論文の内容の要旨

論文題目　Quantum disordered phases in the frustrated honeycomb antiferromagnets

（ハニカム反強磁性体における量子無秩序相）

氏　名　　張　昊

The two-dimensional frustrated quantum spin systems have become a corner stone in the understanding of novel and exotic physical phenomena in quantum magnetism. The inclusion of frustration is expected to enhance the effect of quantum spin fluctuations which may induce novel disordered phases such as quantum spin liquids. One typical two-dimensional system is the quantum J_1-J_2 model on the honeycomb lattice, where the lowest possible coordination number in two-dimensional systems enhances the quantum fluctuations. Recently, the possible spin liquid phase found in the Hubbard model on the honeycomb lattice and the spin liquid behavior observed in the bismuth oxynitrate compound, $Bi_3Mn_4O_{12}(NO_3)$, also induce the interest for this system.

In this thesis, we study quantum disordered phases in the frustrated Heisenberg model on the single layer and bilayer honeycomb lattices. This thesis contains three main parts. In the first part, we study the ground-state phase diagram of the frustrated quantum Heisenberg antiferromagnet on the single-layer honeycomb lattice with the first (J_1) and second (J_2) nearest-neighbor couplings using a mean-field approach in terms of the Schwinger boson representation of the spin operators. We calculate the ground-state energy, local magnetization, energy gap and spin-spin correlations. The system shows magnetic long range order for $0 \leq J_2/J_1 \lesssim 0.2075$ (Néel) and $0.398 \lesssim J_2/J_1 \leq 0.5$ (spiral).

In the intermediate region, we find two magnetically disordered phases: a gapped spin liquid phase which shows short-range Néel correlations ($0.2075 \lesssim J_2/J_1 \lesssim 0.3732$), and a lattice nematic phase ($0.3732 \lesssim J_2/J_1 \lesssim 0.398$), which is magnetically disordered but breaks lattice rotational symmetry.

In the second part, we use a combination of analytical and numerical techniques to study the quantum melting of Néel order in the frustrated Heisenberg model on the bilayer honeycomb lattice. Using a similar Schwinger boson mean-field theory, the ground-state phase diagram is studied as a function of the frustration intralayer coupling J_2 and the interlayer coupling $J_\perp$. We also investigate the spin gap, local magnetization, spin-spin correlations and ground-state energy. We find a novel reentrant behavior in the melting curve of Néel order. We complement the study with exact diagonalization on small clusters performed by C. A. Lamas. Using a linear spin wave approach we also study the melting of Néel phase as a function of the spin S, the frustration coupling J_2 and the interlayer coupling $J_\perp$.

In the third part, we study the Heisenberg antiferromagnet on a bilayer honeycomb lattice including interlayer frustration due to the competing interactions, J_1, $J_\perp$, and J_x. We map out its quantum phase diagram based on Schwinger boson and bond operator approaches. This is also supplemented by dimer series expansion by M. Arlego and W. Brenig, and exact diagonalization by C. A. Lamas. Analyzing ground state energies and spin correlation functions, we find four distinct phases, corresponding to three collinear magnetic long range ordered states, and one quantum disordered interlayer dimer phase. The latter phase is adiabatically connected to an exact singlet product ground state of the the bilayer which exists along a line of maximum interlayer frustration in the phase diagram of (J_x, J_1). The types of orders within the remaining three phases are clarified.

In summary, for the single layer case, we found that two types of magnetically disordered phases exist in the intermediate frustration region and the lattice rotational symmetry breaks in the part of large J_2/J_1 in the magnetically disordered region. For the bilayer case with intralayer frustration, we found a novel reentrant behavior in the melting curve of Néel order. To the best of our knowledge, it is the first time to provide a comprehensive study about the ground-state phase diagram for the bilayer case with interlayer frustration. Our studies of the frustrated systems on the honeycomb single layer and bilayer lattices provide a systematic investigation about the effects of frustration to the ground state and should play an important role in the understanding of the quantum phases and the competition between the frustration and unfrustration couplings in the large family of frustrated magnets.