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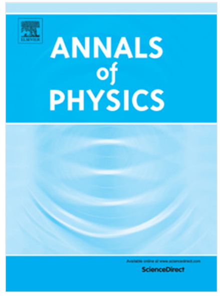

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Dissipative tunnelling by means of scaled trajectories

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Dissipative quantum tunnelling through an inverted parabolic barrier is considered in the presence of an electric field. A Schrödinger-Langevin or Kostin quantum-classical transition wave equation is used and applied resulting in a scaled differential equation of motion. A Gaussian wave packet solution to the resulting scaled Kostin nonlinear equation is assumed and compared to the same solution for the scaled linear Caldirola-Kanai equation. The resulting scaled trajectories are obtained at different dynamical regimes and friction cases, showing the gradual decoherence process in this open dynamics. Theoretical results show that the transmission probabilities are always higher in the Kostin approach than in the Caldirola-Kanai approach in the presence or not of an external electric field. This discrepancy should be understood due to the presence of an environment since the corresponding open dynamics should be governed by nonlinear quantum equations, whereas the second approach is issued from an effective Hamiltonian within a linear theory.

I. INTRODUCTION

Dissipative tunnelling in the presence or not of an electric field has many applications in transport properties, reactive scattering, quantum optics, molecular biology, etc. One of the main goals is to analyze the gradual decoherence process existing in this particular dynamics by using very different theoretical methods within the density matrix, path-integral and Langevin formalisms [1, 2]. A new alternative way which is by far much less used is the Bohmian formalism [3] where the decoherence process is described in terms of trajectories leading, in our opinion, to a more intutitive way of understanding it. In this sense, dealing with analytically solvable models is very useful in order to gain new insights.

By considering dissipation from a phenomenological way, the tunnelling dynamics by an inverted parabollic barrier is very convenient because it provides all the main ingredients to tackle with success such an endeavour as well as to compare with existing results coming from different theoretical treatments. In particular, comparison with the works by Baskoutas and Jannussis [4] and Papadopoulos [5]. Our purpose is to analyze two different approaches to this dissipative dynamics, the nonlinear, logarithmic Schrödinger-Langevin (or Kostin) equation [6] and the linear Schrödinger equation coming from the so-called Cardirola-Kanai Hamiltonian [7–10] within the Bohmian formalism [11–13]. Recently, Tokieda and Hagino [14] have considered the same approaches to study dissipative tunneling without the presence of an electrical field by solving directly the corresponding wave equations. The gradual decoherence process is better studied by using the so-called quantum-classical transition wave equation, originally proposed by Richardson et al. [15] in the context of conservative systems. This quantum-classical transition is governed by a continuous parameter covering these two regimes as being the two extreme cases. Recently, Chou has applied this wave equation to analyze wave-packet interference [16] and the dynamics of the harmonic and Morse oscillators with complex trajectories [17]. Here, we have extended this procedure to dissipative quantum dynamics. Doing this, we have a wave equation even in the classical regime and the Born rule is assumed in this regime too. Then, by considering the *actual momentum* [11] distribution function of particles in the classical ensemble, we have a strict answer to the question of classical phase space distribution function which is problematic otherwise [18]. The resulting trajectories have been called *scaled trajectories* [10] since a scaled Planck's constant in terms of that parameter is used. Furthermore, by assuming a time-dependent Gaussian ansatz for the probability density, theses scaled trajectories are written as a sum of a classical trajectory (a particle property) plus a term containing the width of the corresponding wave packet (a wave property) within of what has been called *dressing scheme* [3]. In the quantum regime, the corresponding trajectories are the well-known quantum trajectories due to Bohm which display the noncrossing property which, in general, is no longer valid in the classical regime but it is kept in the transtion regime. However, in this work, this property is still valid in the classical regime by construction of the transition wave equation itself. This new aspect together with the Born rule for the distribution of particles' position in the classical ensemble lead us to have a good criterium for tunnelling.

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