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Properties of spin polarization state of two-electron system on two-dimensional quantum dots with magnetic field

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Abstract. Influence of the magnetic field on the energy of the spin polarization state of a two-electron system in two-dimensional quantum dots (QDs) is studied by using the method of few-body physics. As example, a numerical calculation is performed for a GaAs semiconductor QD to show the variations of the ground-state energy E_0, the spin-singlet energy $E_1(A)$ and spin-triplet energy $E_1(S)$ of the first excited state and the energy difference (i.e. $\Delta E(A)$ and $\Delta E(S)$) between the first excited and ground states with the effective radius R_0 of the QD and the magnetic field B. The results show that E_0 increases with increasing B, but decreases with increasing R_0; in the magnetic field, the spin-singlet energy $E_1(A)$ of the first excited state splits into two levels as $E_{1+1}(A)$ and $E_{1-1}(A)$, the spin-triplet energy $E_1(S)$ of the first excited state splits into two sets as $E_{1+1}(S)$ and $E_{1-1}(S)$, and each set consists of three "fine structures" which correspond to $M_S = 1, 0, -1$, respectively; each energy level (set, energy difference) decreases with increasing R_0, but there are great differences among the changes of them with B: $E_{1+1}(A)$, $E_{1+1}^{M_S}(S)$, $\Delta E_{1+1}(A)$, and $\Delta E_{1+1}^{M_S}(S)$ increase significantly with increasing B, but the variations of $E_{1-1}(A)$, $E_{1-1}^{M_S}(S)$, $\Delta E_{1-1}(A)$, and $\Delta E_{1-1}^{M_S}(S)$ with B are relatively slow; the splitting degree of each energy level (set, energy difference) is proportional to the first power of the magnetic field B.

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Key words: quantum dot, method of few-body physics, electron-electron interaction, spin polarization state

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1 Introduction

The progress and rapid development of the growth technology of semiconductor materials greatly promote the widespread study on low-dimensional nanostructures which have been a hotspot in the research field of quantum functional devices[1-8]. The quantum dot (QD) is one kind of artificial microstructure and the electron number in it can increase one by one from 1 by controlling the gate voltage, so the few-electron system can be formed. Kastner *et al.*[9] have regarded the QD as the "artificial atom". The reason is that the appearance of the QD is just like a minimal point structure and the electron in the QD is confined in every direction, so the discrete energy arises, thus the charge and the energy of the QD are quantized. Obviously, like the atomic problem, the study on the energy and its corresponding electronic states of the QD is a basic question. The simplest QD with the electron-electron correlation consists of two electrons, and the two-electron (2e) QD is also called the Helium QD. Xie[10] have studied the states of the barrier D^- centre in a arbitrary strength of magnetic field, which consists of a positive ion located on the z-axis at a distance from the two-dimensional (2D) QD plane and two electrons in the dot plane bound by the ion. Yannouleas *et al.*[11] have investigated the rovibrational spectrum of a 2e 2D parabolic QD. Sun *et al.*[12] and Dong *et al.*[13] have studied the energy spectra and electronic structure of a 2e QD within the effective mass theory. Ruan[14] have derived the transformation bracket relating product states of 2D harmonic oscillator functions with different sets of Jacobian coordinates. Recently, Li *et al.*[15] studies the total energy of the 2e QD and the energy of the electron-electron interaction by using a variational method of Pekar type on the condition of the electron-LO phonon strong coupling in a parabolic QD. In this paper, the influence of the magnetic field on the energy level of the spin polarization state of a 2e system in 2D QDs is studied by using the method of few-body physics. The influence of the magnetic field on the ground-state energy, the spin-singlet energy and spin-triplet energy of the first excited state and the energy difference between the first excited and ground states are discussed concretely.

2 Theoretical model and method

Comparing with the three-dimensional QD, the 2D QD can be controlled (the electron number in the QD) and observed (the spatial distribution of the electron) more easily, and it is more important for theoretical predictions and comparisons to the experimental results. In this paper, two electrons with the effective band mass m_b are confined in a 2D parabolic QD, and the plane of the 2D QD is taken as the $x-y$ plane. The applied magnetic field is in z direction of the QD. Based on the effective mass approximation, the Hamiltonian of the system can be written as

$$H = H_e + H_c + H_S \tag{1a}$$