Annals of Physics 373 (2016) 655–664

Contents lists available at ScienceDirect

Annals of Physics

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

Quantum correlations in non-inertial cavity systems

Zeynab Harsij *, Behrouz Mirza

Department of Physics, Isfahan University of Technology, Isfahan 84156-83111, Iran

HIGHLIGHTS

- Non-inertial cavities are utilized to store and send information in Quantum Information Theory.
- Cavities include boundary conditions which will protect the entanglement once it has been created.
- The problem is treated perturbatively and the maclaurian series are applied to expand the related Bogoliubov coefficients.
- When two cavities are considered degradation in the degree of quantum correlation happens and it appears periodically.
- The interesting issue is when a single cavity is studied and the degradation in quantum correlations disappears.

ARTICLE INFO

Article history:
Received 16 February 2016
Accepted 13 July 2016
Available online 21 July 2016

Keywords:
Quantum entanglement
Quantum discord
Non-inertial cavity system

ABSTRACT

Non-inertial cavities are utilized to store and send Quantum Information between mode pairs. A two-cavity system is considered where one is inertial and the other accelerated in a finite time. Maclaurian series are applied to expand the related Bogoliubov coefficients and the problem is treated perturbatively. It is shown that Quantum Discord, which is a measure of quantumness of correlations, is degraded periodically. This is almost in agreement with previous results reached in accelerated systems where increment of acceleration decreases the degree of quantum correlations. As another finding of the study, it is explicitly shown that degradation of Quantum Discord disappears when the state is in a single cavity which is accelerated for a finite time. This feature makes accelerating cavities useful instruments in Quantum Information Theory.

* Corresponding author.
E-mail addresses: z.harsij@ph.iut.ac.ir (Z. Harsij), b.mirza@cc.iut.ac.ir (B. Mirza).

http://dx.doi.org/10.1016/j.aop.2016.07.016

1. Introduction

Quantum Information has received a lot of attention over the past decade [1]. This is partly because nature is known to be both quantum and relativistic, which underlies the recent interest in the development of Relativistic Quantum Information Theory [2,3]. Quantum Entanglement is one of the essential measures in the study of most quantum information systems [4]. As Quantum Entanglement did not properly span all non-classical correlations, Henderson and Vedral [5] and Olivier and Zurek [6] independently introduced a new measure called Quantum Discord, which has been quantitatively investigated recently [7,8]. A fundamental problem in the emerging field of relativistic quantum information is that the quantum degree of correlations is degraded because of the accelerated motion [2]. One main goal of the theory of information is to find appropriate methods and proper systems that are adequately capable of storing and processing information that can be shared between observers in arbitrary motion [9]. A common way to implement quantum information tasks involves storing information in cavity field modes. Alsing and Milburn [10] first introduced the idea of using moving cavities to store quantum information. Because of their structure, cavities include boundary conditions which affect fields inside cavities. When such boundary conditions are properly taken into account, it becomes clear that the cavity walls protect the entanglement once it has been created [11]. Studies have shown how the degree of Quantum Entanglement changes when accelerated cavity is considered as a non-inertial frame [12,13]. A discrete, bosonic spectrum is obtained, as an example, by confining a scalar quantum field to a cavity by appropriate Dirichlet boundary conditions in $(1+1)$ dimensions. The rigid cavity can follow a worldline that is composed of segments of inertial motion and uniform acceleration [12]. This nonuniform motion generates non-trivial Bogoliubov coefficients, which leads to the generation of an entanglement between the modes inside a cavity [13] and, consequently, lead to the degradation of the initial entanglement between modes in different cavities [12]. In this paper, Quantum Discord is studied as a measure of quantum correlation to investigate the way the degree of quantum correlations change.

The rest of the paper is organized as follows: Section 2 briefly introduces the systems in question including cavities and how they work while one or more are accelerated. In Section 3, a two-cavity system is investigated in which one is considered as an inertial observer and the other is accelerating. In this same section, we also study the behavior of initially-entangled quantum correlations. In the next section, a single cavity is considered and Quantum Discord is computed in such a system. Finally, Section 5 presents the conclusion and results.

2. Moving cavities in non-inertial frames

An open question in the field of relativistic quantum information is how parties in arbitrary motion may distribute and store information. Here, we propose a scheme to store quantum information in the field modes of moving cavities and analyze it in a quantum field theoretical framework [11]. We consider two observers called Alice, stationary in Minkowski coordinates (t, x), and Rob as the accelerating observer, each holding a cavity. Alice will encode quantum information in a massless scalar field contained within the cavity's walls which are described by two mirrors, one at x_1 and the other at x_2 with $|x_2 - x_1| = L$, where L is the cavity length. The dynamics of the field inside the cavity is given by the Klein–Gordon equation, $g_{\mu\nu}\nabla^{\mu}\nabla^{\nu}\phi = 0$, where $g_{\mu\nu}$ defines the metric tensor and ∇ defines the covariant derivative. The perfectly reflecting mirrors impose Dirichlet boundary conditions on the field. This bounds the field to vanish on the boundary and gives the solutions to the Klein–Gordon equation by plane waves:

$$u_n(t,x) = \frac{1}{\pi n} \sin\left(\frac{n\pi}{L}[x_2 - x_1]\right) e^{-\frac{in\pi}{L}t}$$

and the quantum field contained within the cavity walls is defined as

$$\phi_A(t,x) = \sum_n (u_n(t,x)\widehat{a}_n + u_n^*(t,x)\widehat{a}_n^{\dagger}),$$