Spin States of Few-Electron Systems in Quantum Rings

Junko Usukura[1] and Dai Hirashima[2]

[1]*Department of Physics, Tokyo University of Science, Tokyo 162-8601, Japan*
[2]*Department of Physics, Nagoya University, Nagoya 464-8602, Japan*

Progress in nano-technology has made it possible to confine a few electrons into a nano-scale region – a quantum dot (QD) – and moreover to control the number of electrons one by one. One can also control the spin state of these 'artificial` atoms by applying a magnetic field; one can fully polarize the total spin of electrons by applying a strong field irrespective of the spin state of the ground state in the absence of the field. It would be more useful if one can control the spin state in the absence of the field, i.e., if one can polarize or depolarize the total spin, for example, by changing the shape of the QD confining the electrons. This would enhance the potentiality of QDs in the further development in nano-technology. In this paper, we investigate the possibility of control of spin state of few-electron systems by varying the shape of the confining potential.

The spin state of few-electron systems in QDs is determined (1) by the shell structure of the one-electron states originating from the confinement potential and (2) by the Coulomb interaction between electrons. When the Coulomb interaction is not dominantly strong, the spin state is determined by the Hund's rule as in 'natural` atoms; in these cases, the shell structure remains valid. However, as the size of the QD becomes large, the Coulomb interaction becomes dominant and the shell structure becomes irrelevant. Finally, electrons will turn into a solid-like state – a Wigner molecule. We pay special attention to the spin state of these localized electron states. In this case, the spin state will be determined by exchange interaction between localized electrons and one can control the exchange interaction by controlling the exchange paths with the shape of the confining potential. In this work, we mainly deal with from two to four electrons confined in 2D by the ring-type potential whose typical shape is shown in Fig. 1.

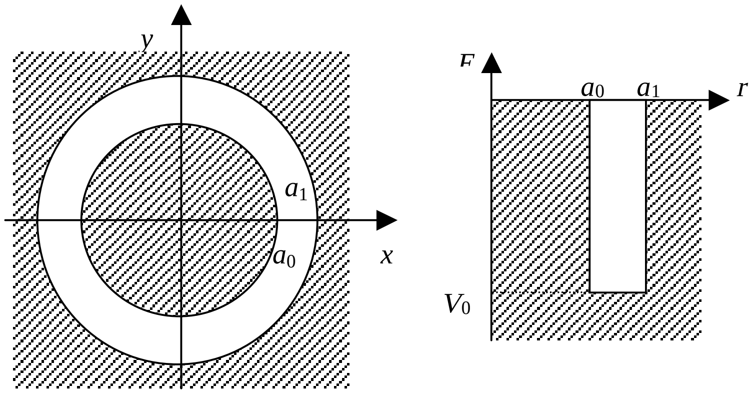

Fig. 1 Quantum ring confinement

In this work, the stochastic variational method (SVM) is used to solve the few-body problems. In this approach, correlated Gaussians are adopted as basis functions and the most adequate ones are selected stochastically. The advantage of this method lies in its flexibility, and a wave function is obtained with a relatively small number of basis functions provided that the parameters are carefully optimized. One can then reliably study the strongly correlated region, which is difficult to reach by exact diagonalization method, and indeed this method has already been successfully applied to artificial atoms (K. Varga, P. Navratil, J. Usukura and Y. Suzuki, Phys. Rev. B 63, 205308 (2001)). We study the ground state and low lying excited states of few electrons confined in a quantum-ring like shape and discuss the possibility of control of the spin state with varying the shape of the ring structure etc.