Annals of Physics 373 (2016) 273–285

Contents lists available at ScienceDirect

Annals of Physics

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

Two-dimensional quantum ring in a graphene layer in the presence of a Aharonov–Bohm flux

José Amaro Neto, M.J. Bueno, Claudio Furtado *

Departamento de Física, Universidade Federal da Paraíba, Caixa Postal 5008, 58051-970, João Pessoa, PB, Brazil

ARTICLE INFO

Article history:
Received 14 April 2016
Accepted 14 July 2016
Available online 22 July 2016

Keywords:
Topological Defect
Dirac oscillator
Graphene
Quantum ring

ABSTRACT

In this paper we study the relativistic quantum dynamics of a massless fermion confined in a quantum ring. We use a model of confining potential and introduce the interaction via Dirac oscillator coupling, which provides ring confinement for massless Dirac fermions. The energy levels and corresponding eigenfunctions for this model in graphene layer in the presence of Aharonov–Bohm flux in the centre of the ring and the expression for persistent current in this model are derived. We also investigate the model for quantum ring in graphene layer in the presence of a disclination and a magnetic flux. The energy spectrum and wave function are obtained exactly for this case. We see that the persistent current depends on parameters characterizing the topological defect.

1. Introduction

With the experimental obtaining of graphene [1], several interesting physical phenomena were observed in this material, such as: anomalous Hall effect [2], Klein paradox [3–5], spin qubits [6], Moiré potential [7], etc. Experiments involving the study of quantum dots in graphene in the presence of magnetic field were performed [8,9], in which the energy spectrum in this system was observed. Theoretical models of quasiparticles confined in quantum dots [10,11] and rings [12–14] in graphene have been recently proposed. In a mesoscopic electronic system, it is well known that when one varies the magnetic flux passing through the centre of device of a ring topology, a persistent current arises

* Corresponding author.
E-mail address: furtado@fisica.ufpb.br (C. Furtado).

http://dx.doi.org/10.1016/j.aop.2016.07.023

due to the Aharonov–Bohm effect [15]. This quantum coherence plays a central role in mesoscopic physics. From the theoretical point of view the persistent current has been investigated recently theoretically in Refs. [16–21] and experimentally in [22].

The Dirac oscillator [23] is introduced as the relativistic version of the harmonic oscillator due to the fact that this coupling produces in the non-relativistic limit a harmonic oscillator with a strong spin–orbit coupling. The Dirac oscillator coupling is introduced via the following replacement in Dirac equation: $p \rightarrow p - iM\omega\widehat{\beta\vec{x}}$, where M is a mass of the particle, and ω is the frequency of the oscillator. The Dirac oscillator has been investigated in several areas of physics: in the study of the hidden supersymmetry by Benitez et al. [24]; within the analogy with the Jaynes–Cummings model which was demonstrated by Rozmej and Arvieu [25]; in the presence of topological defects [26]. Additionally, Bermudez et al. [27] have studied the Ramsey interferometric effect in non-relativistic limit of the Dirac oscillator. Recently, applications of Dirac oscillator have been carried out in graphene by Quimbay and Strange [28], in studies of quantum dots by Belouad et al. [29] performed with use of the confining models proposed in Refs. [30,31]. Thermal properties of the Dirac oscillator have been investigated by Boumali and Hassanabadi [32]. Recently, the Dirac oscillator was observed experimentally in microwave physics [33]. The quantum dot in graphene in the presence **of a** topological defect was studied by Bueno et al. [34], and spectrum of energy and the current persistent are obtained. In Ref. [34] the confinement potential was coupled in Dirac equation in the way similar to Dirac oscillator [23]. In Ref. [35], the Landau levels in a graphene layer with the presence of disclination was investigated.

In this paper we investigate the quantum ring in a graphene layer. We use the model of confining potential proposed in Ref. [36], this model is a relativistic version of the Tan–Inkson model for the confining potential in two-dimensional space [16]. We investigate, in low energy limit, the system described by a massless Dirac equation, where a continuous description near Fermi K-points is employed. We use the Dirac oscillator type coupling to confine harmonically the quasiparticles in quantum ring pierced by Aharonov–Bohm flux in a graphene layer. We also study the influence of a disclination in two-dimensional quantum ring of nanometric size in the presence of Aharonov–Bohm quantum flux. From the Landau levels in graphene layer it is possible to obtain the magnitude of magnetic length $\ell_b = \sqrt{\hbar/eB} \approx 50$ nm. This fact demonstrates the relevance of studying the physical influence of **a** disclination in this quantum ring, keeping in mind that the average size of one topological defect of this kind is of the order of interatomic distances for the carbon atoms in this structure. In both cases, we obtain the eigenvalues and eigenfunctions of energy and persistent current. In the case of dynamics in the presence of defects, we demonstrate the dependence of these physical quantities on the parameter characterizing the disclination, thus demonstrating the influence of the defect in the dynamics in a quantum ring.

This paper is organized as follows: in Section 2, we present the confining model and the corresponding coupling in Dirac equation. In Section 3, we analyse the quantum dynamics of massless Dirac fermions in a quantum ring in graphene layer, and obtain the exact energy spectrum and eigenfunctions for the model where a thin Aharonov–Bohm flux confined to the centre of the ring is introduced, and the persistent current is obtained in this case. In Section 4, we obtain the eigenvalues and eigenfunctions for quantum dynamics of massless Dirac fermions in a quantum ring in the presence of a disclination, and study the influence of topological defect is investigated and the persistent current, and finally, in Section 5 we present the concluding remarks.

2. The ring confinement model

In this section we present the potential used to confine the quasiparticle in a ring-like topology in graphene layer. Recently in Ref. [36] the authors proposed an extension to relativistic case of Tan–Inkson model [16], which has been constructed to model quantum rings within non-relativistic dynamics of electrons and holes. In this relativistic model of confinement the authors [36] also used two control parameters to obtain a harmonic confinement in a two-dimensional ring, and the quantum point limits are obtained when we make one of the parameters to be zero, $a_1 = 0$. In this relativistic model the confining potential is introduced via coupling of the momentum of a quasiparticle in a manner similar to Dirac oscillator [23]. In the non-relativistic limit, the Tan–Inkson