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Electron Transport through a pair of Graphene-Superconductor junctions

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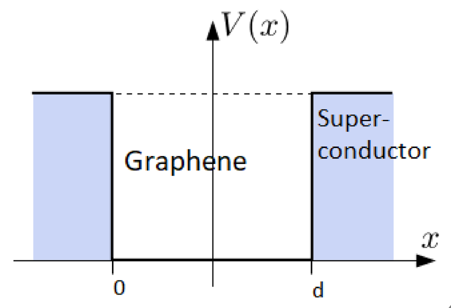
Abstract

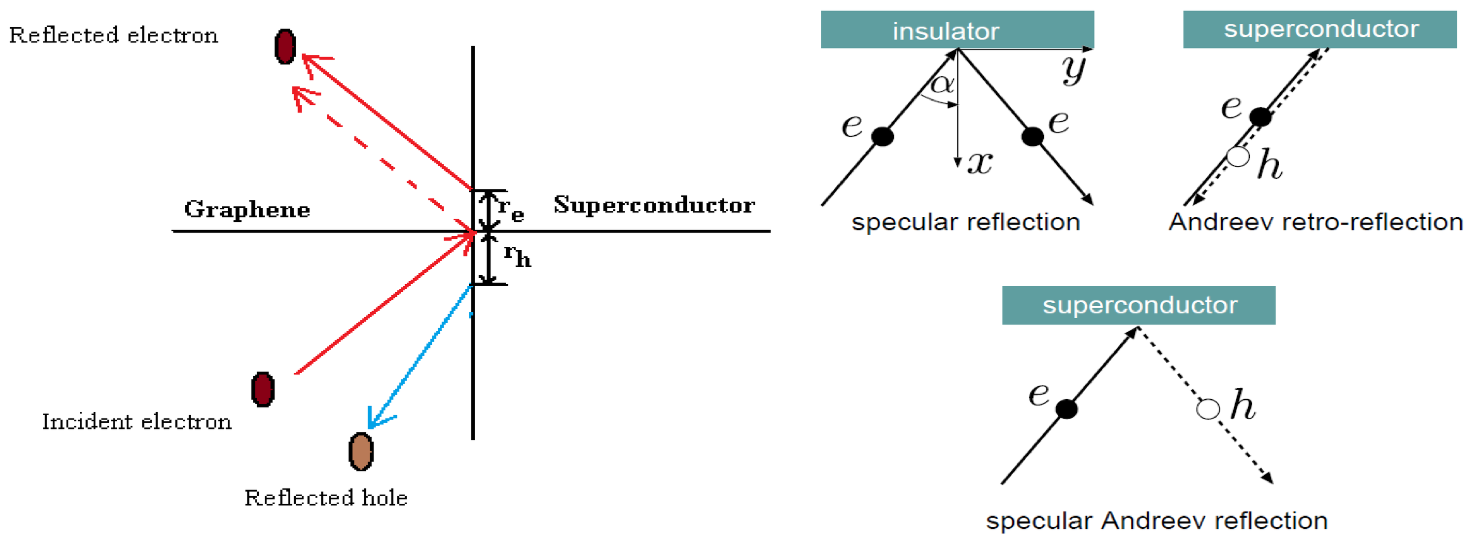
Electron transport across Graphene-Superconductor (GS) junctions has recently attracted a lot of attention [1, 2] after it was pointed out that the Andreev processes in such junctions not only have retro reflection-like properties as in SNS junctions but also have a specular component due to the ultra-relativistic nature of dispersion of mono-layer graphene. In this work, we study in detail the spectrum of such Andreev bound states in Superconductor-Graphene-Superconductor (SGS) junctions in various regimes and compare our studies with experimental observations. We also consider the electronic analogue of optical phenomena like Goos-Hanchen shift [3, 4] in such junctions and discuss their significance.

Introduction

We study the transport of an electron(hole) across a Graphene-Superconductor (GSG) heterojunction. Whenever an electron pass through a Graphene-Superconductor junction it undergoes Andreev Reflection i.e. an incident electron is converted into a hole or vice-versa. As a result of this a charge of 2e is transferred across the junction. These Andreev processes also lead to the formation of the Andreev Bound states in such junctions. These bound states play an important role in the transport of current across such junction. The bound states so formed lie in the gap region. We use the transfer matrix method to calculate the energy dispersion for these processes. We discuss the two process in details below.



Processes at the Junction



Retro Andreev Reflection

- The incident electron and the reflected hole lies in different band.
- The Fermi energy in the graphene region is much greater than the incident energy of the incoming particle. $E_F >> E$.
- Also the incident angle for electron and hole are opposite. α' = -α
- We solve the DBdG equation in the superconducting and the graphene regions

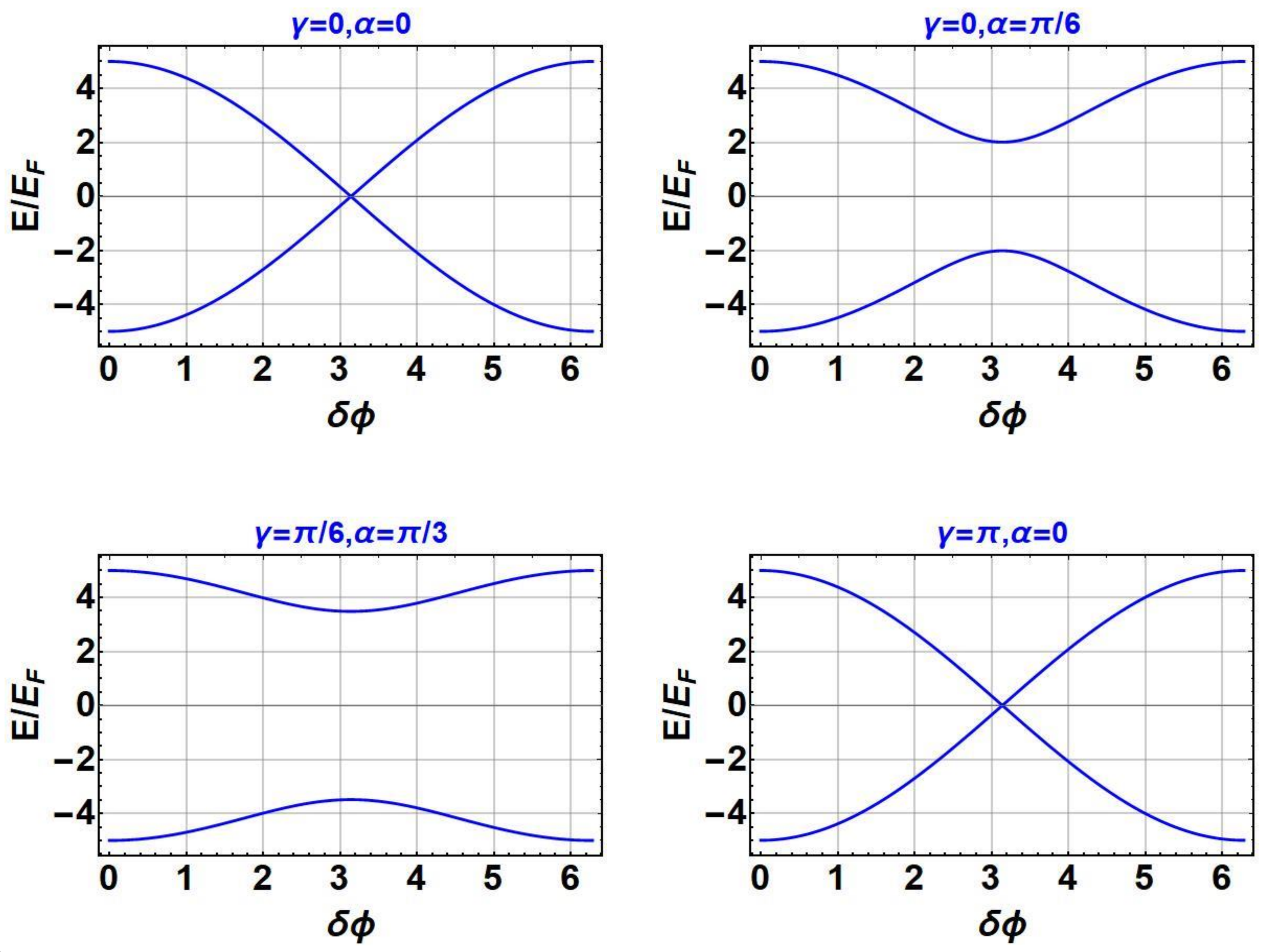
$$\begin{pmatrix} H - E_F & \Delta \\ \Delta * & E_F - H \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = \varepsilon \begin{pmatrix} u \\ v \end{pmatrix}$$

- We match the wavefunctions at the two boundaries to obtain the transfer matrix.
- We use the transfer matrix to get the dispersion.
- The dispersion relation is

$$\cos^2 dk_e \cos^2 \alpha(-1 + 2\cos 2\beta + \cos 2\gamma) - 2\cos^2 \gamma\{\cos^2 \alpha \cos \delta\phi + \sin^2 dk_e(\sin^2 \alpha - \cos 2\beta)\} = 0$$

- Where α and γ are the incident angles for electron(hole), quasiparticles, β is the ratio of the energy and the gap and δφ is the superconducting phase difference.
- The above relation gives us two roots and hence two branches.

Results

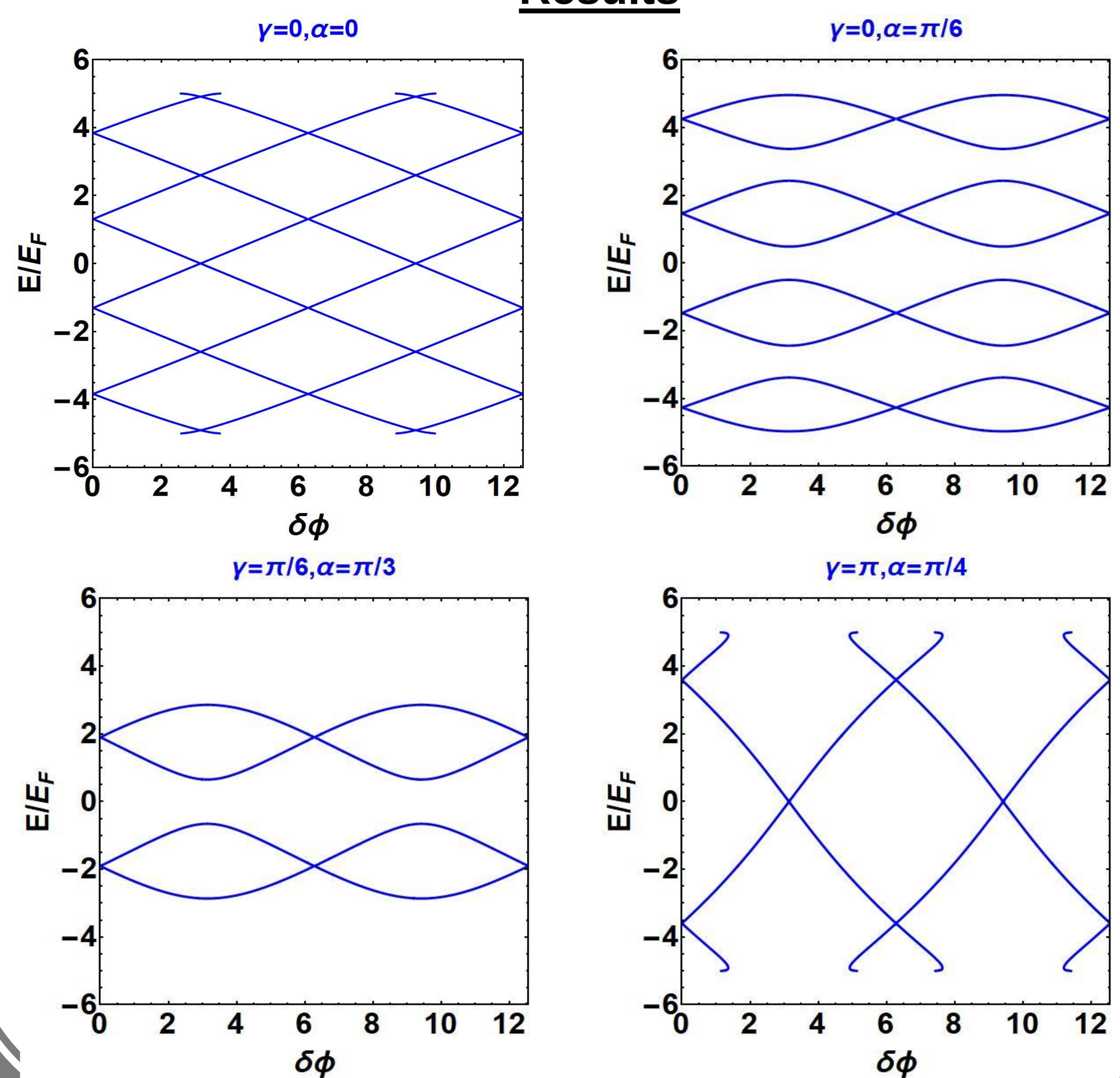


Specular Andreev Reflection

- The incident electron and the reflected hole lies in same band.
- The Fermi energy in the graphene region is much smaller than the incident energy of the incoming particle. $E_F << E$.
- Also the incident angle for electron and hole are opposite. α' = α
- The dispersion relation in this case

$$\sin^2 \frac{\delta\phi}{2} = \left(\frac{\cos dk_e \sin\beta}{\cos\gamma} + \frac{\cos\beta \sin dk_e}{\cos\alpha}\right)^2$$

Results



Conclusions

1. There are only two states possible for the retro process. The energy of these states lie below the gap.
2. The specular process has mor number of states with energies less than the gap.

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