An Introduction to Macroscopic Quantum Phenomena and Quantum Dissipation

Langevin Equation for a Dissipative Macroscopic Quantum System: Bohmian Theory versus Quantum Mechanics

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In this study, we solve analytically the Schrodinger equation for a macroscopic quantum oscillator as a central system coupled to a large number of environmental micro-oscillating particles. Then, the Langevin equation is obtained for the system using two approaches: Quantum Mechanics and Bohmian Theory. Our results show that the predictions of the two theories are inherently different in real conditions. Nevertheless, the Langevin equation obtained by Bohmian approach could be reduced to the quantum one, when the vibrational frequency of the central system is high enough compared to the maximum frequency of the environmental particles.

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INTRODUCTION

In recent years, dissipative quantum systems have been studied broadly as a new research field in physics. The study of open quantum systems has recieved great attention due to the importance of environmental effects in description of seminal phenomena such as quantum decoherence, quantum information, quantum tunneling in physical and biological systems, etc. [1, 2].

Moreover, the investigation of dissipative behavior of macroscopic quantum systems (MQSs), pioneered by Caldeira and Leggett [3], is an attractive topic in the field. MQSs are usually considered as a bridge between the quantum and the classical systems (see, e.g., [4–7]). It is commonly believed that *macroscopic*, here, refers to those situations where a large number of particles are involved. More precisely, it holds when dynamical degrees of freedom for the system is large [8].

A dissipative quantum system, independent of its macro or micro aspect, is often considered as a system coupled to a large number of harmonic oscillators, modeled as a heat bath. The entire system which consists of one particle plus a thermal reservoir allows us to study the origin of irreversibility in a dynamic approach. In this connection, the common representation of the energy fluctuations and the dissipative effects caused by interaction of the system with its environment is analytically discussed by the quantum Langevin equation [9].

In a general way, the quantum Langevin equation is nothing but the Heisenberg equation of motion for a macroscopic quantum particle interacting with the environment. The environment could be considered to exert a fluctuating force on the system. The force depends on the motion of the system and could be experienced by the system at rest even for small displacements. Eliminating the environment's variables in the equation of motion of the central system, one reaches a reduced equation which, besides the system's degrees of freedom, involves additional variables describing the fluctuation effects of the environment, usually known as a noise function. This shows that the system exchanges energy with its surrounding. In other words, it is the signature of dissipation [10, 11].

Many works have been done to describe the dissipative quantum systems by using the quantum Langevin equation in a coherent way. In 1965, Mori derived a generalized Langevin equation for the quantum mechanical operators from the Heisenberg equation of motion, using a projection operator defined in Liouville space [12]. Kostin also derived the quantum Langevin equation for a Brownian particle interacting with a thermal bath [13]. In this approach, a dissipative as well as a random potential are both together incorporated in the time-dependent Schrodinger equation, responsible for the thermal and the statistical influences of the environment, respectively. In the particular case of the quantum Langevin equation, Caldeira and Leggett used the path integral method to study the dissipative quantum tunneling [14]. In this approach, a quantum noise function is introduced to show the environmental thermal fluctuations by which the system is affected. This equation can be reformulated in a Hamiltonian-based model, in which the noise arises from a collection of harmonic oscillators coupled to the system. Similarly, in a series of publications, Ford and others obtained various forms of the quantum Langevin equation for a quantum particle coupled to a heat bath [15–17].

Along these efforts, however, Bohmian mechanics has not been widely used yet, within the studies of the dissipative quantum systems. In this regard, the first study was carried out about 22 years ago by Vandyck, who investigated the decay of the harmonic oscillator eigenstates, lossing the energy [18]. Also, Tilbi and others used Bohmian mechanics

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