

# Momentum and spin relaxation time in graphene with potential and spin-orbit impurities

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Graphene is one of the most perspective materials in materials science now [1,2]. Transport properties of graphene are mostly determined by its very unusual relativistic electron energy spectrum. Besides, the electron relaxation time due to scattering from impurities can have some peculiarities related to appearance of the resonance states. It turns out that in the vicinity of the resonance states the relaxation time is strongly dependent on electron energy and, correspondingly, determines the behavior of conductance, magnetoresistance, Hall effect and especially, various thermoelectric effects.

We consider two main types of impurities in graphene. One of them can be described by using the model of a short range potential, whereas the other one corresponds to spin-orbit impurities and has the meaning of a localized Rashba spin-orbit coupling. The first model can be applied to describe ordinary impurity atoms in graphene, and the second one is for heavy neutral atoms at its surface [3]. We found that for both types of impurities, the resonance levels can be formed, and we found their location in the energy spectrum of graphene as a function of the parameters. In both cases we calculated the momentum relaxation time of electrons, and in the case of spin-orbit impurities we found the resonance behavior of spin relaxation time.

We also discuss the model with additional homogeneous Rashba spin-orbit coupling. This situation corresponds to graphene with impurities at a substrate. In the presence of this interaction, the mirror symmetry is broken and we obtain spin splitting of impurity energy levels, which appears even if the impurity potential is very weak.

Our calculations demonstrate that the peculiarities of electron scattering can essentially modify the charge and spin transport in graphene.

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[2] M. I. Katsnelson, *Graphene: Carbon in Two Dimensions* (Cambridge Univ. Press, 2012).

[3] A. Ferreira, T. G. Rappoport, M. A. Cazalilla et al., *PRL* **112**, 066601 (2013).