Spin-Orbit Coupled Bose-Einstein Condensates:Ground States, Dynamics and Topological Defects

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論　文　内　容　の　要　旨

The thesis focuses on the ground states, dynamics and topological defects of the spinor Bose-Einstein condensates (BECs) with two-dimensional (2D) Spin-Orbit (SO) coupling. We studied two different cases for the external trapping condition: the homogeneous case and optical lattices potential.

In solid-state physics, the SO coupling originated from the relativistic effects. It couples the particle's spin and its orbital degree of freedom. SO coupling plays the central role for the quantum spin Hall effect and the topological insulators. In recent years, as a great breakthrough, the synthetic SO coupled BEC has been realized in experiment. It enables us to investigate the certain issues related to the SO coupling in other fields, such as, solid-state physics and particle physics, as quantum simulator by using the cold atomic systems.

In the first part of my thesis, we studied the SO coupled BECs in optical lattices. Especially, we investigated the energy dispersion, spin textures, vortex-antivortex pair structures, and presented the ground-state phase diagram. First, the general method to solve the Gross-Pitevskii Equation (GPE) for the SO coupled spinor BEC in optical lattices is presented in numerical simulation and analytical calculation. We showed that: (1) The optical lattices will change dramatically the energy dispersion of a SO coupled BEC; (2) The SO coupling generates the spin textures in the ground states; (3) Vortex lattices appear in a certain parameter region.

Second, a vortex–antivortex pair (VAP) appears spontaneously in a SO coupled spinor BEC. The wave functions for the spin-up and spin-down components are mirror symmetric with respect to the y-axis, because the GPE is invariant under the combined operation of the spin inversion and the mirror transformation. Third, the ground-state phase diagram for a SO coupled spinor BEC in an optical lattice is presented. We found that, as a result of the spontaneous symmetry breaking, there are six types of ground-state phases. Among them, the twofold vortex lattices and the lattices chain are predicted for the first time, they reflected the symmetry and topological properties of the system.

In the second part, we researched the SO coupled BECs in 2D free space. Especially, we focus on the stable soliton and half-quantum vortices in the system. We found that a new stable soliton emerge spontaneously in 2D free space in a SO coupled BEC. The general systems cannot hold stable solitons in 2D free space, because of the occurrence of the collapse. Our results showed that the SO coupling prevents the collapse, and stabilizes the solitons in the ground state. Furthermore, we confirmed that the stable solitons include the half-quantum vortices and the mixed modes, in which the half-quantum vortices coexist with its time-reversed partner.