Transmission and conductance across a square barrier potential in monolayer graphene

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The transport properties and the tunneling resonant in graphene have attracted very attention [1], [2]. We have studied the transmission coefficient (T) and the conductance across a square barrier in monolayer graphene.

We obtain an analytical expression for the transmission coefficient of a square barrier in graphene which depends on the one hand, of the energy (E) and the angle (ϕ) of the carrier incident, and on the other hand of the barrier potential (V_0) and of the barrier length (D):

$$T(E,V_0,D,\phi)=\left[1+\frac{V_0^2\sin^2\left(\frac{1}{658.2}D\sqrt{(V_0-E)^2-E^2\sin^2\phi}\right)\cdot\tan^2\phi}{(V_0-E)^2-E^2\sin^2\phi}\right]^{-1}.$$

We study the T versus the incident angle for different values of the energy, the height of potential, and the barrier length. The T is an even function of the incident angle, and T is always the unity when the incidence is perpendicular to the barrier due to the *Klein paradox* [3], but we also found there are others incident angles that make the T to achieve the unity.

Afterwards we calculate the conductance in the scope of the Landauer-Büttiker formalism [4]

$$G=\frac{2e^2}{h}\int M(E)T(E)\left(-\frac{\partial f_0}{\partial E}\right)dE$$

We define the *effective conductance* like the conductance by the unit of width W in a sheet of graphene on fundamental units e^2/h. By using the previous expression of the T, we have obtained the effective conductance across a square barrier in monolayer graphene

$$G_{ef}(E_F,V_0,D,\phi)=\frac{4E_F}{658.2\cdot\pi}\left[1+\frac{V_0^2\sin^2\left(\frac{1}{658.2}D\sqrt{(V_0-E_F)^2-E_F^2\sin^2\phi}\right)\cdot\tan^2\phi}{(V_0-E_F)^2-E_F^2\sin^2\phi}\right]^{-1}$$

We note that this expression depends on the Fermi energy (E_F), because has been obtained for the case of very low temperatures. We represent in Fig. 1 the effective conductance versus the incident angle for a particular value of the Fermi energy and the barrier length and for three different values of the potential barrier (V_0). We observed that increasing the potential barrier the conductance takes relevant values for a wider set of incident angles.

Finally we consider that in a experiment of electronic transport across a barrier in a graphene sheet the carriers will arrive with different angles and therefore could have sense to calculate a *weighted conductance* in accordance with a certain probability distribution to the incidence angles on the barrier. Two typical cases are considered by using a delta function (only one angle is possible) and the arithmetical average function (all angles have equal probability).

In a standard configuration with the barrier perfectly perpendicular to the current, without considering any scattering mechanism, we can expect all carriers will achieve the barrier with angle $\phi=0$. In this particular case ($\phi=0$) the transmission coefficient is the unity and therefore the effective conductance is maxima, and only depend on the Fermi energy. We can prepare a different set-up as proposed in [5] just preparing the barrier with a particular angle ϕ_0 with the electrical current direction then all carriers will achieve the barrier with this particular angle, again in the absence of any scattering. Nevertheless in this situation the T will not need to be the unity and will depends also of the rest of parameters.

In the case of high scattering we could expect that all angles will have the same probability and then by using an arithmetical average function we can study such a situation showed in Fig 2 as a function of both the Fermi energy and the barrier potential.

References

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Figures

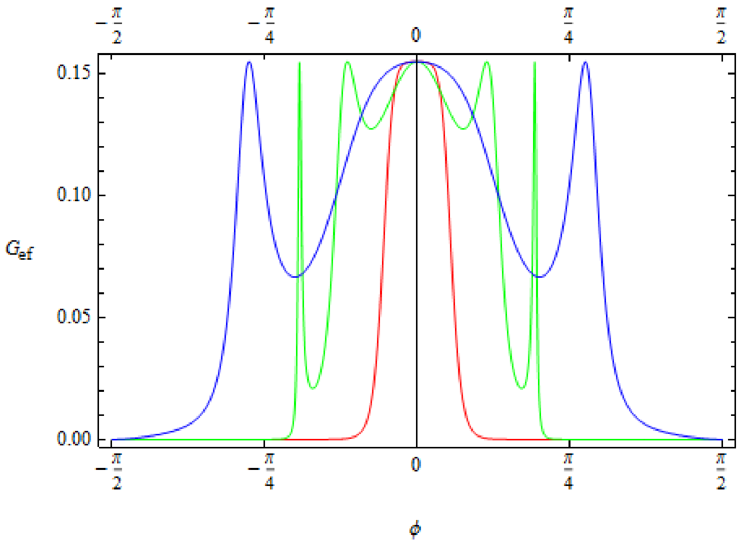

Figure 1 : Conductance effective for E_F = 80 meV, V_0 = 100(red), 130(green), 200(blue) and D = 100 nm

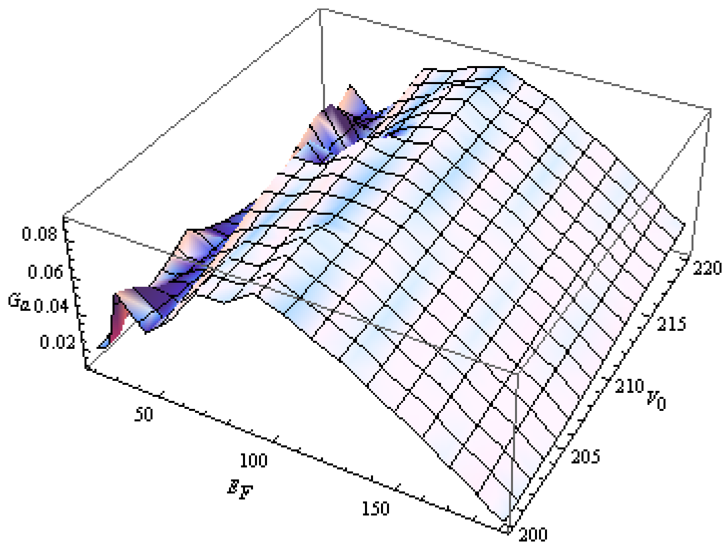

Figure 2 : Conductance with arithmetical average function for D = 100 nm with E_F in meV and V_0 in mV