Ritus Propagator and Transverse Electrical Conductivity in Multilayer Graphene

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Since it was first isolted [1], graphene opened a bridge of common interests between the condensed matter and high energy physics communities. It was shown that the low-energy effective theory of graphene in a tight-binding approach is the theory of two species of massless Dirac electrons in a (2+1)-dimensional Minkowski spacetime [2, 3], each one described by an irreducible representation of the Clifford algebra. Then, the graphene can be studied through the Dirac Hamiltonian in (2+1) dimensions in the zero mass limit.

The unique electronic properties of single layer graphene and stacking multilayer graphene sheets [4, 5] make them promising novel materials to be used in carbon-based electronic devices principally because of its potential optoelectronic properties [6, 7, 8].

In this work we study the electrical properties of the multilayer graphene. We specifically study the transverse electrical conductivity along the stacked graphene planes in presence of an electromagnetic external field, being the electrical field parallel to the magnetic field, both perpendicular to the multilayer graphene planes. In order to obtain the corresponding photon polarization operator to achieve the electromagnetic properties, we obtain the charge carrier propagator in a quantum electrodynamics (QED) framework using the Ritus formalism [9, 10, 11]. The Ritus method consists in the diagonalization of the electron propagator in external electromagnetic fields in the basis of the operator $(\gamma \cdot \Pi)^2$ with $\Pi^\mu = p^\mu - eA^\mu$.

For some class of external static electromagnetic fields, the corresponding Dirac equations can be analyzed within the formalism of supersymmetric quantum mechanics (SUSY-QM) [12, 13], leading us to an exactly solvable model whose solutions are used to calculate the charge carrier propagator. Under the SUSY-QM framework, the Dirac equation for any external static magnetic field reduces to a corresponding Pauli equation with effective mass $m = 1/2$ and gyromagnetic ratio $g = 2$. Also, there is an important property of SUSY-QM that relates the spectrum and eigenfunctions of the resulting effective hamiltonians and due to the fact that there are two irreducible representations for the Dirac matrices in the (2+1)-dimensional case, for the graphene Hamiltonian there is also a direct relation between the solutions of the electron wave functions with different pseudo-spin eigenvalues. Within the SUSY-QM formalism, we show how the solutions for the multilayer graphene in an external magnetic field can be expressed only in terms of that of a monolayer in the same external conditions.

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