Spectroscopy of Light Flavoured Baryons

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Introduction

Quantum Chromodynamics (QCD), a theory of strong interaction, relies on the factors, asymptotic freedom and quark confinement. With the advancement in experimental facilities in high energy physics, a number of light and heavy hadrons including new hybrid, exotic states have been observed [1]. Yet so, the strange baryons particularly Ξ and Ω are the least explored ones owing to the fact that they are not easily produced in reactions. Hadron spectroscopy has allowed us to explore many properties revealing the quark dynamics starting from resonance spectra to decay widths.

The light, strange sector encompasses a lot of yet unknown or missing resonances leading to scarce experimental data [2]. The experiments ELSA, MAMI, Jefferson-lab, LHC have collected some of the states of N and Δ baryons as well as from strange sector Λ, Σ baryons. Some of the facilities are expected to look for least explored higher strange baryons namely PANDA, BESIII through various decay processes.

Theoretical Framework

The baryons with a constituent quark masses of u, d and s quarks has been studied with linear confining potential. The resonances obtained with this hypercentral CQM relies on the hyperradius x obtained though Jacobi co-ordinates ρ and λ, has contribution from all the three interquark distances [3, 4].

The hyper-radial equation whose solution is $\psi(x)$ will then be,

$$\left[\frac{d^2}{dx^2} + \frac{5}{x}\frac{d}{dx} - \frac{\gamma(\gamma+4)}{x^2}\right]\psi(x) = -2m[E - V_{3q}(x)]\psi(x) \tag{1}$$

The spin-dependent terms in the potential to account for spin-spin, spin-orbit and tensor interactions has allowed to get all the spin-parity states for a given orbital state. The first-order $\frac{1}{m}$ and second-order $\frac{1}{m^2}$ corrections to spin interactions has allowed to reach the expected hierarchy of the excited states[5–10]. The final Hamiltonian on incorporating all the terms in potential is as follows,

$$H = \frac{P^2}{2m} + V(x) + V_{SD}(x) + \frac{1}{m}V^1(x) + \frac{1}{m^2}V^2(x) \tag{2}$$

The constituent quark mass has been taken as $m_u = m_d = 290MeV$ and $m_s = 500MeV$ for u, d and s quark respectively.

N, Δ Baryon

In case of N and Δ baryons, the number of one star states are less. The available four and three star states have been attempted to reproduce through the linear potential. It has been observed that low-lying states are well matched with experimental data as well as other theoretical models [11, 12].
Incorporating the recent additions, 8 four star, 4 three star and many other experimental status have been explored with the values ranging from $J = \frac{1}{2}$ to $J = \frac{15}{2}$ and still many states are awaited of confirmation of existence as listed by Particle Data Group (PDG).

Λ, Σ, Ξ, Ω Baryons

For Λ baryon, the more interesting part deals with associating 1 star stated resonances to our predictions. Also, 2S and 1P($\frac{3}{2}^-$) are

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within 20 MeV variation from PDG and other comparison. Theoretically 1405 state was established as a quasi-bound molecular state. The 1710 ($\frac{1}{2}^+$) is associated with 1D state but is comparatively lower than nearby spin-partners.

Σ baryon happens to have a large number of states with 1 and 2 stars clearly marking the need to look for resonances. The four star states $(1670)\frac{3}{2}^-$, $(1775)\frac{5}{2}^-$, $(1915)\frac{5}{2}^+$, and $(2030)\frac{7}{2}^+$ have been established with good consistency. The three star state 2250 doesn't have known spin-parity but here we have tentatively assigned it to be 3S($\frac{3}{2}^+$) by a difference of 15 MeV. The two star state 1880 might be somewhere in 1D family but in the present data nearly 120 MeV higher predicted.

For Ξ baryon, this model has obtained 1971 and 1964 compared to 1950 of PDG for $\frac{3}{2}^+$. Also, the 1820 state is in variation of 30 MeV from experimental results. However, the narrow states 1620 and 1690 are naturally not reproduced in the current model. Here, we assign $J^P = \frac{1}{2}^-$ to PDG state 2370, with our obtained masses 2373 and 2333 for 2P but it is also matching with our 3S($\frac{1}{2}^+$) state. The $\Xi(2250)$ is very much in accordance with our 1D$\frac{5}{2}^+$ state.

The Ω baryon is completely associated with the decuplet representation, in the same way that the Δ baryon is, whereas the Σ and Ξ baryons have the potential to be realized as a combination of octet and decuplet states. For Ω with only ground state being known completely opens many possibility to look into. The $\Omega(2012)$ state is matching with our 1P($\frac{1}{2}^-$) [13]. Also, the three star state 2250 is in accordance with 1D($\frac{3}{2}^+$) of the current model but it can also be assigned any of the positive parity J values of 1D. The two star state 2380 is most near to our 2P i.e. negative parity state however, the exact J value assignment is still open to all possible values ranging from $\frac{1}{2}^-$, $\frac{3}{2}^-$ and $\frac{5}{2}^-$.

A large number of one star states inclusive of all the strange baryons have been assigned appropriate spin-parity groups not only based on the predicted data but also based on the natural an unnatural parity curves of Regge trajectories. Incorporating higher order correction terms to the potential solved the years long hierarchy pattern.

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References

[1] R.L. Workman *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2022**, 083C01 (2022) and 2023 update

[2] A. Thiel *et al.*, Prog. Part. Nucl. Phys. **125**, 103949 (2022)

[3] Z. Shah and A. K. Rai, Eur. Phys. J. C **77**, 129 (2017); Few-Body Syst. **59**, 112 (2018); Few-Body Syst. **59**, 76 (2018)

[4] A. Kakadiya *et al.*, Int. J. Mod. Phys. A **38**, 234102 (2023)

[5] C. Menapara *et al.* Chin. Phys. C **45**, 023102 (2021)

[6] C. Menapara and A. K. Rai, Chin. Phys. C **45**, 063108 (2021)

[7] C. Menapara and A. K. Rai, Chin. Phys. C **46**, 103102 (2021)

[8] C. Menapara and A. K. Rai, Int. J. Mod. Phys. A **37**, 2250177 (2022)

[9] C. Menapara and A. K. Rai,Int. J. Mod. Phys. A **38**, 2350053 (2023)

[10] A. Ansari *et al.*, Int. J. Mod. Phys. A, doi:10.1142/S0217751X23501087 (2023)

[11] C. Menapara and A. K. Rai, EPJ Web of Conf. **258**, 03004 (2022)

[12] C. Menapara *et al.*, AIP Conf. Proc. **2220**, 140014 (2020)

[13] C. Menapara and A. K. Rai, Proceedings of DAE Sym. on Nucl. Phys. **64**, 673 (2019); **65**, 529 (2021); **66**, 901 (2022).

[14] J. Oudichhya *et al.* Nucl. Phys. A **1035**, 122658 (2023)