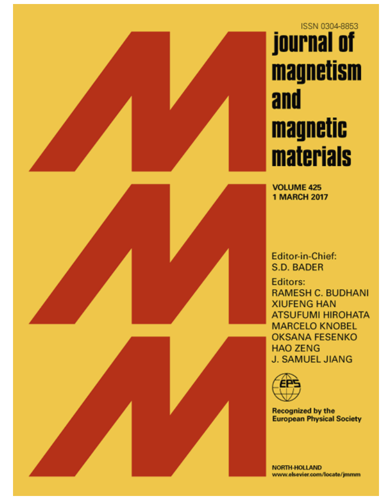

Anomalous Magnetism for Dirac Electrons in Two Dimensional Rashba Systems

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Anomalous Magnetism for Dirac Electrons in Two Dimensional Rashba Systems

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Abstract

Spin-spin correlation function response in the low electronic density regime and externally applied electric field is evaluated for 2D metallic crystals under Rashba-type coupling, fixed number of particles and two-fold energy band structure. Intrinsic Zeeman-like effect on electron spin polarization, density of states, Fermi surface topology and transverse magnetic susceptibility are analyzed in the zero temperature limit. A possible magnetic state for Dirac electrons depending on the zero field band gap magnitude under this conditions is found.

Keywords: Rashba coupling, Spin Orbit Interaction, Dirac electrons, Magnetic Susceptibility

1. Introduction

Subtle relativistic effects on reduced dimensional electronic systems have brought exciting perspectives on fundamental physics and technological advances since the Rashba's breakthrough [1, 2, 3, 4]. Spin Orbit Interaction dwells in the always evolving spintronics world, providing interesting applications based on its subsequent, wide and sophisticated phenomena. For instance, magnetic switching control via induced current on metal/ferromagnet/oxide trilayers at room temperature [5], tunable spin-orbit strength via stoichiometry manipulation on deposited concentration of Bi atoms on $\mathrm{Bi}_x\mathrm{Pb}_{1-x}$/Ag alloys [6], quantized Hall conductance on doped $\mathrm{Bi}_2\mathrm{Te}_3$ layered arrays without external magnetic field [7], characteristic Knight shift behavior in non-centrosymmetric superconducting CrIrSe_3 crystals below critical temperature [8], or Rashba interaction control for out-of-plane Zeeman spin polarization on transition metals such as WSe_2, MoS_2 via biased voltage [9], constitute few examples that demonstrate the currently hectic activity in this area. In this paper, we discuss the zeroth order transverse spin-spin susceptibility response for 2D Dirac interacting electrons in the low density regime and zero temperature, under an externally applied electric field on the plane. We derive general expressions at finite temperature for the correlations functions on arbitrary Dirac spin directions, as well as the features of the density of states (DOS) in the limit of the Fermi energy instability and fixed number of particles.

2. Spin-Spin Correlation Function Formalism

The Hamiltonian formulation for 2D magnetically polarized surfaces or interfaces in a non-interacting electron system under an externally applied electric field $\mathbf{E}$ might be approached by taking the lowest-order coupling between the electron momentum in the XY plane $\mathbf{k} = (k_x, k_y, 0)$, its spin $\hat{\vec{\sigma}}$ and $\mathbf{E}$: $\hat{\mathcal{H}}_{\mathbf{k}} \sim \hat{K}_{\mathbf{k}} + \hat{\vec{\sigma}} \cdot (\mathbf{k} \times \mathbf{E})$, where $\hat{K}_{\mathbf{k}} = (\hbar^2 k^2/2m^\star)\hat{\mathbf{1}}$ corresponds to the single free-particle kinetic energy operator [10, 11, 12, 13]. For an arbitrary field orientation, $\hat{\mathcal{H}}_{\mathbf{k}} \sim \hat{K}_{\mathbf{k}} + \hat{\sigma}_Z(k_x E_y - k_y E_x) + (\hat{\sigma}_X k_y - \hat{\sigma}_Y k_x)E_z$, where the last term is recognized as the typical Rashba-type interaction. By introducing the appropriate constants, the upper-lower ($\pm$) double band structure for Dirac electrons might be taken as $\hat{\mathcal{H}}^{\pm}_{\mathbf{k}} = \hat{K}_{\mathbf{k}} + \hat{\sigma}_Z \Delta_{\mathbf{k}} - \alpha\hat{\sigma}_Y k_x \pm \alpha\hat{\sigma}_X k_y$. Defining the effective magnetic field $\gamma\mathbf{B}_{\mathbf{\Sigma}} = (-\alpha k_y, \alpha k_x, -\Delta_{\mathbf{k}})$, the complete electron Hamiltonian takes the form:

$$\hat{\mathcal{H}}^{\pm}_{\mathbf{k}} = \hat{K}_{\mathbf{k}} - \gamma\hat{\mathbf{S}} \cdot \mathbf{B}_{\mathbf{\Sigma}}, \tag{1}$$

with the spin basis $\hat{\mathbf{S}} \equiv (\hat{\sigma}_Z \otimes \hat{\sigma}_X, I \otimes \hat{\sigma}_Y, I \otimes \hat{\sigma}_Z)$ and I, $\hat{\sigma}_j$ as the 2×2 identity and Pauli matrices respectively. Operators $\hat{S}_j$ satisfy the necessary anticommutation rules $[\hat{S}_i, \hat{S}_j]_+ = 2\delta_{ij}$. The Zeeman-like term $\hat{\mathcal{H}}_{\mathbf{\Sigma}} = -\gamma\hat{\mathbf{S}} \cdot \mathbf{B}_{\mathbf{\Sigma}}$ in Eq. (1) has a Dirac-type form, and its genesis can be explained, among several approaches, from fairly simple geometric-based arguments for materials with inversion symmetry [14, 15, 16]. Specifically, the 2D Dirac equation $\hat{\mathcal{H}}_{\mathbf{\Sigma}} = \alpha\hat{\gamma}^0(\hat{\vec{\gamma}} \cdot \mathbf{k} + \alpha m^\star)$ reduces into the Zeeman-like Hamiltonian straightforwardly under the set of transformations $\alpha^2 m^\star \equiv \Delta_{\mathbf{k}} = \Delta_0 + (k_x\bar{E}_y - k_y\bar{E}_x)$, where Δ_0 corresponds to the energy band gap magnitude at zero field. The parameter α denotes the typical Rashba spin-orbit interaction constant, although contributions due to crystal asymmetries might be taken into account via Dresselhaus Hamiltonian [17]. Upon this representation, the Dirac matrices $\hat{\gamma}^\mu = (\hat{\gamma}^0, \hat{\vec{\gamma}})$, $\hat{\gamma}^\mu = (I \otimes \hat{\sigma}_Z, iI \otimes \hat{\sigma}_X, i\hat{\sigma}_Z \otimes \hat{\sigma}_Y)$ must fulfill the constraint $[\hat{\gamma}^\mu, \hat{\gamma}^\nu]_+ = 2g^{\mu\nu} = 2\mathrm{diag}(1, -1, -1)$. In a matrix-block scheme:

$$\hat{\mathcal{H}}_{\mathbf{\Sigma}} = \begin{pmatrix} A_{\mathbf{k}+} & 0 \\ 0 & A_{\mathbf{k}-} \end{pmatrix}, \tag{2}$$

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