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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Open systems are one of the important subjects in nonequilibrium physics. They show interesting nonequilibrium behaviors, and there are many examples of open systems in various branches of physics. Due to the development of experimental techniques recently, analytical studies are more and more important. We focus on the open XY spin chain with boundary dissipations. In the closed system, the XY spin chain has several phases which are characterized by the asymptotic behavior of the spin-spin correlation. Open XY spin chain is also expected to have a phase transition and new physical phenomena not seen in isolated systems can be observed. There are two conventional methods for studying open quantum systems such as an analysis using the Lindblad equation and the nonequilibrium Green's function (NEGF) method. We mainly use the Lindblad equation. This equation is one of the quantum master equations. This equation has the Markov property and complete positivity. In recent years, one has discussed about the feasibility of this equation in experiments and the validity of the theoretical framework. In addition, transient behaviors of open systems whose dynamics is described by this equation are not well understood, although there are many studies of phenomena in steady state.

In this thesis, we obtain the exact solution of the Open XY spin chain with boundary dissipations. The main results are exact formulas of time-dependent physical observables such as magnetization, spin current, and correlation function. In order to obtain these formulas, we introduce the third quantization whose main concept is the projection from the original Hilbert space to the Liouvillian-Fock space. Evaluating our formulas, we observe interesting behaviors numerically. This procedure is generally adaptable to Hamiltonians described by the quadratic form and linear dissipative operators. We have evaluated this formula and observed interesting numerical behavior. Furthermore, our formulas allow us to discuss analytically some behaviors.

In the isotropic case (XX spin chain), the matrix describing the Lindblad dynamics is diagonalizable, yielding an exact formula for the time-dependent physical observables. In this diagonalization, it is important that we can reduce the size of the matrix to be diagonalized by appropriate matrix transformations and obtain exact formulas for eigenvalues and the corresponding eigenvectors from the analysis of a complex symmetric tridiagonal matrix. Using this formula, several transient behaviors are studied analytically. When the spatio-temporal behavior of the magnetization is observed for a short time window, a light-cone structures appear. This behavior is estimated by analogy from the quench dynamics of the corresponding isolated system. The wave fronts of the light-cones are also determined by the start and end times of the plateau regime where the magnetization does not change. This behavior can be

discussed analytically by asymptotically analyzing the integral representation of the physical observable. On the other hand, it is known that long-time behaviors are characterized by the Liouvillian gap which is obtained as the maximum real part in the non-zero eigenvalues for the Liouvillian and the relaxation time of a physical observable is defined by its inverse. For sufficiently large system sizes, we analytically obtain the O(N^{-3}) scaling behavior for the Liouvillian gap including its coefficients.

Furthermore, even in the anisotropic (XY spin chain) case, the matrix describing the Lindblad dynamics can be diagonalized by solving a five-term recurrence relation and we obtain analytical solutions for its eigenvalues and eigenvectors. Using this diagonalization, we obtain an exact formula for the time-dependent physical observables. By using this formula, we observe different behaviors which are observed in the isotropic case. One of them is the overlap of light-cones with different velocities. The second wave front of the light-cone is observed only when the magnetic field is small. As the magnetic field increases, this wave front disappears beyond a critical point. This critical point is the same as that in the non-equilibrium steady state. The location of the second wave front is represented as the site where the spatial behavior of the magnetization changes. The disordered-oscillatory behavior is observed inside the second wave fronts, and it is numerically inferred that this behavior is related to the presence of correlations. On the other hand, the system size scaling behavior of the Liouvillian gap, which characterizes the long-time behavior, can be studied. We examine that the Liouvillian gap is O(N^{-3}) scaling except at the critical point and O(N^{-5}) scaling at the critical point. The Liouvillian gap under a zero magnetic field can be calculated rigorously for the scaling behavior including its coefficient. (736)