Negative Trions in Coupled Quantum Dots

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We present an exact-diagonalization study of negatively charged excitonic trions in two vertically coupled parabolic quantum dots. The electrons and the hole are confined to different dots. We assume GaAs material parameters and investigate the system behaviour in a broad range of values of the dot confinement length, inter-dot separation (d) and external perpendicular magnetic field strength (B). The confinement radii are varied between 10 nm and 30 nm, the distance between the dots are changed from 0 to 50 nm and the magnetic field strengths are set between 0 and 14 T.

We find that for $d \neq 0$ the ground state angular momentum and spin multiplicity of the trion undergoes transitions as a function of the magnetic field, i. e. the so-called singlet-triplet transitions. For $d = 0$ the singlet state is the ground state for the considered magnetic field range. Our results are summarized in a $B - d$ phase diagram. Comparing the trion energies to the one of an exciton plus a free electron we reveal regions where the trions are bound with respect to dissociation to an exciton and an electron (i. e. when there is a positive Coulomb binding). We find that with the increasing electron-hole separation the trion becomes unbound.

We take a closer look at the character of the electron and hole charge distributions in the quantum dots. When the inter-dot separation decreases, the radius of the electronic dot is contracting monotonically, however, this is not the case for the distribution of the hole. The radius of the hole dot attains a minimum at a certain finite distance between the dots. We show that the angular momentum transitions are accompanied by abrupt changes in the dot radii. In the case of the electronic component these charge redistributions may be quite substantial (more than 10 %) and thus readily detectable. On the other hand, the charge distribution of the hole is altered to a much lesser extent. A more detailed insight into the system is obtained by computing the electron-electron and electron-hole correlation functions which will also be presented. The effect of these charge redistributions and of the singlet-triplet transitions on the oscillator strength of the magneto-photoluminescence is calculated.

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References

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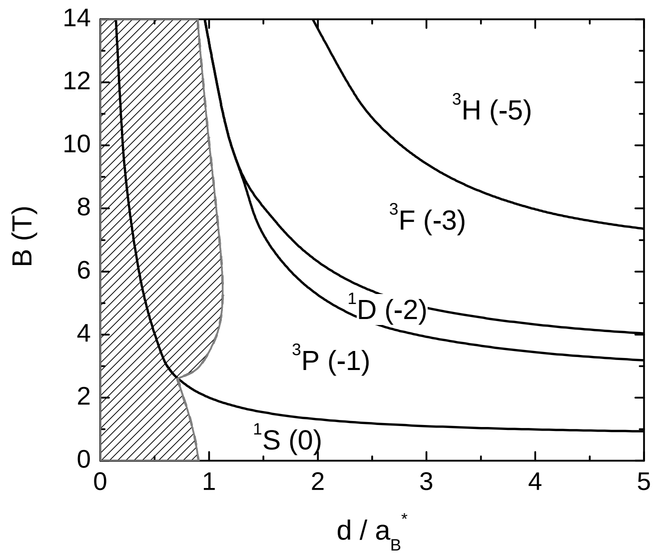

Fig. 1: The phase diagram of a negatively charged excitonic trion confined in vertically coupled quantum dots of lateral confinement length $l = 2.5\, a_B^*$ ($a_B^* = 9.8\,\mathrm{nm}$ is the effective Bohr radius). The axes show the inter-dot distance d and the magnetic field B. The hatched area signifies the region where the trion is bound. The thick lines denote the boundaries between the ground states of different angular momenta and spin multiplicities. The trion ground states are given in the spectroscopic notation. Superscripts 1 and 3 denote singlet and triplet states, respectively, and the capital letters stand for the angular momenta, given also in parentheses. The effective g-factor for the electron was taken $g^* = -0.44$.

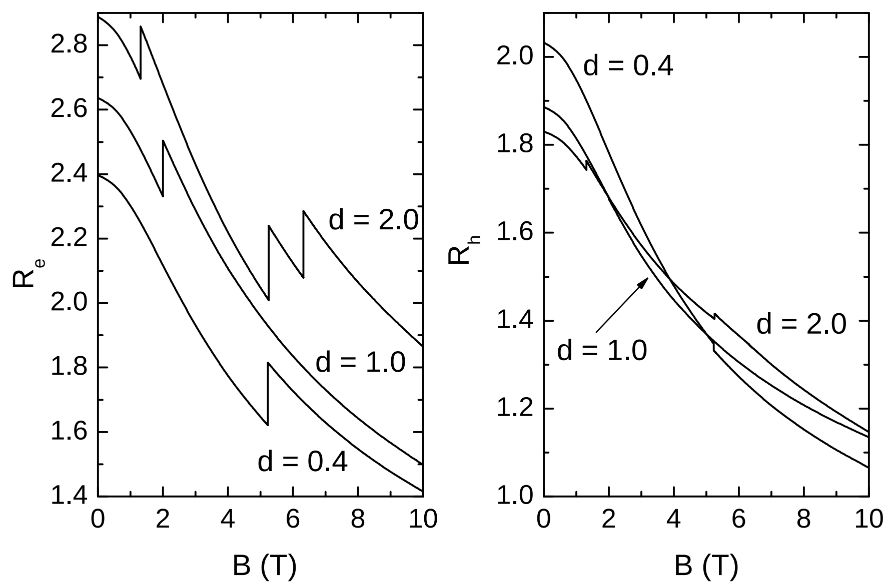

Fig. 2: The radii of the electron (R_e) and hole (R_h) lateral distributions in the quantum dots plotted versus the magnetic field strength B for a number of values of the inter-dot distances d measured in the effective Bohr radii $a_B^* = 9.8\,\mathrm{nm}$. Abrupt jumps associated with the angular momentum transitions at certain magnetic field values (predicted in Fig. 1) are clearly visible. The response of the electrons is much stronger than that of the hole.