論文の内容の要旨

Effective Theory of Quantum Many-Body Systems Coupled with Mechanical Degrees of Freedom

（力学自由度と結合した量子多体系の有効理論）

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Studying quantum many-body systems both experimentally and theoretically involves the following dilemma: in theory, the Schrodinger equation provides a simple tool, but the corresponding isolated quantum system is not easy to realize experimentally; on the other hand, many experiments involve coupling with external systems, which is virtually impossible to analyze theoretically by the Schrodinger equation. One approach to this dilemma is to realize such an isolated quantum system by force, and the other is to theorize an open quantum system

coupled with external systems.

Of the above approaches, the theory of open quantum systems allows us to model the external system in many ways. For example, we can replace the external system with a small number of classical degrees of freedom. Such an equation of motion for the classical degrees of freedom, if available, would give us information about the quantum system. Based on this concept, we pay our attention to two problems: one is to theorize pre-existing experimental setups, and the other is to develop mechanisms that convey information from the quantum system to the classical system. Chapter 2 proposes a model of two-dimensional ^{4}He on a graphite substrate as an example of the former, and Chapter 3 predicts the generation of initial-state-sensitive dynamics in a spin system as an example of the latter.

Chapter 2 derives an effective Hamiltonian for two-dimensional ^{4}He on a graphite substrate and presents a classical equation of motion for the substrate, assuming that the substrate is movable. First, to derive the effective Hamiltonian, we use a coordinate transformation inspired by an existing method. This coordinate transformation eliminates the need to introduce a coupling Hamiltonian, as in many studies of quantum composite systems. The resulting equation of motion allows us to infer the behavior of the two-dimensional ^{4}He on the substrate. In equilibrium, the ^{4}He atoms are usually adsorbed on the absorption sites of the substrate and behave like trapped cold atoms. However, when the substrate moves, the ^{4}He atoms also move between the adsorption sites. This movement would affect the effective mass of the entire system. Our equations of motion provide information about this effective mass. In particular, we replace the two-dimensional ^{4}He with hard-core bosons on a lattice, an effective model for the two-dimensional ^{4}He, and write down a formula for the effective mass as a function of both the hopping parameter of the hard-core boson and the number of particles.

Chapter 3 discusses a possible onset of long-range interactions in a quantum spin system and the generation of initial-state-sensitive dynamics from these interactions. In the presence of long-range interactions, the state of a localized spin at one point affects many other localized spins. It also enlarges the effect of a perturbation at one time at a later time in the time evolution. Interestingly, it works explosively for some types of long-range interactions. We consider such an example in this study. We prepare periodically driven exchange interactions and derive such long-range interactions from them according to the Floquet picture. We find that under the long-range interactions, a small difference in the initial state can even determine whether the system evolves in time or not. In Chapter 3, we show this analytically and numerically.

In Chapter 4, we summarize the results obtained in Chapters 2 and 3. We also discuss the application of our findings to the field of quantum information and quantum thermodynamics. We also compare our results with those of various studies on the coupling of quantum and classical systems.