Summary of Research

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We have developed numerical algorithm for calculating thermodynamic properties and applied it to bosonic and quantum spin systems listed as follows.

(1) Bosonic systems

We performed quantum Monte Carlo simulations for the Bose-Hubbard model to study the superfluidity which is characterized as non-viscous current and appears in liquid ^{4}He and atomic gases at quite low temperatures.

• 2-dimensional Kosterlitz-Thouless transition and random potential

It is well-known that Kosterlitz-Thouless (KT) transition occurs and the superfluidity appears in two-dimensional bosonic systems. We studied effects of an uniform random chemical potential on the KT transition and the superfluidity by numerical calculations of the Bose-Hubbard model. This study was motivated by the recent experiments for atomic gases confined in two-dimensional optical lattices. As a result, we confirmed that the system has the superfluidity through the KT transition even in the random potential. In addition, as the randomness increases, a quantum phase transition occurs, the superfluidity disappears, and the bose glass phase appears at high randomness. We also calculated the critical exponent ν to investigate the criticality of the quantum phase transition.

• Superfluidity of ^{4}He confined in quasi 1-dimensional nano-porous media

The superfluid transition at a finite temperature is theoretically prohibited in one-dimensional systems. Nevertheless, the superfluidity is observed experimentally in the ^{4}He confined in a nano-porous medium FSM that consists of one-dimensional tube, even though the diameter of the tube is quite small. We performed numerical calculations for the quasi one-dimensional system to explain the experimental results, considering the effects of the potential of the medium. As a result, we confirm that the correlation develops along the wall of the tube because of the adsorbing potential of the medium and the system has the superfluidity.

(2) Quantum spin systems

• Quantum criticality of spin 1 Ni compound

The Ni compound $NiCl_2$-$4SC(NH_2)_2$ has a magnetic order when magnetic field is applied. This magnetic filed induced phase transition is known as a Bose-Einstein condensation (BEC) of the magnon. Since the Ni has spin $S = 1$, the system can be described by the $S = 1$ Heisenberg model with uni-axial anisotropic term $D\sum_i (S_i^z)^2$. We developed the algorithm for calculating the $S = 1$ spin systems and performed the calculation of the system. Comparing the results with the experimental results for $NiCl_2$-$4SC(NH_2)_2$, we estimated the exchange interaction J and the anisotropy D. Using the estimated value, we obtained the temperature-magnetic field phase diagram and the temperature dependence of the magnetization. The results are consistent qualitatively with the experimental results. We confirmed the BEC of the magnon from the consistence between the experimental and the numerical results. In addition, we investigated the pressure induced quantum phase transition of the system and showed that the logarithmic correction appears in critical exponents.