Bipolar supercurrent in graphene

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1. Effective time reversal symmetry breaking in graphene

In the long wavelength limit, the effective Hamiltonian for the valley around one K-point is a 2x2 matrix acting on the components of the wavefunction on the two independent sublattices of graphene (the so-called A and B atoms). It reads

$$H_K = \hbar v_F \begin{pmatrix} 0 & k_x - ik_y \\ k_x + ik_y & 0 \end{pmatrix}$$

with $\vec{k} = (k_x, k_y)$ the momentum of the electron measured relative to the K-point. This 2x2 matrix is left invariant by the anti-unitary transformation $U = i\sigma_y \hat{K}$, i.e. $U^\dagger H_K U = H_K$, where σ_y is the usual Pauli matrix and $\hat{K}$ denotes complex conjugation. *U* is the usual operator associated to the time reversal symmetry transformation for spin ½ particles. In this sense, the operator *U* defines an "effective" time reversal symmetry transformation that is applicable in a single valley only and reverses the sign of the momentum $\vec{k}$ relative to the K-point.

In the presence of certain types of smooth scattering potentials (see Ref. [1]), there exist "effectively" time-reversed trajectories along which the electrons can propagate while remaining within the same valley. On this basis, Suzuura and Ando[1] predicted that these trajectories cause a quantum correction to the conductivity in the form of weak antilocalization.

The operator *U* however does not represent the true time reversal symmetry transformation for electrons in graphene, as true TRS connects states belonging to the two opposite K-points in graphene and cannot be described within the single K-point approximation. For this reason the effective TRS symmetry represented by *U* is not robust against physical perturbations that normally preserve TRS (e.g. static potentials). For instance, effective TRS is broken by (i) curvature in graphene[2,3] (that can be described within a single K-point approximation as a vector potential), (ii) scattering at edges[4], and (iii) trigonal warping[5] (i.e., by including quadratic terms in the long wavelength expansion from which the one K-point Hamiltonian is obtained). As a consequence, in real experimental samples the observation of effects associated to the symmetry *U* is expected to be very difficult (at least in samples of current quality).

References

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