Quantum Condensed Matter Theory Group

Every material around us is composed of numerous atomic nuclei and electrons. It sometimes exhibits various fascinating interaction-caused phenomena that cannot be expected from a single-particle viewpoint. Theoretical condensed matter physics aims to understand these phenomena and predict new properties based on thermodynamics, statistical mechanics, quantum mechanics, quantum field theory, etc. Our research includes studies of ultracold atoms, superconductivity, superfluidity, critical phenomena, spin systems, simulation techniques, and others. The Quantum Condensed Matter Theory Group actively works on a variety of topics, some of which are shown above, and leads graduate students to the frontier of physics research.

(Keyword: condensed matter, superconductivity, superfluidity, critical phenomena, statistical physics)

1. Staff Members and HP

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2. Recent Activities

2-1) Ultracold Bose-Fermi atoms

Recent developments in trapping and cooling neutral atoms enable us to build up a mixed system of ultracold Bose-Fermi atoms. Mixing different quantum statistics particles opens up new possibilities in quantum condensed matter physics. We can then focus on specific phenomena expected in the Bose-Fermi mixture systems.

Included in our study target are phase diagrams, the internal structure of a mixed Mott phase, the localization effect of random potentials, the effect of interactions between Bose-Fermi interactions, the fermion-induced Mott transition of bosons, etc.

To solve these problems we employ a variety of tools from analytical calculation to numerical calculation, including renormalization group technique, numerical computation of the Gross-Pitaevskii equation, quantum Monte Carlo calculation, and more.

The effect of a synthesized electromagnetic field applied to mixture systems is also of our recent interest. Unlike electrons in an electromagnetic field, a mixture of bosons and fermions is expected to have rich physical properties that we are trying to unveil.

2-2) Superfluid in ultracold atomic gases and unconventional superconductors

We study theoretically basic properties of superfluids in ultracold atomic gases. A superfluid behaves like a fluid with zero viscosity and is strongly connected with superconductors. One of the phenomena currently attracting attention is the dynamics of superfluids in ultracold atomic gases. We focus on the propagation of sounds and fluxes, which are specific properties of superfluids. We analyze these phenomena qualitatively and quantitatively by deriving general expression.

We also study basic properties of unconventional superconductors. Specifically, we focus on the noncentrosymmetric heavy Fermion superconductors, which show superconductivity together with magnetic order. We study theoretically further unusual properties that arise out of t the interplay of magnetism and superconductivity.

One purpose of our studies is to find common properties of superfluidity and superconductivity in a variety of different systems.

2-3) New Monte-Carlo method

Frustration effects are of importance in condensed matter physics because they can result in unconventional phases and exotic excitations. Spin-ice materials such as $Dy_2Ti_2O_7$ and $Ho_2Ti_2O_7$ do not order down to low temperature and exhibit residual entropy as a hallmark of frustration.

Recently, we invented a cluster algorithm for Monte Carlo simulation of a spin-ice model in which ten types of graphs are introduced to decompose the system into a mixture of loops and strings.

This method, the loop-string algorithm, has some good points:

- It is free from the so-called spin-freezing problem.
- It is a simple enough implementation that it could provide a building block for simulations of more complicated systems with ice-type degeneracy.

Using the loop-string algorithm, we clarified that Debye screening works among magnetic monopole-like excitations, and that the deconfinement transition triggered by a fugacity of monopoles z is dictated by a singular part of the free-energy density proportional to z.

3. Collaborating Institutions

University of Tokyo, Tokyo University of Science, University of Hiroshima, Nara Medical University Institute for Solid State Physics, ETH Zurich, Princeton University,

4. Recent Papers

1) A. Masaki and H. Mori J. Phys. Soc. Jpn. 82, (2013) 074002.
2) N. Miyamoto and H. Mori, J. Phys. Soc. Jpn. 82, (2013) 105001.
3) E. Arahata and T. Nikuni, Phys. Rev. A 90 043601 (2014)
4) M. Achermann, T. Neupert, E. Arahata, and M. Sigrist J. Phys. Soc. Jpn 83, (2014) 044712.
5) E. Arahata and Y. Kato J. Low Temp. Phys. 175, (2014) 346.
6) E. Arahata and T. Nikuni, Phys. Rev. A 87, (2014) 033601.
7) H. Otsuka, Phys. Rev. B 90 (2014) 220406(R).
8) H. Otsuka, H. Takatsu, K. Goto, and H. Kadowaki, Phys. Rev. B 90, (2014) 144428.
9) H. Takatsu, K. Goto, H. Otsuka, R. Higashinaka, K. Matsubayashi, Y. Uwatoko, and H. Kadowaki, J. Phys. Soc. Jpn 82, (2013) 073707.
10) H. Otsuka, Phys. Rev. Lett. 106, (2011) 227204.