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Two-dimensional Klein tunneling for massive Dirac fermions with a defined helicity [1]

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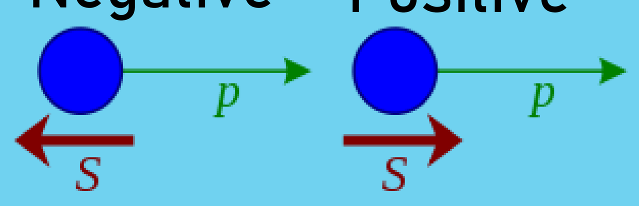
1. Abstract

We studied the role of the helicity in two-dimensional Klein tunneling of massive Dirac fermions. We consider scattering of helicity-polarized fermions through step and barrier potentials of magnitude V_0, calculating the contributions of conserved and inverted helicity to the reflection and transmission coefficients. In the step potential, we found that the transmission probability for fermion states with inverted helicity is small when $V_0 < E$, but becomes dominant when $V_0 > E$, being E the energy of the incoming fermion. In the barrier potential, the probability for transmission with inverted helicity is always null. This behavior is explained by the breaking of the helicity conservation by the mass term, allowing the reflection of states with inverted helicity in both potentials, and transmission of inverted helicity states only in the step potential.

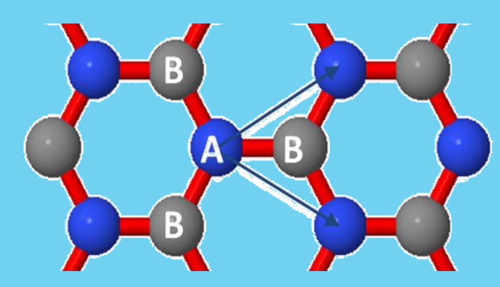
Finally, we give some insights on the consequences of our results in materials with Dirac-like quasiparticles, such as graphene, topological insulators and Weyl semimetals.

2. Introduction

- Klein tunneling is the non-null transmission of relativistic fermions through very high potential barriers.
- In graphene, it manifests as the perfect transmission of electrons (or holes) in tunnel barriers, due to pseudo-spin conservation and zero effective mass of the carriers.
- Nevertheless, it is known that a mass term in a relativistic fermion mixes its helicity components, breaking the helical (or chiral) symmetry.



Helicity



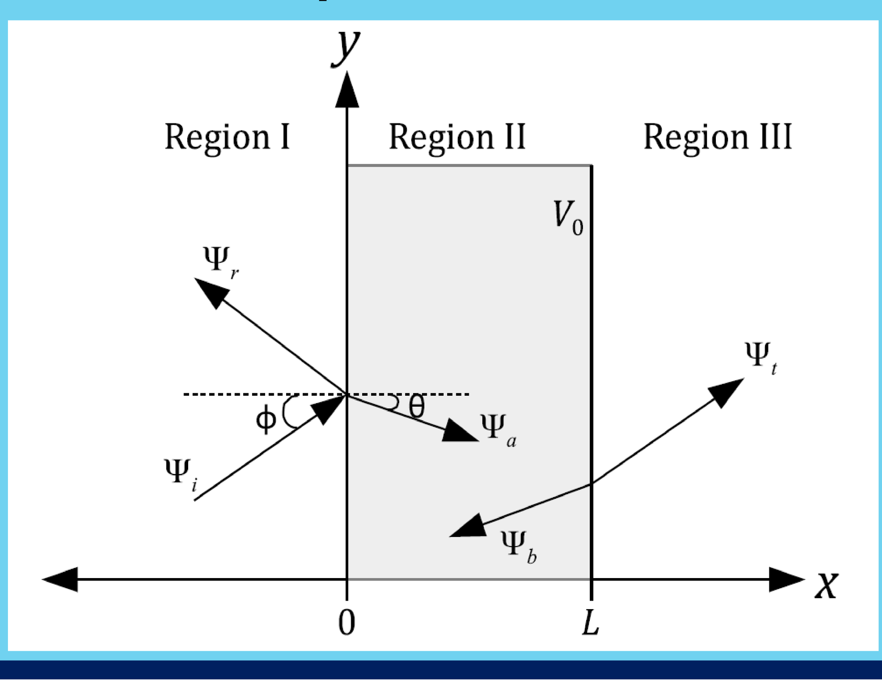
Pseudospin

3. Question

How do the mass and helicity of relativistic fermions affect Klein tunneling?

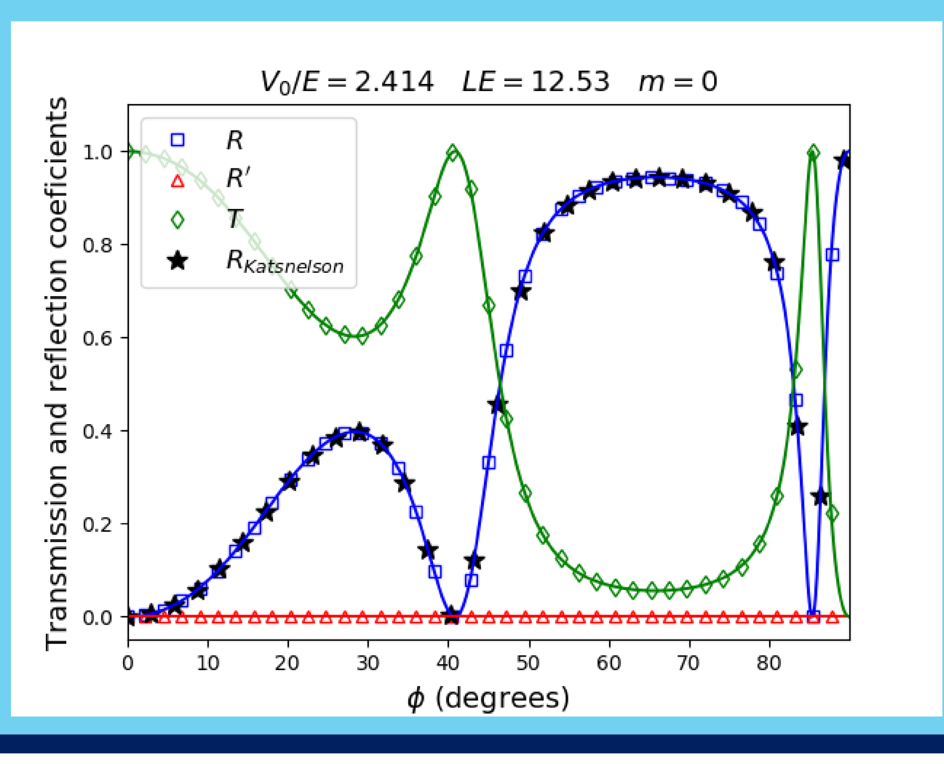
4. Formalism

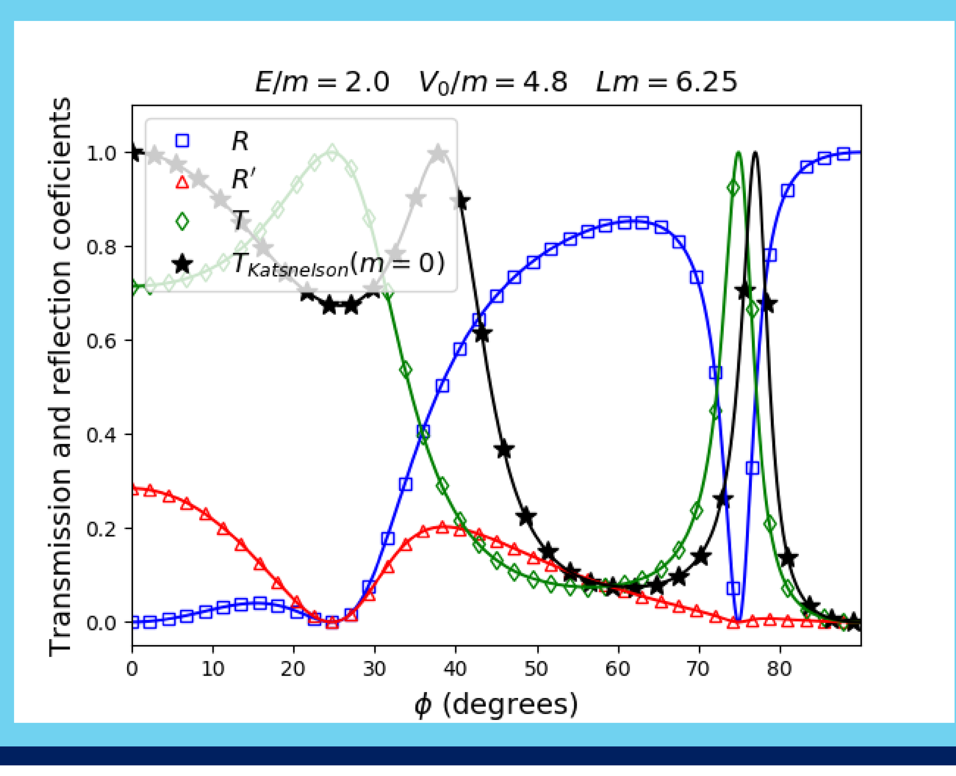
- Study the transmission of relativistic fermions through step and barrier potentials of magnitude V_0.
- Fermions described by Dirac Hamiltonian $H = v_F\, \boldsymbol{\alpha} \cdot \boldsymbol{p} + \beta m c^2$
- Consider helicity polarized incoming fermions $\Lambda = \frac{\boldsymbol{p} \cdot \boldsymbol{S}}{p}$, with energy E.



5. Results

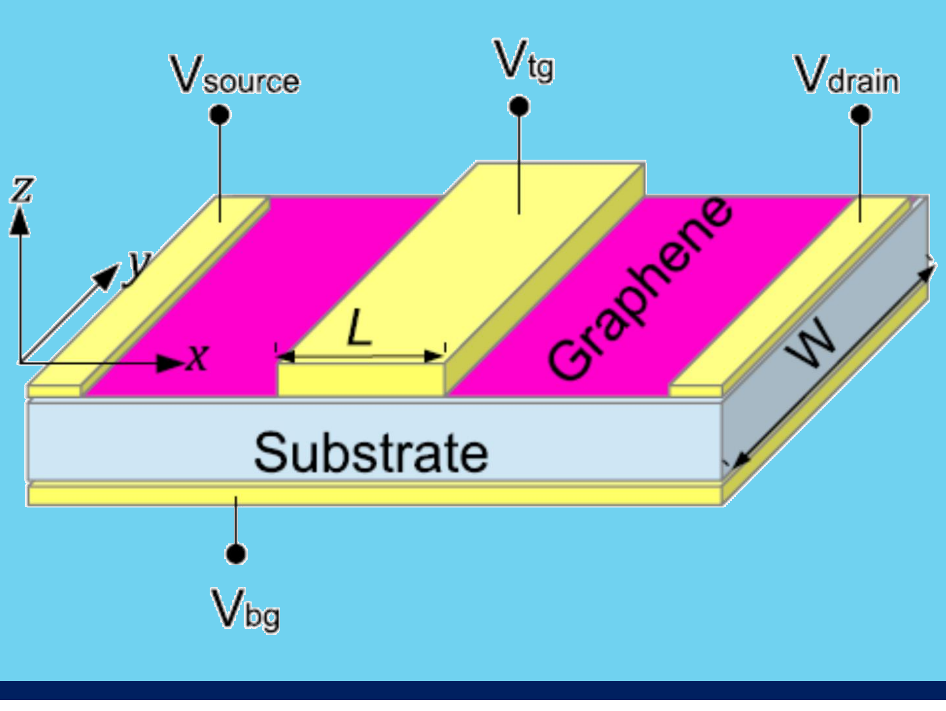
- The mass term breaks helicity conservation, allowing reflection of massive fermions with inverted helicity.
- In the step potential, transmission is dominated by helicity conserved states if $V_0 < E$, but if $V_0 > E$ helicity inverted states become dominant.
- In the barrier potential, helicity inversion in the transmitted fermions is not possible.

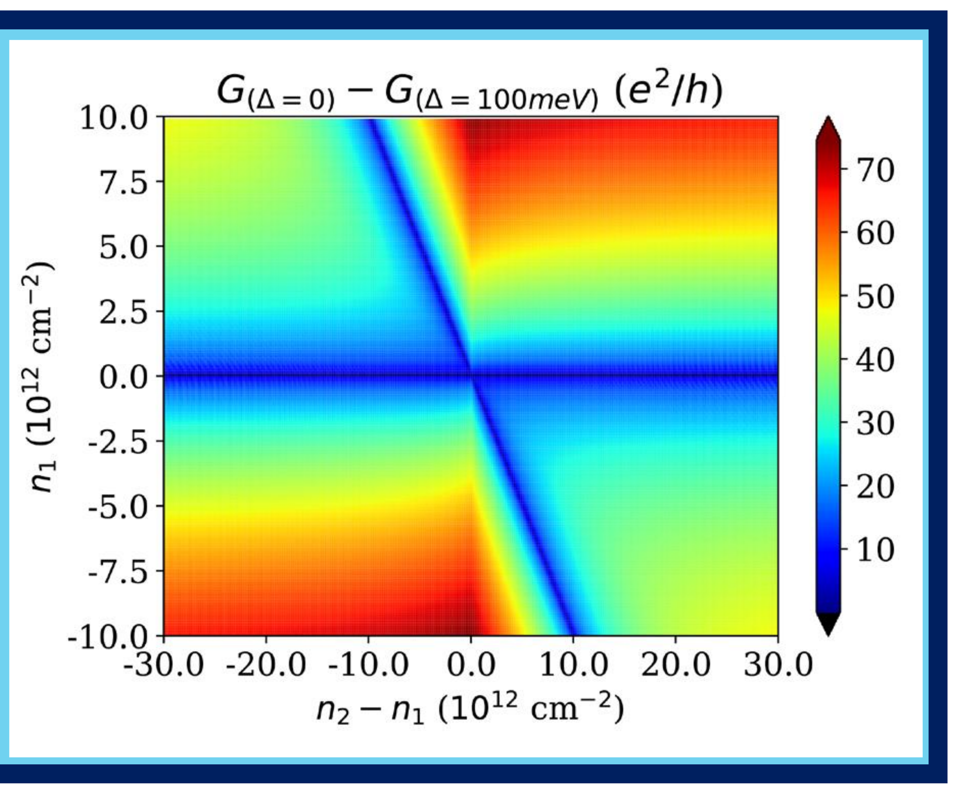




6. Application

- In reference[2], we have applied our results to the conductance of p-n and n-p-n gapped-graphene devices.
- We found that a conductance gap depending on the bandgap squared appears in the system.
- The formalism can be applied to other systems with Dirac-like carriers, such as Weyl semimetals.





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REFERENCES

[1] Navarro-Giraldo, J. Quimbay, C. Ann. Phys. (N. Y). 412, 168022 (2020)

[2] Navarro-Giraldo J. A. and Quimbay C. J., J. Phys.: Condens. Matter 30 265304

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jcmm Brno Ph.D. Talent

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