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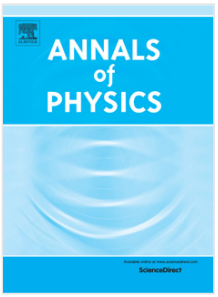

Steady quantum coherence in non-equilibrium environment

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Steady quantum coherence in non-equilibrium environment

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Abstract

We study the steady state of a three-level system in contact with a non-equilibrium environment, which is composed of two independent heat baths at different temperatures. We derive a master equation to describe the non-equilibrium process of the system. For the three level systems with two dipole transitions, i.e., the Λ-type and V-type, we find that the interferences of two transitions in a non-equilibrium environment can give rise to non-vanishing steady quantum coherence, namely, there exist non-zero off-diagonal terms in the steady state density matrix (in the energy representation). Moreover, the non-vanishing off-diagonal terms increase with the temperature difference of the two heat baths. Such interferences of the transitions were usually omitted by secular approximation, for it was usually believed that they only take effect in short time behavior and do not affect the steady state. Here we show that, in non-equilibrium systems, such omission would lead to the neglect of the steady quantum coherence.

Keywords: Non-equilibrium thermodynamics, quantum coherence, decoherence
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1. Introduction

Isolated quantum systems evolve unitarily according to the Schrödinger equation, while an open quantum system, which is inevitably coupled to a heat bath in practical, usually quickly lose all its quantum coherence. That is, all the off-diagonal terms of the density matrix of the system $\langle E_m|\rho|E_n\rangle$ (in the energy representation) will decay to zero when the open system approaches the steady state [1–4]. This phenomenon is called decoherence, and it is also believed that this is why our world appears as a classical one and no macroscopic superposition can exist stably in usual cases [5]. It has been reported that if some non-vanishing steady quantum coherence exists in certain special environment, even with a quite small amount, it can result to some novel physics, such as lasing without inversion [6], or extracting work from a single heat bath [3, 7, 8].

Then an important question arises: how can quantum coherence survive stably in the steady state against decoherence [3]? In this paper, we find that the steady quantum coherence can indeed exist stably when the system contacts with a non-equilibrium environment, which is composed of multiple equilibrium heat baths at different temperatures. Here we study the steady state of a three-level system, which is coupled to two heat baths with temperatures $T_{L/R}$ respectively (Fig. 1). We find that, for the Λ-type and V-type systems, non-vanishing quantum coherence can exist in the steady state when the temperatures of the two heat baths are different. Moreover, the amount of the nonzero off-diagonal terms increase with the temperature difference ΔT of the two heat baths. While the quantum coherence always vanishes in a Ξ-type system. Here we must emphasize that, unlike previous studies [7, 8], in our model there is no quantum coherence in the environment in priori, and the steady quantum coherence in the system is naturally brought in by the non-equilibrium environment.

Physically, this steady quantum coherence results from the interference of transitions in non-equilibrium systems. In the three kinds of three-level systems we study, there are two transition