Simulation of a Quantum Jump in Three-Level Systems Using Photonic Gaussian Modes

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Quantum systems are most of the time subjected to uncontrolled interactions with an external quantum system and/or to its surrounds. The system interactions with the environment cannot be described by unitary operations acting on the system and lead to dissipation and decoherence, consequently to degradation in quantum protocols. Different uncontrolled interactions that affect the coherence of the quantum system state or entanglement in bipartite or multipartite state systems have been simulated aquatically, more specifically, dephasing, amplitude damping and Pauli noise. Another important source of noise is the fundamental process called quantum jump, where a quantum system evolves stochastically in an abrupt unpredictable operation. Quantum jump is an essential topic in the interpretation of quantum dynamics and has been part of the historical debates about quantum mechanics fundamentals.

The transverse profile of optical beams at the photon count scenario has been a rich platform for preparing discrete quantum states and for investigating quantum information theories and protocols. Some useful optical systems make use of the photon transverse momentum, which can be discretized by slits or in different photon paths with the aid of interferometers for preparing one-, two- or four-photon quantum states in slits modes or Gaussian modes. The use of the spatial light modulator (SLM) in these optical systems allows the photon state to be manipulated in different ways and can be used to implement a wide range of quantum operations.

We simulate experimentally a decaying dynamics of a three-level system by preparing a photonic qutrit path state and letting the photon beam in the qutrit state be modified by periodical phase modulation produced by an SLM [1]. The spontaneous decay dynamics of a three-level atomic system is implemented in different configurations: cascade decay, Lambda decay and V decay. An excited atomic system may undergo spontaneous decay through the interaction with the vacuum state of the electromagnetic field. This kind of system typically experiences a time-dependent exponential decay, in which the probability of an excited state i decaying to j is related to the spontaneous decay rate between levels i and j. This process causes a reduction in the population of the excited state and also decoherence. We simulate the three-level state dynamics by using a photonic qutrit path state for representing the three-level system. The qutrit state is prepared initially by generating a photon superposition state of three-path Gaussian modes. The photon state preparation is realized by using a laser beam, attenuated to the single-photon regime. Programming a temporal sequence of phase spatial gratings, an SLM diffracts the Gaussian modes and implements Kraus operators that describe the three-level decay dynamics. Therefore, the SLM is responsible for implementing generalized quantum operations on the initial three-level photonic quantum state. An intensified charged-coupled device (ICCD) camera records the photon counts. The experimental characterizations of the density matrix for the output state are in agreement with the theoretical predictions despite a small deviation. With a precise periodical phase modulation of the photonic paths, we are able to implement a large number of operations and simulate the different dynamics of decay in a three-level system. This simulation gives us a better comprehension of how quantum jump affects the coherence of a three-level system.

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References

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