S & P-Wave spectroscopy of Ω_b baryon in relativistic Dirac formalism with independent quark model

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Introduction

LHCb collaboration recently observed four of the excited Ω_b^- states $(6316), (6330), (6340), (6350)$ as the narrow peaks in the $\Xi_b^0 K^-$ mass spectra [1]. These experimental observations of heavy baryons are providing valueable data for verifying various models of heavy flavour hadron sector from last two decades. Baryons are studied in many different phenomenological aspects, one of the approach is independent quark model and it provides very good results for mesons [2–4]. We have calculated the mass spectra of the Ω_b^- states having the orbital angular momentum $l = 0$ and $l = 1$ using the independent quark model under mean field confinement of martin potential with parametric centre of mass.

Methodology

We consider the independent confinement of quarks in baryon using the potential of the form $\frac{1}{2}(1+\gamma_0)(\lambda r^{0.1} + V_0)$ in relativistic Dirac formalism. The spin-average mass of a baryon can be written as

$$M_{SA}^{Qqq} = E_Q^D + 2E_q^D - E_{CM}, \tag{1}$$

Where, E_Q^D and E_q^D represents the Dirac energy of Q and q quarks respectively, which can be obtained by solving the Dirac equation for this system

$$[\gamma^0 E_q - \vec{\gamma}\vec{P} - m_q - V(r)]\psi_q(\vec{r}) = 0 \tag{2}$$

and E_{CM} is the parametric centre of mass correction. The spin-spin$(j \cdot j)$ interactions is expressed as

$$\left\langle V_{Qqq}^{jj}(r)\right\rangle = \sum_{i=1,i<k}^{i,k=3} \frac{\sigma\left\langle j_i j_k JM|\widehat{j_i}\widehat{j_k}|j_i j_k JM\right\rangle}{(E_{q_i}+m_{q_i})(E_{q_k}+m_{q_k})}, \tag{3}$$

where, σ is the $j-j$ coupling constant, λ and V_0 are the potential parameter. The computed S-wave masses are given in the following **TABLE I**.

TABLE I : S state of Ω_b^- in GeV

$n^{2S+1}S_J$	Our mass	Experiment[5]	[6]	[7]	[8]
$1^2S_{\frac{1}{2}}$	6.047	6.0452	6.046	6.043	6.064
$1^4S_{\frac{3}{2}}$	6.083	-	6.082	6.069	6.088
$2^2S_{\frac{1}{2}}$	6.436	-	6.438	6.446	6.450
$2^4S_{\frac{3}{2}}$	6.465	-	6.462	6.466	6.461
$3^2S_{\frac{1}{2}}$	6.661	-	6.740	6.633	6.804
$3^4S_{\frac{3}{2}}$	6.687	-	6.753	6.650	6.811
$4^2S_{\frac{1}{2}}$	6.823	-	7.022	6.790	7.091
$4^4S_{\frac{3}{2}}$	6.846	-	7.030	6.804	7.096
$5^2S_{\frac{1}{2}}$	6.949	-	7.290	-	7.338
$5^4S_{\frac{3}{2}}$	6.971	-	7.296	-	7.343

In the non zero angular momentum case, we consider the total two particle interaction which is obtained by adding spin-spin interactions (Eqn.(3)) along with spin-orbit (Eqn.(4)) and tensor (Eqn.(5)) parts of confined one-gluon exchange

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potential(COGEP)[9].

$$V^{LS}_{qqq}(r) = \frac{\alpha_s}{4}\sum_{i=1,i<k}^{i,k=3} \frac{N^2_{q_i}N^2_{q_k}}{(E_{q_i}+m_{q_i})(E_{q_k}+m_{q_k})}\frac{\lambda_{q_i}\lambda_{q_k}}{2r} \otimes [[r\times(\widehat{p}_{q_i}-\widehat{p}_{q_k})(\widehat{\sigma}_{q_i}+\widehat{\sigma}_{q_k})](D'_0(r)+2D'_1(r)) + [r\times(\widehat{p}_{q_i}+\widehat{p}_{q_k})(\widehat{\sigma}_{q_i}-\widehat{\sigma}_{q_k})](D'_0(r)-D'_1(r))] \quad (4)$$

$$V^{T}_{qqq}(r) = -\frac{\alpha_s}{4}\sum_{i=1,i<k}^{i,k=3} \frac{N^2_{q_i}N^2_{q_k}}{(E_{q_i}+m_{q_i})(E_{q_k}+m_{q_k})} \otimes \lambda_{q_i}\lambda_{q_k}\left(\left(\frac{D''_1(r)}{3}-\frac{D'_1(r)}{3r}\right)S_{q_iq_k}\right) \quad (5)$$

where $S_{q_iq_k} = [3(\sigma_{q_i}\widehat{r})(\sigma_{q_k}\widehat{r}) - \sigma_{q_i}\sigma_{q_k}]$, $\widehat{r} = \widehat{r}_{q_i} - \widehat{r}_{q_k}$ and running coupling constant can be calculated as

$$\alpha_s = \frac{\alpha_s(\mu_0)}{1+\frac{33-2n_f}{12\pi}\alpha_s(\mu_0)ln\left(\frac{m_1+m_2+m_3}{\mu_0}\right)} \quad (6)$$

We keep the parametric form of the confined gluon propagators as it is mentioned in Ref.[9]

$$D_0(r) = \left(\frac{\alpha_1}{r}+\alpha_2\right)exp\left(\frac{-r^2c_0^2}{2}\right) \quad (7)$$

$$D_1(r) = \frac{\gamma}{r}exp\left(\frac{-r^2c_1^2}{2}\right) \quad (8)$$

The computed P-wave masses are mentioned in the **TABLE II** along with the available experimental data and other phenomenological approaches.

Result and Conclusion

We have estimated the mass of the ground state ($1^2S_{\frac{1}{2}}$) 6.0467 GeV which is very near to the experimentally observed ground state $\Omega_b^-(6045)$. We also predict that the experimentally observed state $\Omega_b^-(6316)$ can be $1^2P_{\frac{1}{2}}$ at 6315.24 GeV or $1^4P_{\frac{3}{2}}$ at 6315.94 GeV. The calculated masses of higher S and P waves are in close agreement with the masses predicted by other theoretical approaches [6–8].

TABLE II : P-Wave of Ω_b^- in GeV

$n^{2S+1}P_J$	Masses	[6]	[7]	[8]
$1^2P_{\frac{3}{2}}$	6.363	6.341	6.336	6.340
$1^2P_{\frac{1}{2}}$	6.315	6.344	6.329	6.330
$1^4P_{\frac{3}{2}}$	6.316	6.343	6.326	6.331
$1^4P_{\frac{1}{2}}$	6.319	6.345	6.334	6.339
$1^4P_{\frac{5}{2}}$	6.388	6.339	6.339	6.334
$2^2P_{\frac{3}{2}}$	6.616	6.594	6.664	6.705
$2^2P_{\frac{1}{2}}$	6.578	6.596	6.658	6.706
$2^4P_{\frac{3}{2}}$	6.579	6.595	6.655	6.699
$2^4P_{\frac{1}{2}}$	6.581	6.597	6.662	6.710
$2^4P_{\frac{5}{2}}$	6.635	6.592	6.666	6.334
$3^2P_{\frac{3}{2}}$	6.791	6.827	6.846	7.002
$3^2P_{\frac{1}{2}}$	6.758	6.829	6.841	7.003
$3^4P_{\frac{3}{2}}$	6.759	6.828	6.839	6.998
$3^4P_{\frac{1}{2}}$	6.760	6.83	6.844	7.009
$3^4P_{\frac{5}{2}}$	6.807	6.826	6.848	6.700
$4^2P_{\frac{3}{2}}$	6.926	7.043	6.970	7.258
$4^2P_{\frac{1}{2}}$	6.896	7.044	6.966	7.257
$4^4P_{\frac{3}{2}}$	6.897	7.043	6.964	7.250
$4^4P_{\frac{1}{2}}$	6.898	7.043	6.969	7.265
$4^4P_{\frac{5}{2}}$	6.941	7.042	6.972	6.996

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