Coupling, geometric phases, and properties of quantum dots: analytics and numerics for the Berry phase case

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Abstract

Recent experimental spin-based realizations of universal geometric quantum gates [1] open new exciting opportunities for practical applications and pose new challenges for theoretical research on geometrical phases. They clearly highlight the importance of geometric phases in nanotechnology in general and in the design and control of low dimensional nanostructures in particular.

In this contribution, we analyze and quantify the influence of such geometric phases on the properties of quantum dots. We focus on the Berry phase and demonstrate its high sensitivity to electric fields coming from the interplay between the Rashba and Dresselhaus spin-orbit couplings. The Berry phase is induced by letting the quantum dots to move adiabatically in a closed loop in the 2D plane along a closed trajectory [2]. We demonstrate that the accumulated geometric phase can be induced from other available quantum states that differ only by one quantum number of the corresponding spin state. Moreover, the sign change in the g- factor can be reflected in this phase. We carry out the analysis for typical spatial scales in such situations, namely for spin-orbit length, hybrid orbital length, and orbital radius, and determine the key characteristics of the Berry phase for these scales. The technique, developed for our analysis of spin dynamics evolution during the transport of quantum dots as describe above, is based on a combination of analytical and numerical tools. The time-dependent Schrodinger equation is solved by applying the Feynman disentangling technique supplemented by the finite element methodology. It is shown that the superposition effect can be observed during the transport process, while the Berry phase for the pure Rashba and pure Dresselhaus cases are well separated at smaller values of the spin-orbit lengths. Finally, applications of the observed effects are discussed.

References

[1] C. Zu, W.-B. Wang, L. He, et al, Nature. 514 (2014) 72-76.

[2] S. Prabhakar, R. Melnik, L. L. Bonilla, Phys. Rev. B. 89 (2014), 245310.