators. Therefore, in this case, they can be disregarded from the outset. However, they must be treated carefully when considering single-electron properties.

The theory is first illustrated on heavily doped graphene, which is the prototype of weakly interacting single-band electron-phonon systems. A steplike increase of the width of the quasiparticle peak in angle-resolved photoemission spectra (ARPES) at frequencies of the order of the frequency of in-plain optical phonons [4] is shown to be consistent with similar behavior of the intraband plasmon peak in energy loss spectroscopy spectra [5]. Both anomalies can be understood as a direct consequence of weak electron scattering from in-plane optical phonons. It is also pointed out that the only way to understand the ratio (of one order of magnitude) between the width of the quasiparticle peak in ARPES at $\omega \approx 0$ and the $\omega \approx 0$ relaxation rate in the electrical conductivity is to use the model for conduction electrons in which the long-range Coulomb interactions are included and where their effects are treated in the gauge-invariant way.

The macroscopic Kubo relation between the exact current-dipole and the exact current-current correlation functions is used to reconsider gauge-invariant aspects of the widely used current-current approach [6], in which the vertex corrections are usually disregarded, and to formulate a more accurate current-current approach, which takes care of the charge continuity equation in the intraband channel as well as in the interband channel. Such a gauge-invariant response theory [7] is used to explain temperature dependence of the measured DC conductivity of graphene in the ballistic conductivity regime [8]. The charge carriers are found to be thermally activated with the mobility which has a slightly different meaning than in the usual transport theory [9].

References

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