Spectroscopy of Ω_b^- in relativistic Dirac formalism with independent quark model

Manan Shah[1],* Rameshri V. Patel[1],† Smruti Patel[2],‡ and Ajay Majethiya[1]§
[1]Department of Physical Sciences, P. D. Patel Institute of Applied Sciences,
Charotar University of Science and Technology,
CHARUSAT, Changa - 388421, Gujarat, INDIA
[2] Government Science College, Fort Songadh, Tapi - 394670 , Gujarat.
[3] Department of physics, V.S.Patel College of Arts Science, Bilimora,
Veer Narmad South Gujarat University, Surat - 395007,Gujarat, INDIA

Introduction

The simplest interpretation of recent observation of four narrow peaks in the $\Xi_b^0 K^-$ mass spectrum at LHCb is that they correspond to excited Ω_b^- states, in particular the $L = 1$ orbital excitation of the ground state, or possibly $n = 2$ radial excitation [1]. In the present work, we investigate the excited state mass spectra of Ω_b^- system using the framework of relativistic Dirac formalism with a mean field confinement potential [2–4]. Additionally, we delve into static properties like magnetic moment and radiative decay width for these baryonic states.

1. Methodology and Mass Spectra

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

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

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

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

and E_{CM} is the parametric center of mass correction. The spin-spin, spin-orbit, and tensor interactions are considered as given in Ref. [2–4] The computed P & D-wave masses are listed in **TABLE I** & **TABLE II** along with the other model predictions.

2. Magnetic moment and radiative decay of Ω_b^-

We find the magnetic moment in terms of its effective quarks masses as given in Ref. [5] where the bound state effects are absorbed by defining the effective mass as

$$m_q^{eff} = E_q^D \left(1 + \frac{< H > -E_{CM}}{\sum_q E_q^D}\right) \qquad (3)$$

TABLE I : P-Wave of Ω_b^- in GeV

$n^{2S+1}P_J$	Masses	[6]	[7]	[8]
$1^2P_{\frac{1}{2}}$	6.3247	6.344	6.329	6.330
$1^2P_{\frac{3}{2}}$	6.3614	6.341	6.336	6.340
$1^4P_{\frac{1}{2}}$	6.3253	6.345	6.334	6.339
$1^4P_{\frac{3}{2}}$	6.3244	6.343	6.326	6.331
$1^4P_{\frac{5}{2}}$	6.3797	6.339	6.339	6.334
$2^2P_{\frac{1}{2}}$	6.5847	6.596	6.658	6.706
$2^2P_{\frac{3}{2}}$	6.6143	6.594	6.664	6.705
$2^4P_{\frac{1}{2}}$	6.5852	6.597	6.662	6.710
$2^4P_{\frac{3}{2}}$	6.5851	6.595	6.655	6.699
$2^4P_{\frac{5}{2}}$	6.6291	6.592	6.666	6.334
$3^2P_{\frac{1}{2}}$	6.7635	6.829	6.841	7.003
$3^2P_{\frac{3}{2}}$	6.7897	6.827	6.846	7.002
$3^4P_{\frac{1}{2}}$	6.7642	6.83	6.844	7.009
$3^4P_{\frac{3}{2}}$	6.7641	6.828	6.839	6.998
$3^4P_{\frac{5}{2}}$	6.8028	6.826	6.848	6.700

*Electronic address: mnshah09@gmail.com
†Electronic address: rameshri.patel1712@gmail.com
‡Electronic address: fizix.smriti@gmail.com
§Electronic address: ajay.phy@gmail.com

TABLE II : D-Wave of Ω_b^- in GeV

$n^{2S+1}P_J$	Masses	[6]	[7]	[8]
$1^2D_{\frac{3}{2}}$	6.4903	6.480	6.556	6.530
$1^2D_{\frac{5}{2}}$	6.5230	6.476	6.555	6.520
$1^4D_{\frac{1}{2}}$	6.5133	6.485	6.556	6.540
$1^4D_{\frac{3}{2}}$	6.5148	6.482	6.561	6.549
$1^4D_{\frac{5}{2}}$	6.5584	6.478	6.561	6.529
$1^4D_{\frac{7}{2}}$	6.5748	6.472	6.562	6.517
$2^2D_{\frac{3}{2}}$	6.6914	6.726	6.846	6.846
$2^2D_{\frac{5}{2}}$	6.7186	6.723	6.846	6.837
$2^4D_{\frac{1}{2}}$	6.7094	6.730	6.846	6.857
$2^4D_{\frac{3}{2}}$	6.7106	6.727	6.852	6.863
$2^4D_{\frac{5}{2}}$	6.7468	6.724	6.852	6.846
$2^4D_{\frac{7}{2}}$	6.7604	6.720	6.853	6.834
$3^2D_{\frac{3}{2}}$	6.8411	6.953	7.022	-
$3^2D_{\frac{5}{2}}$	6.8655	6.951	7.021	-
$3^4D_{\frac{1}{2}}$	6.8569	6.956	7.021	-
$3^4D_{\frac{3}{2}}$	6.8580	6.954	7.026	-
$3^4D_{\frac{5}{2}}$	6.8905	6.951	7.026	-
$3^4D_{\frac{7}{2}}$	6.9027	6.948	7.027	-

which follows the property of $M_J = \sum_{q=1}^{3} m_q^{eff}$. Our prediction and comparison with other different approaches of magnetic moments are given in **TABLE III**.

TABLE III : Magnetic moments in terms of nuclear magneton

State	Our	[5]	[6]	[9]
$\Omega_b^- \frac{1}{2}^+$	-0.539	-0.916	-0.761	-0.545
$\Omega_b^- \frac{3}{2}^+$	-0.906	-1.178	-1.236	-0.919

J. Dey et.al [10] showed the way to calculate the radiative decay widths for the singly heavy baryon using the heavy quark effective theory (HQET) in terms of the radiative transition magnetic moment.

$$\Gamma = \frac{k^3}{4\pi} \frac{2}{2J+1} \frac{e^2}{m_p^2} \mu^2_{B_{\frac{3}{2}} \to B_{\frac{1}{2}}} \quad (4)$$

where the radiative transition magnetic moment can be calculated as

$$\mu_{B_{\frac{3}{2}} \to B_{\frac{1}{2}}} = < B_{\frac{3}{2}} | \hat{\mu}_B | B_{\frac{1}{2}} >.$$

We predict the decay width for $\Omega^-_{b\,(\frac{3}{2}^+)} \to \Omega^-_{b\,(\frac{1}{2}^+)}\gamma$ to be 0.006 keV which is in the range of other predictions [6, 11]

3. Discussion and Conclusion

Our calculations indicate that the masses of P and D waves using the relativistic Dirac formalism with a mean field confinement potential fall within the mass range of $6-7$ GeV, aligning with similar predictions made by researchers in prior studies, as referenced in [6], [7], and [8]. Our prediction for the mass range of the $1P$ states coincides with the mass range of recently observed resonances of Ω_b^- $(6316, 6330, 6340, 6350)$[12].

Additionally, our computed magnetic moment of the ground state ($-0.539\ \mu_N$), is consistent with other theoretical predictions.

Furthermore, our investigation demonstrates that the radiative transition decay width is exceptionally small, approximately at the level of 10^{-3} keV.

Acknowledgments

We thank CHARUSAT for providing reqired facilities and acknowledge the University Grants Commission for the UGC-SJSGC fellowship(F No. 82-7/2022 (SA-III)) for the financial support to Rameshri Patel.

References

[1] R. Aaij *et al.* [LHCb], Phys. Rev. Lett. **124**, no.8, 082002 (2020).

[2] M. Shah, B. Patel and P. C. Vinodkumar, Phys. Rev. D **93**, no.9, 094028 (2016).

[3] M. Shah, B. Patel and P. C. Vinodkumar, Phys. Rev. D **90**, no.1, 014009 (2014)

[4] M. Shah, R. Patel and P. C. Vinodkumar, Few Body Syst. **64**, no.2, 34 (2023)

[5] B. Patel, A. K. Rai and P. C. Vinodkumar, J. Phys. G **35**, 065001 (2008).

[6] A. Kakadiya,*et al.* Int. J. Mod. Phys. A **37**, no.11n12, 2250053 (2022).

[7] G. L. Yu, *et al.* [arXiv:2206.08128 [hep-ph]].

[8] D. Ebert, *et al.* Phys. Rev. D **84**, 014025 (2011).

[9] A. Bernotas and V. Simonis, [arXiv:1209.2900 [hep-ph]].

[10] J. Dey, V. Shevchenko, P. Volkovitsky and M. Dey, Phys. Lett. B **337**, 185-188 (1994).

[11] A. Majethiya, B. Patel and P. C. Vinodkumar, Eur. Phys. J. A **42**, 213-218 (2009).

[12] R. L. Workman *et al.* [Particle Data Group], PTEP **2022**, 083C01 (2022).