ESQPTs AND QUANTUM QUENCHES IN THE DICKE-LIKE MODELS

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One of the main topics in many-body physics is the understanding of the quantum phase transitions. A quantum phase transition (QPT) is a sudden change of the ground-state structure at a certain critical value of a control parameter λ. It can be observed as a non-analytic evolution of the ground-state system's energy and wave function induced by an *adiabatic* variation of the control parameter λ across the quantum critical point λ_{c0} at zero temperature. Recently, attention has been paid to a new class of phase transitions, not related with the ground state but to excited states. These are known as excited-state quantum phase transition (ESQPT) [1]. This phenomenon represents a non-analytic evolution of individual *excited* states in the system with a variable control parameter. ESQPT's have been studied for simple systems up to now. Another topic of interest in quantum physics is the effect of a sudden change in the control parameter governing the Hamiltonian and the subsequent relaxation processes of the system. This abrupt, *diabatic* change of the control parameter is known as quantum quench (QQ) and its study is a hot topic in physics, see Ref. [2]. Not surprisingly, the QPT and QQ effects can be mutually related. If the initial state before a quench coincides with the ground state near a QPT, the dynamics after the quench depends substantially on whether the parameter change does or does not bring the system to the other quantum phase, or eventually to the narrow quantum critical region between the phases [2-3]. In parallel, it has been shown that the existence of an ESQPT in simple quantum systems entails dramatic consequences in time-evolution after a quench [4].

In this contribution we work with models of interest in quantum optics as the Dicke and related models. The Dicke model describes a collective light-matter interaction and present an interesting QPT from a normal to a superradiant phases [5]. The Dicke model represents the interaction between a set of N_a two-level atoms and a single bosonic mode via dipole interaction with an atom-field coupling strength λ. They can be written in terms of bosonic creation (annihilation) operators $b^\dagger$ (b), describing a bosonic mode with frequency ω, and the SU(2) generators, describing the ensemble of two-level atoms of level-splitting ω_0 in terms of a pseudospin of length $J=N_a/2$.

$$J_+ = \sum_{i=1}^{2J} a_{\uparrow i}^\dagger a_{\downarrow i}, \quad J_- = J_+^\dagger, \quad J_z = \frac{1}{2}\sum_{i=1}^{2J}(a_{\uparrow i}^\dagger a_{\uparrow i} - a_{\downarrow i}^\dagger a_{\downarrow i})$$

Here, $a_{\uparrow i}^\dagger$ or $a_{\uparrow i}$ and $a_{\downarrow i}^\dagger$ or $a_{\downarrow i}$ create or annihilate spin-up and spin-down states of the fermion on site *i* and the ladder operators $J_\pm$ describe spin flips along the array. The Dicke Hamiltonian [6] reads

$$H = \omega_0 J_z + \omega b^\dagger b + \frac{\lambda}{\sqrt{M}}[(b + b^\dagger)(J_+ + J_-)],$$

where M=4J. This Hamiltonian is not integrable. In this contribution, the non-integrable Dicke model and some integrable related models are used to show the existence of ESQPT in them, the effect of QQ and the corresponding relaxation processes. The existence of an ESQPT in both the integrable and the non-integrable Dicke based quantum models is revealed for finite systems as a sudden increase of the level density for some critical value of the energy, which in the thermodynamic limit transforms into a singularity. The ESQPT manifests itself in the expectation values of quantum observables that depict singularities at the critical scaled energy. These signals of the presence of an ESQPT open the possibility of using the concept of order parameter and to resort to the Landau theory to characterize and classify them. We have investigated the consequences of an ESQPT on the relaxation dynamics after a quantum quench that drives the systems to the critical energy region. Starting from an initial state that we choose as the ground state of the system for a specific value of the control parameter λ, a sudden quench is applied and the relaxation process is followed by solving exactly the time dependent Schrodinger equation. Various relevant magnitudes related to the relaxation process after the quench are studied. In particular, we see a dramatic effect in the survival probability for the critical quench that drives the system from the initial ground state to the critical ESQPT.

In spite of the differences observed in integrable and non-integrable models, we believe that relaxation dynamics offers clear signals of an ESQPT in the Dicke and related models whose character deserves more studies.

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