11 Miyashita Group

Research Subjects: Statistical Mechanics, Phase Transitions, Quantum Spin systems, Quantum Dynamics, Non-equilibrium Phenomena

Member: Seiji Miyashita and Keiji Saito

1. Cooperative Phenomena in Long-Range Interacting Systems

So far, phase transitions of spin systems have been studied mainly on the fixed lattice. However, we pointed out that difference of sizes of the high-spin (HS) and the low-spin (LS) states causes lattice distortions. This degree of freedom of lattice deformation causes an effective long range order. We found that the critical property of this model belongs to the universality class of the mean-field model. We also found that its dynamical critical properties, such as the spinodal phenomena, are described by the corresponding mean-field theory. We analyzed the critical properties of divergence of the relaxation time near the spinodal point, and obtained asymptotic forms of the divergence and a finite size scaling form. We also pointed out that the threshold phenomena in the switching from LS state to HS state at a low temperature by photo-irradiation belong to this category. We performed Monte Carlo simulation of excitation process in the model with elastic interaction, and found that the scaling relation of the relaxation time describes its critical behavior.

We also pointed out that the boundary condition plays an essential role in long range interacting models. In particular, if we use the infinite-range model (Husimi-Temperley model), the distance between spins has no role, and the boundary condition has no sense. In contrast, in the present model, the open boundary condition causes significant different relaxation processes. We study that in what extent the mean-field description works in various long range models. We found that for a power law interacting model, there exists a parameter region in which the mean-field description does not work. It would be a very interesting problem to study static and dynamical critical properties of systems for which the thermodynamic limit does not exist.

2. Quantum Statistical Mechanics

In quantum systems, they show interesting non-classical behavior. As to the ordered states, the super-fluidity and super-conductivity are so-called off-diagonal long range order (ODLRO) which are specific to the quantum system. The coexistence of the ODLRO and the diagonal order such as the solidity of the particles has been one of the topics in the He system as the super-solid problem. We studied existence of the super-solid state by a quantum Monte Carlo simulation (stochastic series expansion method) on the soft-core Bose Hubbard model in a three-dimensional lattice (simple cubic). We observed successive phase transitions of the solid order and of the super-fluidity at finite temperatures, and also that the super-solid phase exists in a less-filled region, which is not the case in one- and two-dimensional systems. We also pointed out that importance of lattice structure for the super-solid state.

Coherent dynamics of quantum systems has also various characteristic features, and attracts interests from the view point of quantum information processing. We have studied such novel quantum phases and quantum responses. Parts of the subject are studied as an activity of the JST CREST project (Quantum-mechanical cooperative phenomena and their applications).

We study magnetic properties of itinerant electron systems described by the Hubbard model. When the system is in the so-called half-filled case, the system is in the Mott state where the total spin of the system is zero, while when an electron is removed from the half-filled state, the total spin of the system changes to the maximum value if the lattice satisfies a certain condition. This mechanism is called Nagaoka-ferromagnetism. We demonstrated an adiabatic change of the total spin by a mechanism inspired by the Nagaoka-ferromagnetism. There, we can produce a state with a large total spin but zero magnetization, which is called Dicke state. We studied the characteristics of this state and discussed how we observe the state. Moreover we studied the ground state of itinerant systems with particles of larger spins, e.g. $S = 1$ (Boson) and 3/2 (Fermion), etc., and found that the ground state has a degeneracy for the $\mathrm{SU}(2S + 1)$ symmetry due to the symmetry among the particles with different magnetizations. It is expected that these new magnetic phenomena are realized in the optical lattice of the laser cooled atom systems.

The property of energy gap at the quasi-crossing point is important for manipulation of quantum states by an external field. We studied nontrivial degeneracy of eigenenergies uniaxial large spins with terms of the single-ion type anisotropy from the view point of a parity symmetry of magnetization. We also studied the gap opening phenomena for Floquet operator which describes the dynamics of periodically driven system. It has been known that periodic external field induces a kind of Rabi oscillation, and the frequency becomes zero at certain values of the amplitude of the AC field. This phenomenon is called the coherent destruction of tunneling (CDT). The CDT can be regarded as a degeneracy of eigenvalues of the Floquet operator. We found that the degeneracy comes from the time reversal symmetry of the AC field, and demonstrated a gap opening in asymmetric shape of the field. We also demonstrate a Landau-Zener analogue when we sweep the amplitude of AC field.

We studied dynamics of the transverse Ising model, and found a kind of quantum spinodal decomposition phenomena when we sweep the field fast in the ordered phase. We also studied the so-called quantum annealing by making use of the quantum fluctuation.

We also studied a control of the state by measurement procedures. Controls of photon state in micro-cavity with atom beams have been performed in experiments (Haroche group, France), and the measurement is a type of quantum non-demolition for the number distribution of photons, but when we measure states of atoms, the photon state changes to a number state. We studied time-dependence of the photon state by Jaynes-Cummings model, and investigated the statistical property of the ensemble of measurements.

We also studied properties of generalized Yang-Baxter relation in large spin system.

3. Formulations of Non-equilibrium Statistical Physics

We studied the formulism of time-evolution equation for systems contacting with the thermal bath. When we study the complex admittance in dissipative environments, we need time evolution of the autocorrelation function. We pointed out that the equation of motion of the autocorrelation function is the same as that of the density matrix. But the intial state must be treated properly. We make a formulation in which no assumption was made except for the second order perturbation of the strength of the interaction between the system and the thermal bath. We demonstrated the method and studied parameter dependence of the line width. We also compare formulations of the complex admittance by obtaining explicit forms.

We also studied fundamental mechanisms and statistical properties of the heat conductivity.

12 Ogata Group

Research Subjects: Condensed Matter Theory

Member: Masao Ogata, Youichi Yanase

We are studying condensed matter physics and many body problems, such as strongly correlated electron systems, high-T_c superconductivity, Mott metal-insulator transition, magnetic systems, low-dimensional electron systems, mesoscopic systems, organic conductors, unconventional superconductivity, and Tomonaga-Luttinger liquid theory. The followings are the current topics in our group.

- High-T_c superconductivity
  High-T_c superconductors as a strongly correlated electron system.
  Inhomogeneity and two-gap features in high-T_c cuprates. [1]
  Phase diagram of multilayered cuprate superconductors.
- New superconductor: Iron-pnictide
  New mechanism for iron-pnictide superconductivity, "unscreening" effect of Coulomb interaction.
  Simple description of the nodeless and nodal s-wave gap functions in iron pnictides. [2]
  Normal-state spin dynamics of five-band model for iron pnictides. [3]
- Organic conductors
  Renormalization group study on quasi-one-dimensional superconductivity under magnetic field.
  Novel spin-liquid states in anisotropic triangular spin systems.
  Steady nonequilibrium state with competing charge orders under an electric field. [4]
- Theories of anisotropic superconductivity
  Antiferromagnetic order in the FFLO superconductivity. [5]