Annals of Physics 360 (2015) 596–604

Contents lists available at ScienceDirect

Annals of Physics

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

On a relativistic scalar particle subject to a Coulomb-type potential given by Lorentz symmetry breaking effects

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ARTICLE INFO

Article history:
Received 24 February 2015
Accepted 26 May 2015
Available online 1 June 2015

Keywords:
Lorentz symmetry violation
Klein–Gordon equation
Coulomb-type potential
Linear confining potential
Relativistic bound states
Biconfluent Heun function

ABSTRACT

The behaviour of a relativistic scalar particle in a possible scenario that arises from the violation of the Lorentz symmetry is investigated. The background of the Lorentz symmetry violation is defined by a tensor field that governs the Lorentz symmetry violation out of the Standard Model Extension. Thereby, we show that a Coulomb-type potential can be induced by Lorentz symmetry breaking effects and bound states solutions to the Klein–Gordon equation can be obtained. Further, we discuss the effects of this Coulomb-type potential on the confinement of the relativistic scalar particle to a linear confining potential by showing that bound states solutions to the Klein–Gordon equation can also be achieved, and obtain a quantum effect characterized by the dependence of a parameter of the linear confining potential on the quantum numbers $\{n, l\}$ of the system.

1. Introduction

The Higgs particle, a cornerstone of the standard model finally has been detected. This fact closes a cycle of research that has initiated in the beginning of the twentieth century and it closes a scenario

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http://dx.doi.org/10.1016/j.aop.2015.05.025

of forecasts that have a great experimental success. Despite this relevant fact, there is a lack of a more fundamental theory that covers the description of neutrinos without mass and can also explain the microscopic origin of the boson which generates the mass of all the particles of the universe. Another intriguing point of discussion in the area of particle physics is the origin of electron electric dipole moment which has not been explained by the Standard Model of particle physics yet. At present days, it is well-known that just experimental upper bounds have been established [1]. Based on the Standard Model, an upper limit for electron electric dipole moment has been established as $d_e \leq 10^{-38}$ e cm [1]. On the other hand, experiments measured an upper limit given by $d_e \leq 10^{-29}$ e cm by using a polar molecule thorium monoxide (ThO) [2]. This experimental result has shown us a necessity of investigating the physics beyond the Standard Model because the term associated with the electric dipole moment violates the CP symmetry.

A possible way of dealing with a scenario beyond the Standard Model is the extension of the mechanism for the spontaneous symmetry breaking through vector or tensor fields, which implies that the Lorentz symmetry is violated. This scenario has been established after the seminal work made by Kostelecký and Samuel [3] in the string theory. It is shown that the Lorentz symmetry is violated through a spontaneous symmetry breaking mechanism triggered by the appearance of nonvanishing vacuum expectation values of nontrivial Lorentz tensors. Such models that deal with the physics beyond the Standard Model are considered as effective theories, whose analysis of the phenomenological aspect at low energies can provide information and impose restrictions on the fundamental theory in which they stem from. A general framework for testing the low-energy manifestations of the CPT symmetry and the Lorentz symmetry breaking is known as the Standard Model Extension (SME) [4]. In this framework, the effective Lagrangian operator corresponds to the usual Lagrangian operator of the Standard Model to which is added to the Standard Model operators a Lorentz violation tensor background. The effective Lagrangian is written as being an invariant under the Lorentz transformation of coordinates in order to guarantee that the observer independence of physics. However, the physically relevant transformations are those that affect only the dynamical fields of the theory. These changes are called as particle transformations, whereas the coordinate transformations (including the tensor background) are called as the observer transformations. In Refs. [5–7], one can find a deep analysis of these concepts. Concerning the experimental searches for the CPT/Lorentz-violation signals, the generality of the SME has provided the basis for many investigations. In the flat spacetime limit, empirical studies include muons [8], mesons [9,10], baryons [11,12], photons [13,14], electrons [15], neutrinos [16] and the Higgs sector [17]. The gravity sector has also been explored in Refs. [18–20]. In Ref. [21], one can find the current limits on the coefficients of the Lorentz symmetry violation. In recent years, Lorentz symmetry breaking effects have been investigated in the hydrogen atom [22], in Weyl semi-metals [23], on the Rashba coupling [24,25], in the quantum Hall effect [26], in tensor backgrounds [27,28] and geometric quantum phases [29–33].

In this paper, we study a relativistic scalar particle in a possible scenario of anisotropy generated by a Lorentz symmetry breaking term defined by a tensor $(K_F)_{\mu\nu\alpha\beta}$ that corresponds to a tensor that governs the Lorentz symmetry violation out of the Standard Model Extension. We investigate the effects of a Coulomb-type potential induced by a Lorentz symmetry violation background on a relativistic scalar particle by showing that bound states solutions to the Klein–Gordon equation can be obtained in a particular scenario of the Lorentz symmetry violation. Further, we investigate the effects of a Coulomb-type potential induced by a Lorentz symmetry violation background on the confinement of the relativistic scalar particle to a linear confining potential and obtain a quantum effect characterized by the dependence of parameter η of the linear confining potential on the quantum numbers $\{n, l\}$ of the system, whose meaning is that not all values of the parameter η are allowed in order to obtain the bound states solutions to the Klein–Gordon equation.

The structure of this paper is as follows: in Section 2, we introduce a background of the Lorentz symmetry violation defined by a tensor $(K_F)_{\mu\nu\alpha\beta}$ that governs the Lorentz symmetry violation out of the Standard Model Extension; thus, we establish a possible scenario of the Lorentz symmetry violation that gives rise to a Coulomb-type potential and solve the Klein–Gordon equation; in Section 3, we confine the relativistic scalar particle to a linear scalar potential, and discuss the effects of the Coulomb-type potential that stems from Lorentz symmetry breaking effects on this confinement; in Section 4, we present our conclusions.