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Relativistic New Yukawa-Like Potential and Tensor Coupling

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Abstract We approximately solve the Dirac equation for a new suggested generalized inversely quadratic Yukawa potential including a Coulomb-like tensor interaction with arbitrary spin-orbit coupling quantum number κ. In the framework of the spin and pseudospin (p-spin) symmetry, we obtain the energy eigenvalue equation and the corresponding eigenfunctions, in closed form, by using the parametric Nikiforov–Uvarov method. The numerical results show that the Coulomb-like tensor interaction, $-T/r$, removes degeneracies between spin and p-spin state doublets. The Dirac solutions in the presence of exact spin symmetry are reduced to Schrödinger solutions for Yukawa and inversely quadratic Yukawa potentials.

1 Introduction

Relativistic symmetries of the Dirac Hamiltonian had been discovered many years ago. However, these symmetries have been recently recognized empirically in nuclear and hadronic spectroscopies [1]. Within the framework of Dirac equation, the p-spin symmetry used to feature deformed nuclei and the superdeformation to establish an effective shell-model [2–4]. The spin symmetry is relevant to mesons [5] and occurs when the difference of the scalar $S(r)$ and vector $V(r)$ potentials are constant, i.e., $\Delta(r) = C_s$ and the p-spin symmetry occurs when the sum of the scalar and vector potentials are constant, i.e., $\Sigma(r) = C_{ps}$ [6,7]. The p-spin symmetry refers to a quasi-degeneracy of single nucleon doublets with non-relativistic quantum number $(n, l, j = l + 1/2)$ and $(n-1, l+2, j = l + 3/2)$, where n, l and j denote the single nucleon radial, orbital and total angular quantum numbers, respectively [8,9]. Further, the total angular momentum is $j = \tilde{l} + \tilde{s}$, where $\tilde{l} = l + 1$ pseudo-angular momentum and $\tilde{s}$ is p-spin angular momentum [10]. Recently, the tensor potentials were introduced into the Dirac equation with the substitution $\vec{p} \to \vec{p} - im\omega\beta.\hat{r}U(r)$ and a spin-orbit coupling is added to the Dirac Hamiltonian [11,12]. Lisboa et al. [13] have studied a generalized relativistic harmonic oscillator for spin-1/2 particles by considering a Dirac Hamiltonian that contains quadratic vector and scalar potentials together with a linear tensor potential under the conditions of p-spin and spin symmetry. Alberto et al. [14] studied the contribution of the isoscalar tensor coupling to the realization of p-spin symmetry in nuclei. Akçay [15] solved exactly the Dirac equation with scalar and vector quadratic potentials including a Coulomb-like tensor potential. He also solved exactly the Dirac equation for a linear and Coulomb-like term containing the tensor potential too [16]. Aydoğdu and Sever [17] obtained exact solution of the Dirac equation for the pseudoharmonic potential in the presence of linear tensor potential under the p-spin symmetry and showed

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