Annals of Physics 388 (2018) 162–172

Contents lists available at ScienceDirect

Annals of Physics

journal homepage: www.elsevier.com/locate/aop

Generation of one-way Einstein–Podolsky–Rosen steering using interference-controlled asymmetric dissipation process

Fei Wang [a,d,*], Jun Xu [b], Guang-Ling Cheng [c], C.H. Oh [d]

[a] College of Science, China Three Gorges University, Yichang, 443002, China
[b] College of Physical Science and Technology, Central China Normal University, Wuhan, 430079, China
[c] Department of Applied Physics, East China Jiaotong University, Nanchang, 330013, China
[d] Centre for Quantum Technologies and Department of Physics, National University of Singapore, 3 Science Drive 2, 117543, Singapore

A R T I C L E I N F O

Article history:
Received 25 July 2017
Accepted 5 November 2017
Available online 11 November 2017

Keywords:
Einstein–Podolsky–Rosen steering
Quantum entanglement
Quantum interference
Dissipation

A B S T R A C T

We show that one-way Einstein–Podolsky–Rosen (EPR) steering effects can be generated via the asymmetric dissipation scheme induced by the spontaneously generated coherence (SGC) in a resonantly driven V-type atomic system. According to the dressed atomic states and Bogoliubov transformation, we find that there exist two identical dissipation channels being responsible for the appearance of entanglement and symmetric two-way steering effects in the absence of SGC effect. More interestingly, the one-way EPR steering effect occurs when the population differences between the dressed states are prominently modified by the SGC effect. As a consequence, the symmetry of the two dissipation channels is broken by the quantum interference, leading to the generation of one-way EPR steering effect.

1. Introduction

As is well known, quantum entanglement has been regarded as one of the most important nonclassical correlations and entangled states correspond to inseparable states being key resources for quantum teleportation [1,2], quantum dense [3] and universal quantum computation [4]. The

* Corresponding author.
E-mail addresses: feiwang@ctgu.edu.cn (F. Wang), phyohch@nus.edu.sg (C.H. Oh).

https://doi.org/10.1016/j.aop.2017.11.011
0003-4916/

Einstein–Podolsky–Rosen (EPR) steering, which is first introduced by Schrödinger in 1935 [5] in response to the famous EPR paradox [6], is a special type of quantum correlation intermediate between quantum entanglement and Bell nonlocality. Physically, the steering refers to the phenomenon where one observer can perform local measurements to remotely control the state of the other. Whether the states exhibit steering could be effectively deduced based on the violation of the quadrature inequalities defined by Reid in her EPR work in light of the Heisenberg uncertainty principle [7]. If the two inequalities are violated simultaneously, the symmetric steering named as two-way EPR steering would happen. In the case of two-way steering, the roles of the two observers are interchangeable and it is usually unimportant. Nevertheless, the asymmetric one-way steering, wherein one observer can steer the state of the other but not vice versa, is of more interest because it reflects the asymmetry of quantum correlation. This indicates that the steering is different from quantum entanglement.

In past years, continuous variable (CV) entanglement has been paid special attention owing to its relative simplicity and high efficiency in generation, manipulation, and detection [8]. The classical schemes to prepare CV entanglement include parametric interaction process [9,10], multi-wave mixing [11–13], coherence-controlled two-photon process [14–16] and atomic reservoir [17] etc. On the other hand, Reid's pioneering work demonstrated that the phenomena of steering was also applicable to the continuous-variable system [7]. The experimental implementation of EPR paradox was first performed by Ou et al. using nondegenerate parametric amplification [18]. Recently, rapid progress has been made and much attention has been paid on EPR steering in experiment and theory [19–31]. Particularly, the criteria to classify the entanglement, EPR steering and Bell-nonlocality were proposed not only in bipartite system but also extended to multipartite cases in different physical systems [32]. Based on the effective criteria, a pulse scheme was suggested to obtain EPR steering between two distant micromechanical oscillators [24]. However, the steering only exists in a transient regime and is strongly dependent on the initial conditions. Furthermore, Tan et al. showed the generation of steady state one-way Gaussian steering effect of two electromagnetic fields mediated by a mechanical oscillator [33]. Subsequently, they proposed the hybrid EPR steering effect in an atom-optomechanical system, in which the atomic ensemble was prepared into ground state under large detuning conditions [34].

Note that the dissipation scheme is a promising idea to produce steady state entanglement under adiabatic evolution conditions [17,35,36]. The merits of this scheme mainly lie in the fact that it does not require the initial preparation and is applicable to the resonant and non-resonant coupling cases. Also, the quantum correlations arising from dissipation, in principle, can exist for a long enough time. In the dressed-state representation, we find that the quantum interference (QI) created dynamically by the strong driving field plays an important role in modifying the dressed-state population difference, which essentially determines the absorption and amplification process. Besides, it is interesting that the QI between the spontaneous emission can be used to generate and control the quantum entanglement [37,38]. Generally, the spontaneously generated coherence (SGC) originates from the atomic system consisting of nearly degenerate levels with non-orthogonal dipole moments [39]. It has been shown that the entanglement is either created or enhanced by the SGC effect.

Here we investigate the generation of one-way EPR steering effects in a resonantly driven V-type atomic system, in which a pair of cavity modes are coupled to the same atomic transition. Different from the off-resonant coupling cases, the population differences of the dressed states are controllable by adjusting the relative intensity of the driving fields. Based on dressed-atom approach and Bogoliubov modes transformation, two-channel interaction is obtainable under proper conditions. The two channels are always equivalent to each other in the absence of SGC effect and then the symmetric two-way EPR steering effect appears. It is noted that the symmetric dissipation processes would be broken when the SGC effect is introduced. This leads to the fact that the entanglement between the two modes is reduced, which is different from the results reported in Refs. [37,38]. Interestingly, the asymmetric dissipation gives rise to asymmetric one-way EPR steering effect in this case. Specifically, when the two dipoles are nearly parallel, one of the cavity modes is steerable to the other but not vice versa; while it is reversed when they are antiparallel. In essence, the coherence fields are used to establish dissipative atomic reservoir while the SGC effect breaks the symmetry of the two dissipation channels, resulting in the occurrence of one-way EPR steering effect.