Charge, spin currents and magnetism in Graphene nanoislands

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Abstract:

Recently, very precise experimental techniques[1] have been developed to build graphene nano-island structures using either scanning tunneling microscope lithography or catalytic cutting using Fe atoms for multilayer or single layer graphene. Using a tight binding model of graphene, we address the problem of persistent charge and spin currents and their magnetic signatures in disk-like and corbino nanoislands. Graphene is described by the Hamiltonian[2,3]

$$H = t\sum_{\langle ij\rangle} e^{i\phi_{ij}} c_i^\dagger c_j + i\Delta \sum_{\langle\langle ij\rangle\rangle} \nu_{ij} c_i^\dagger s^z c_j + i\lambda_R \sum_{\langle ij\rangle} c_i^\dagger \left(s \times \hat{d}_{ij}\right)_z c_j$$

including the kinetic energy, both intrinsic (Δ) and Rashba (λ_R) spin-orbit interactions and an external magnetic field (hopping phase factor). We only consider weak fields the Zeeman contribution is ignored. Our tight-binding model generates hexagonal graphene nanoislands[4] with several diameters that we use as template. The selection of two radii, the minor radius and the major radius in the Corbino geometry, determines the carbon atoms that the program will extract of the template (Figure 1.a). Cutting the template and excluding the sites with coordination number less than two, we obtain disk or annular geometries with armchair and zigzag edges (Figure 1.b). We compute the eigenstates of electrons subject to the boundary conditions of Graphene sheets in disk and Corbino geometries (see Figure 2), which retain the symmetry of the island. A linearization[2] of the Hamiltonian in the vicinity of the Fermi energy is also considered, to assess the regimes of validity of the continuum approximation as compared to the lattice description.

The linear dispersion of graphene produces charge persistent currents induced by a weak external magnetic field in step-like patterns when spin-orbit interactions are small. For stronger interactions, persistent charge currents alternate between smooth steps and sharp steps due to the opening of a gap and well defined level crossings respectively. Figure 3 shows the persistent charge and spin currents, for the continuum approximation as a function of the Rashba spin-orbit interaction λ_R for a finite value of the intrinsic term Δ. As can be assessed from the figure it is possible to control persistent currents by the application of perpendicular electric fields that modulate the Rashba interaction.

References

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Figures

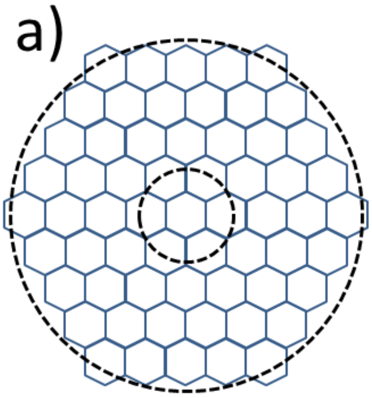

Figure 1: Construction scheme of a graphene Corbino, a) Selection of the minor and major radii that determine the cut of the template, b) The resulting graphene Corbino after the cut with armchair and zigzag edges.

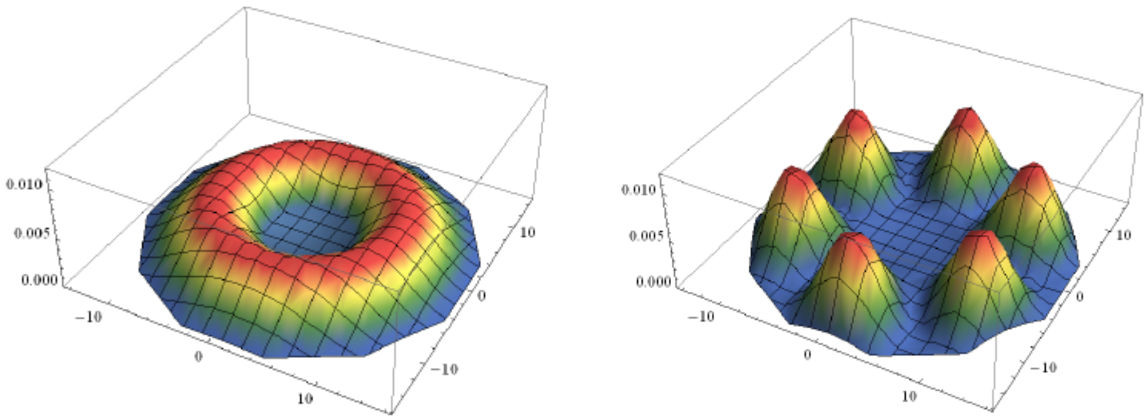

Figure 2: Tight binding ground state (left panel) and an excited state (right panel) on a Corbino geometry.

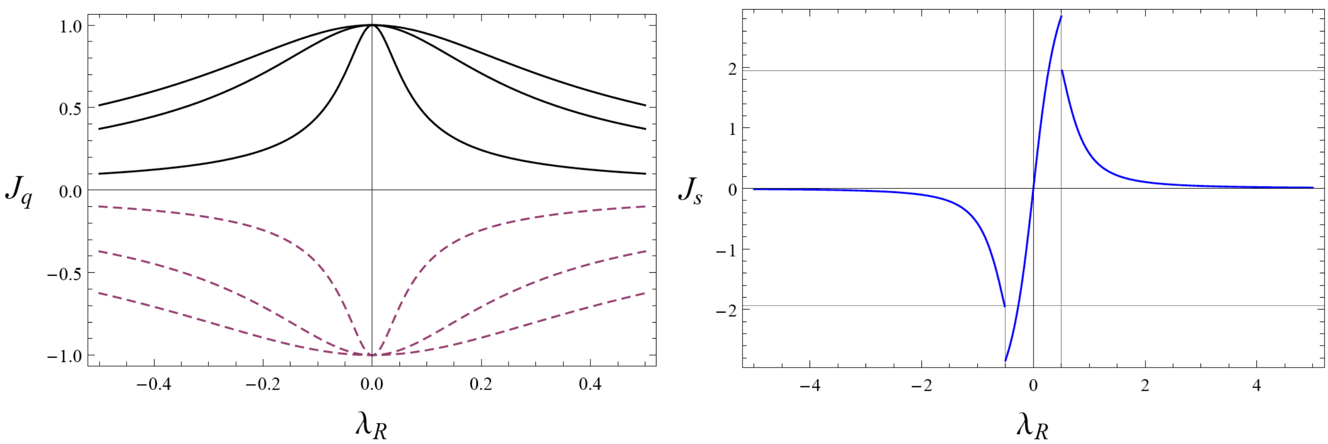

Figure 2: Persistent charge (left panel) and spin current (right panel) for the continuum model and for Δ =0.5. The spin current is non-zero when the Rashba interaction is turned on, its value depending on the ground state as a function of the SO parameters.