Mass spectra and decay widths of strangeonium using Non Relativistic CPP$_\nu$ Potential.

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Introduction

In the present study, the important features of theoretical work on light-light quarkonia (strangeonium) is done in the nonrelativistic formalism. The quark-antiquark interaction potential is assumed to be the coulomb plus power potential expressed with a power exponent. The generated trial wavefunction adopted by variational technique is used to calculate the variational parameter which is used to calculate spin average mas, vector mass, pseudoscalar mass corresponding to each potential index 'ν' at each wavefunction index 'p' such that the wavefunction varies from hydrogenic (p=1) to harmonic (p=1) type. Square of the wavefunction at the origin $|R_{n,l}(0)|^2$ is used as an important parameter to calculate the leptonic decay width and digamma decay width.

Mass spectra and Decay widths

In the study of light-light bound state system, we consider a non-relativistic hamiltonian given by,

$$H = \frac{-1}{2m}\left(\frac{d^2}{dr^2} + \frac{2}{r}\frac{d}{dr} - \frac{l(l+1)}{r^2}\right)R_{n,l} + V(r)$$

Where, $m = \frac{m_q m_{\bar{q}}}{m_q + m_{\bar{q}}}$ and we have used the CPP_ν (Coulomb plus power potential) as follows,

$$V(r) = \frac{-\alpha_c}{r} + A(n)^a r^\nu + V_0$$

A and α_c are the potential parameters. The different choices of ν corresponds to different potential forms. a and V_0 are constants(set intentionally to fix the ground state), $\alpha_c = \frac{4}{3}\alpha_s$; α_s is the strong running coupling constant expressed as [1],

$$\alpha_s = \frac{4\pi}{\left(11 - \frac{2}{3}n_f\right)\left[\frac{m^2 + m_b{}^2}{\Lambda^2}\right]}$$

m_b is the background mass, Λ is the QCD scale factor, n_f is the number of flavours and α_s=0.521. Here, we have considered the general form of the trial wave function which is normalized and is given as,

$$R_{n,l} = \left(\frac{n!p}{\alpha^{\left(\frac{2lp-(2l+3)}{p}\right)}(n+k)!}\right)^{\frac{1}{2}}(\text{⍰r})^p e^{-\frac{\text{⍰}r^p}{2}} L_n^k$$

⍰ is the variational parameter and L_n^k is the laguerre polynomial. The hyperfine splitting of the quarkonia are calculated by using ,

$$M_v = M_{sa} + \frac{1}{4}k \qquad \text{(for vector meson)}$$
$$M_p = M_{sa} - \frac{3}{4}k \text{ (for pseudoscalar meson)}$$

The leptonic and digamma decay widths are calculated by using Van-Royen-Weisskopf formula [2-4],

$$\Gamma_{ll} = \frac{16\pi(\alpha_e)^2(e_Q)^2}{(Mv)^2}\,|R_{n,l}(0)|^2\,[C(\alpha)]$$
$$\Gamma_{\gamma\gamma} = \frac{3(\alpha_e)^2(e_Q)^4 Mp}{2(m_q)^3}\,|R_{n,l}(0)|^2\,[C(\beta)]$$

$(e_Q)^2$ is the squared sum of the charge of quarks , $\alpha_e = \frac{1}{137}$, is the electromagnetic coupling constant. [C(α)]and [C(β)]are the QCD correction factors given as,

$$[C(\alpha)] = \left(1 - \frac{16}{3\pi}\alpha_s + \frac{16}{3\pi}(\alpha_s)^2\left(\frac{(n_f)(n+1)^{\nu+2}}{(e_Q)^2}\right)\right.$$

And [C(β)]=

$$1 - \frac{\alpha_s}{3\pi}(20 - \pi^2)\frac{(20-\pi^2)}{3\pi}(\alpha_s)^2\left(\frac{(n_f)(n+1)^{\nu+2}}{(e_Q)^2}\right.$$

Here, following formalism is used to calculate the vector decay constant,

$$F_V = \frac{\sqrt{3Mv(\Gamma_{ll})}}{4\pi(\alpha_e)^2\,(e_Q)^2}$$

Table I:S-wave mass spectra for strangeonium for hydrogenic and harmonic wavefunctions

nL	State	P	Present			Others	[1]
			υ=0.1	υ=0.5	υ=1.0		
1s	1^3S_1	1	0.9856	0.9856	0.9856	1.0195 [5,6]	1.038
		2	1.0168	1.0169	1.0170		
	1^1S_0	1	0.9826	0.9825	0.9825	0.9578 [5,6]	0.743
		2	1.0145	1.0143	1.0142		
2s	2^3S_1	1	1.6749	1.6764	1.6781	1.6800 [5,6]	1.698
		2	1.6829	1.6859	1.6869		
	2^1S_0	1	1.6673	1.6504	1.6458	~1.4400 [6]	1.536
		2	1.6780	1.6729	1.6610		
3s	3^3S_1	1	2.0365	2.0469	2.0492	~2.0500 [6]	2.119
		2	2.1068	2.1399	2.1207		
	3^1S_0	1	1.9355	1.9101	1.9097	~1.9500 [6]	2.085
		2	2.0152	2.0098	1.9883		

Table II: Values hydrogenic and harmonic type wavefunctions at origin for S-wavein GeV^3

nL	P	$\lvert R_{n,l}(0)\rvert$		
		υ=0.1	υ=0.5	υ=1.0
1S	1	0.00806	0.00808	0.00818
	2	0.00694	0.00733	0.00777
2S	1	0.01286	0.02398	0.02643
	2	0.01029	0.01680	0.02579
3S	1	0.04669	0.05436	0.05489
	2	0.04446	0.05301	0.05347

Result and discussion

In present study, we have done comprehensive study of strangeonium through variational approach for the wavefunction lying between hydrogenic (p=1) to harmonic (p=2). The results are shown in the tables **I, II ,III** for different potential indeces 'ν' at each wavefunction index 'p'.

Table III:Γ_{ll} and $\Gamma_{\gamma\gamma}$ decay width of 1S state of strangeonium for different potential indices using p = 1and p = 2 wave function (keV)

nL	υ	Present (p=1)	Present(p=1)	Present(p=2)	Present(p=2)
		Γ_{ll}	$\Gamma_{\gamma\gamma}$	Γ_{ll}	$\Gamma_{\gamma\gamma}$
1S	0.1	1.0634	2.1534	0.7883	1.5965
	0.5	1.4096	2.8474	1.1600	2.3433
	1.0	2.0295	4.0899	1.8311	3.6901

The experimental value of leptonic decay width and digamma decay width is 1.26 keV and 4. 35 keV respectively. The results obtained are quite satisfactory with experimental values.

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