Spectroscopic behavior of N baryon in Regge phenomenology

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Introduction

Hadron spectroscopy is a valuable approach for investigating the dynamics of quark interactions inside composite systems, such as mesons and baryons. It helps to uncover the internal structure of hadrons, revealing how quarks and gluons are organized. Also, in recent years there has been a significant experimental advancement in the observation of a number of new light baryonic states. In the current work we focus on the study of lightest baryon; N baryon composed of light quarks (u or d).

Experimentally, a quite number of N resonances have been detected and listed in the latest Particle Data Group (PDG) [1]. Till now total of 28 states are listed in PDG with experimentally observed masses and quantum numbers, among which some of the states are mentioned with one or two star, indicating the need for further confirmation. Apart from this, over the years various theoretical approaches have been used to investigate the light baryon sector [2–6]. Also, the upcoming experimental facility PANDA have been seeking for these light baryons and making efforts in finding more and more excited resonances [7–9]. This motivate us to explore the light baryons particularly the N baryon.

Here, the Regge phenomenology with the assumption of quasi linear Regge trajectories is employed to study the spectra of N baryon. The same approach is successfully used in our previous study to estimate the mass spectra of hadrons ranging from light strange baryons and mesons to singly, doubly, and triply heavy baryons [10–16]. Several relations have been extracted in terms of Regge parameters and baryon masses and using these derived relations the excited state masses of N baryon are evaluated. Further the possible quantum numbers are assigned to the newly observed resonances whose J^P values still needs more confirmation.

Methodology

To study the mass spectra of hadrons, the Regge theory is one of the most successful and widely used theoretical approach. Since the Regge trajectories connects the spin and mass of the hadrons, the general form of linear Regge trajectories can be represented as [10, 11, 17],

$$J = \beta(0) + \beta^{'} M^2, \tag{1}$$

where $\beta(0)$ and $\beta^{'}$ are respectively, the Regge intercept and slope of the trajectory. There are two well-established relations between Regge parameters for different quark flavors which are states as;

$$\beta_{iiq}(0) + \beta_{jjq}(0) = 2\beta_{ijq}(0), \tag{2}$$

$$\frac{1}{\beta^{'}{}_{iiq}} + \frac{1}{\beta^{'}{}_{jjq}} = \frac{2}{\beta^{'}{}_{ijq}}, \tag{3}$$

where i, j, q represents the quark flavors. These two relationships are described in detail in refs. [12, 17] and therein. Now after merging the eqs. (1), (2), and (3), two pairs of solutions are produced which are expressed as,

$$\frac{\beta^{'}_{jjq}}{\beta^{'}_{iiq}} = \frac{1}{2M^2_{jjq}} \times [(4M^2_{ijq} - M^2_{iiq} - M^2_{jjq}) \pm \sqrt{(4M^2_{ijq} - M^2_{iiq} - M^2_{jjq})^2 - 4M^2_{iiq}M^2_{jjq}}], \tag{4}$$

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and,

$$\frac{\beta^{'}_{ijq}}{\beta^{'}_{iiq}} = \frac{1}{4M^2_{ijq}} \times [(4M^2_{ijq} + M^2_{iiq} - M^2_{jjq}) \pm \sqrt{(4M^2_{ijq} - M^2_{iiq} - M^2_{jjq})^2 - 4M^2_{iiq}M^2_{jjq}}]. \quad (5)$$

These are the general relations in terms of slope ratios and baryon masses which are used to determine the Regge slope for any baryonic system. The detailed information pertaining to this study can be found in the refs. [10–12]. Hence, using the above derived relations the Regge slope ($\beta^{'}$) for the N baryon can be evaluated as 1.0223 GeV^{-2}.

From eq. (1), it is also possible to express,

$$M_{J+1} = \sqrt{M^2_J + \frac{1}{\beta'}}, \quad (6)$$

By utilizing the extracted Regge slope for the N baryon, the aforementioned relation enables the estimation of orbitally excited state masses.

Results and Discussion

TABLE I: Excited state masses of N baryon (in MeV).

States	Present	PDG [1]	[5]	[3]
$1^2S_{\frac{1}{2}}$	939	939	939	939
$1^2P_{\frac{3}{2}}$	1364	1510-1520	1493	1535
$1^2D_{\frac{5}{2}}$	1685	1680-1690	1792	1769
$1^2F_{\frac{7}{2}}$	1954	2140-2220	2107	2045
$1^2G_{\frac{9}{2}}$	2190	2250-2320	2433	-
$1^2H_{\frac{11}{2}}$	2403	-	-	-

The excited state masses for L = 1,2,3,4,.. of N baryon are successfully obtained using the well-established Regge theory, as presented in the table I. The computed results are compared with the experimentally observed masses listed in PDG [1] and also with the predictions of other theoretical models. With a few Mev of difference, our estimated masses and the experimental masses shows a general agreement. For low lying states the computed masses are in agreement with the results obtained in refs. [3, 5] but a slight discrepancies in the higher excited state is observed with a slight large mass difference.

The predicted mass spectra and the spin-parity assignment of newly detected states as well as the unseen resonances will undoubtedly offer valuable insights for future experimental facilities such as PANDA. Additionally, these findings will be of great interest to other experimental groups that aim to investigate the light baryon sector.

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