Fine structure of a biexciton in a quantum dot with magnetic impurity: Magnetic sensing of a spinless system

Marek J. Korkusinski[1], **Anna H. Trojnar**[1,2], **Udson Mendes**[1], **Mateusz Goryca**[3], **Maciej Koperski**[3], **Tomasz Smolenski**[3], **Piotr Kossacki**[3], **Piotr Wojnar**[4], **and Pawel Hawrylak**[1,2]

[1] *Quantum Theory Group, Security and Disruptive Technologies, National Research Council of Canada, Ottawa, Canada*
[2] *Department of Physics, University of Ottawa, Ottawa, Canada*
[3] *Institute of Experimental Physics, University of Warsaw, Warsaw, Poland*
[4] *Institute of Physics, Polish Academy of Sciences, Warsaw, Poland*

In molecular and solid state systems, localised spins are coupled to the spins of electrons residing in their environment due to the spin-spin exchange interaction. This coupling is exploited in techniques such as the nuclear (NMR) and electron (EPR) spin-based resonance, in which the localised spin is treated as a local probe. When the environment is in the spin singlet state, the localized spin does not interact with it directly except for the Kondo effect [1].

Here we demonstrate that spin-singlet few-electron systems such as pairs of holes or excitons confined in a quantum dot are probed by the spin of a magnetic impurity. Specifically, building on our earlier work [2], we show theoretically and experimentally that the ground state of a bi-exciton in a CdTe self-assembled quantum dot with a magnetic Mn impurity exhibits a fine structure due to electron-electron Coulomb and hole-Mn exchange interactions. The bi-exciton-Mn complex is described by a Hamiltonian which accounts for the electron and hole single-particle shell structure, quantum dot anisotropy, direct, short- and long-ranged electron-hole exchange and isotropic electron-Mn and anisotropic hole-Mn exchange interactions. Results of exact diagonalization of the microscopic bi-exciton-manganese ion model predicts a pattern of three pairs of states in the ground-state manifold, each pair labeled by the projection of the Mn spin. The origin of the fine structure is traced to the Mn-mediated interaction of spin singlet and excited spin triplet two-hole configurations. We show that the fine structure determines the relative positions of the bi-exciton emission maxima and can be derived from the bi-exciton and exciton emission spectra. Theoretical predictions are successfully compared with measured bi-exciton and exciton emission spectra of a single CdTe dot with a Mn ion in its center in samples fabricated in Grenoble [3] and Warsaw.

The coupling of the localized spin to the spinless environment enables imaging of nonmagnetic molecular and solid-state systems and is important for operation of electron spin-based qubits [4], operation of single-spin quantum memory [5], and nanomagnetism [6].

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