The status of $\Xi_c(2970)^0$ & $\Xi_c(3080)^0$ using relativistic formalism

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Introduction

The eight states of the Ξ_c^0 are observed till now, and the spin parity of five of them is known [1]. The spin parity(J^P) of $\Xi_c(2923)^0$, $\Xi_c(2930)^0$, & $\Xi_c(3080)^0$ is still unknown and can be confirmed through the phenomenological study of the baryon. We have used the independent quark model, which is quite successful in meson spectroscopy [2, 3] and light [4] as well as heavy baryon [5, 6] spectroscopy, to compute the ground state masses along with the radial excitation and magnetic moment of Ξ_c^0.

Methodology

We have considered independent confined quarks, in relativistic Dirac formalism, within the baryon using the potential of the form $\frac{1}{2}(1+\gamma_0)(\lambda r^{0.1}+V_0)$. The Dirac equation for a quark in this scheme can be expressed as,

$$[\gamma^0 E_q - \vec{\gamma}\vec{P} - m_q - V(r)]\psi_q(\vec{r}) = 0 \qquad (1)$$

. Here, E_q represents the Dirac energy of the confined quark (q) within the baryon. The spin-average mass of a baryon consists of charm quark, down quark and strange quark can be written as

$$M_{SA}^{Qqq} = E_c^D + E_d^D + E_s^D - E_{CM}, \qquad (2)$$

Here, E_c^D, E_d^D, and E_s^D denote the Dirac energies of the c, d, and s quarks, respectively.

For simplicity, we treat the center-of-mass correction, E_{CM} parametically, and can be fitted using the experimental masses. We can equate the theoretical spin-averaged mass obtained using Eqn 2 with the spin-averaged mass calculated using the experimental mass of the respective spin states (M_{nJ}) using Eqn 3 to fit the potential parameters.

$$M_{SA} = \frac{\sum_J (2J+1)M_{nJ}}{\sum_J (2J+1)}. \qquad (3)$$

We calculated the spin-averaged masses of the radially excited S wave states with the fitted parameters. Here the spin degeneracy is removed by considering the total spin of the baryon, given by $\vec{J_{3q}} = \vec{J_1} + \vec{J_2} + \vec{J_3}$.

$$\left\langle V^{jj}_{q_1q_2q_3}(r)\right\rangle = \sum_{i=1,i<k}^{i,k=3} \frac{\sigma\left\langle j_i.j_kJM|\hat{j_i}\cdot\hat{j_k}|j_i.j_kJM\right\rangle}{(E_{q_i}+m_{q_i})(E_{q_k}+m_{q_k})}, \qquad (4)$$

which describes the interaction as sum of the interaction of individual pair of quarks and σ is $j-j$ coupling constant for Ξ_c^0 baryon.

Magnetic Moment

In addition to mass determination, the magnetic moment of a baryon is crucial in understanding its internal structure. The magnetic moment, generated by the intrinsic spins and orbital motions of its constituent quarks, can be calculated using the following equation

$$\mu_B = \sum_q < \phi_{sf}|\vec{\mu}_{qz}|\phi_{sf} >, \qquad (5)$$

where

$$\mu_q = \frac{e_q}{2M_q^{eff}}\sigma_q. \qquad (6)$$

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Here, e_q and σ_q represent the charge and the spin of the quark, and $|\phi_{sf} >$ is the spin-flavor wave function. The effective mass M_q^{eff} is obtained as, $M_q^{eff} = E_q(1 + \frac{<H>+E_{cm}}{\Sigma_q E_q})$, it takes into account because the inertia of the bound quarks within the baryon.

TABLE I: S State mass of Ξ_c^0 (In GeV).

State	V_{jj}	Mass	[1]	[8]	[9]	[10]
$1^2S_{\frac{1}{2}}$	-0.109	2.478	2.471	2.471	2.488	2.433
$1^4S_{\frac{3}{2}}$	0.066	2.653	2.646	2.647	2.673	2.648
$2^2S_{\frac{1}{2}}$	-0.091	2.953	2.966	2.937	-	-
$2^4S_{\frac{3}{2}}$	0.055	3.099	3.079	3.004	-	-
$3^2S_{\frac{1}{2}}$	-0.083	3.226	-	3.303	-	-
$3^4S_{\frac{3}{2}}$	0.050	3.359	-	3.338	-	-
$4^2S_{\frac{1}{2}}$	-0.077	3.422	-	3.626	-	-
$4^4S_{\frac{3}{2}}$	0.046	3.545	-	3.646	-	-
$5^2S_{\frac{1}{2}}$	-0.074	3.574	-	3.921	-	-
$5^4S_{\frac{3}{2}}$	0.044	3.692	-	3.934	-	-

TABLE II: Magnetic moment of Ξ_c^0 (In GeV).

State	Expression	our	[8]	[9]
$\frac{1}{2}^+$	$\frac{2}{3}\mu_d+\frac{2}{3}\mu_s-\frac{1}{3}\mu_c$	-0.823	-1.011	-0.932
$\frac{3}{2}^+$	$\mu_d + \mu_s + \mu_c$	-0.418	-0.825	-0.671

Discussion

The agreement of the predicted ground state masses with the experimental masses validates the fitted parameters. The ground state masses are also in the range of other theoretical predictions like [8] & [9]. The predicted masses of $1S - 5S$ are in the range of $2.4-3.6\ GeV$. We also predict that the experimentally observed state $\Xi_c(3080)^0$ could be the $2^4S_{3/2}$ and $\Xi_c(2970)^0$ coule be the $2^2S_{1/2}$, but this needs verification from further studies like Regge trajectories. This study enables us to calculate masses of orbitally excited states of Ξ_c^0 baryon and that can lead to the further validation of the potential model.

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