Chiral-Induced Spin Selectivity: Orbital Mechanisms and Quantum Applications

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Abstract: Chiral-Induced Spin Selectivity is becoming relevant in developing quantum technologies. This study explores orbital mechanisms for spin and orbital selectivity in chiral and achiral systems, highlighting the potential exploitation of these phenomena for quantum applications.

Chiral-Induced Spin Selectivity (CISS) is a phenomenon that is gaining increasing interest, particularly due to its potential implications for the development of quantum devices and technologies [1-3] both with molecular systems and chiral crystals [3]. This effect is rooted in the compelling correlation between the carrier spin orientation and the chiral properties of the transmission medium. CISS enables the control of spin injection and detection without relying on magnetic materials, making it considerably relevant for applications in quantum spintronics. Despite many experimental observations and theoretical investigations, there is no general agreement on a comprehensive theory that can explain the phenomenon.

Recently, it has been shown that orbital texture and orbital polarization effects can induce spin-polarization [3] both in chiral systems but also in achiral materials that, however, lack a center of inversion. These findings suggest a subtle connection between the symmetry properties of the transmission medium and spin selectivity. Indeed, although the orbital degrees of freedom contribute to explaining spin-selectivity effects, the presence of spin filtering in both chiral and achiral media indicates that the underlying symmetries and mechanisms behind this phenomenon are still not completely understood. In this study, we evaluate which type of orbitally based interactions can result in spin selectivity by investigating both centrosymmetric and chiral medium [4,5]. Our results reveal how to control the orientation of the spin and orbital angular momentum, and which are the optimal regimes for achieving highly efficient simultaneous spin and orbital selectivity in both chiral and achiral environments. Contrary to the common view, we demonstrate how spin and orbital selectivity can be realized even in centrosymmetric systems. Finally, we discuss potential platforms, both for molecular and materials systems, as well as detection methods, for observing these phenomena and employ them for quantum applications.

References

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