Synthetic Haldane phase of correlated electrons in a chain of semiconductor quantum dots embedded in a nanowire

Błażej Jaworowski [1], Nick Rogers[2], Marek Grabowski[3], Paweł Hawrylak[2]

[1] *Department of Theoretical Physics, Wrocław University of Science and Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland*

[2] *Department of Physics, Advanced Research Complex, 25 Templeton Str., University of Ottawa, Ottawa, Ontario, K1N 6N5, Canada*

[3] *Department of Physics, University of Colorado at Colorado Springs, Colorado Springs, CO, USA*

Recently, the topological phases of macroscopic quantum matter have gained wide interest. A characteristic features of these phases is the existence of topologically protected edge states. Their robustness suggests their potential applications, e.g. in quantum computing. Some of the topological phases of macroscopic quantum matter can be explained within single-particle picture, whereas others orignate from the strong correlation of electrons. An example of the strongly-correlated topological phase is the Haldane phase , predicted theoretically[1] and observed experimentally[2] in spin-1 antiferromagnetic chains. The ground state of the spin-one chain in Haldane phase is characterized by two edge states with spin-$\frac{1}{2}$.

In this work, we propose a synthetic many-body system of correlated electrons in a chain of semiconductor quantum dots embedded in a nanowire as a candidate for a macroscopic Haldane phase [3]. We consider a chain of N quantum dots embedded in a quantum wire, with 4 electrons per dot . We describe the system using extended Hubbard-Kanamori (HK) model limited to 2 electrons per dot on a degenerate p-shell. The parameters of the HK model , tunneling between dots, direct and exchange interaction within a dot and between dots, are determined from a microscopic calculation for two coupled dots with Ne=8 electrons. We find the ground state and energy spectrum of the N electron HK chain using exact-diagonalization, Lanczos and Density Matrix Renormalization Group [4] methods. We show that the exchange interaction of each two electrons on a degenerate p-shell effectively pairs electrons into spin one objects on each dot and the low energy sector of the HK chain can be mapped onto the low energy sector of a spin one chain. The ground state of the HK chain is shown to correspond to localized states at the edge with effective spin-$\frac{1}{2}$. We note that the spin-$\frac{1}{2}$ edge states can be used as a singlet-triplet qubit [3] encoded in a macroscopic quantum state. Finally, we describe optical transitions between the valence and conduction band states of quantum dots with electrons [5] and identify the signatures of the Haldane phase in absorption spectra. Therefore, our results allow to describe the transfer of quantum information from the singlet-triplet qubit to the photon.

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