Real-space correlations in dissipative quantum systems

Etienne Gärtner

Abstract

In this thesis two different dissipative quantum impurity systems are studied. The dissipative environment in both models is described by a one-dimensional chain of bosons with an ohmic spectral density. By coupling to the impurities, the translational invariance in the environment is broken. It is investigated to what extent impurities of different nature can be traced in the environment by means of static thermal averages as a function of distance to the impurities.

In the first model, an oscillator is used as the impurity in the system. The impurity oscillator can act on itself via density-density interactions. For zero self-interaction, the system is studied analytically via equations of motion, as all relevant propagators can be expressed in terms of the bare ones. In the limit of infinite self-interaction, the system then transforms into the renowned spin-boson model. [2, 4]. Here, the system shows a Kosterlitz-Thouless quantum phase transition as a function of the coupling strength between impurity and an ohmic environment. This transition can be observed between a delocalised phase where the reduced two-level impurity system performs oscillations between the two states and a localised phase where the impurity is frozen in either of those two remaining states. In the range from zero to infinite self-interaction the system is elusive to a purely analytic treatment. To investigate the model in that regime, the Numerical Renormalization Group method (NRG) is employed. Based on the NRG results, a renormalization-group flow of the system-parameters is suggested, incorporating a whole line of quantum-phase-transitions as a function of coupling strength between impurity and environment.

As a second model two identical spin-1/2 impurities are coupled at a variable distance to the environment. The model has been studied before in case of zero inter-impurity distance [3, 1], where the chosen interaction of the spins via their z-component to the bath induces a ferromagnetic interaction between the spins. In the two-dimensional subspace of parallel aligned spins there is again a quantum phase transition of the Kosterlitz-Thouless nature as a function of the coupling strength between impurities and environment. For infinite distance, each spin is independently treatable and the system can be described by two uncoupled spin-boson models. A wide range of impurity

distances is studied within this thesis in order to trace the quantum phase transition between zero and infinite inter-impurity distance. To this end, a two-channel NRG for Bosonic models is developed that is capable of dealing with both limits. Details on the algorithm and its implementation are presented in this work.

In the delocalised phases of the models, the average site occupation in the environment is changed due to the presence of the impurities. This change is found to drop in a power-law manner with growing distance to the impurities, where different phases show different power-law exponents. In addition, the change in the average displacement of the environmental bosons due to the coupling to the impurities is calculated. While this change is highly sensitive to numerical noise in intermediate parameter regimes, power-laws can be extrapolated as well for a large range of parameters. Between the two spin-1/2 impurities of the second model the changes in the thermal averages remain comparably large, indicating an effective coupling of the impurities which is mediated by the common environment. In conclusion, no intrinsic length scale is found in the environment in either of the models. The implemented bosonic two-channel NRG proved successful in describing the physics of the two-spin-boson model in its delocalised phase.

References

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