Symmetry patterns in the (N, Δ) spectrum

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We revise the role played by symmetry in the study of the low-lying baryon spectrum and comment on the difficulties when trying to generalize the symmetry pattern to higher energy states. We show that for the (N, Δ) part such a generalization is plausible allowing the identification of spectral regularities and the prediction of until now non-identified resonances.

1. Introduction

The PDG Baryon Summary Table [1] contains 123 resonances. This richness is telling us about the existence, properties and dynamics of the intrabaryon constituents. In order to extract this physical content, the knowledge of spectral patterns is of great help. For instance the classification of the low-lying baryons according to $SU(3)_{\rm flavor}$ multiplets in Gell Mann's *eightfold way* revealed the existence of quarks and made clear spectral regularities from which to predict new states as the Ω particle. The consideration of additional spin and orbital degrees of freedom demanded the enlargement of the symmetry group. The assumption that quarks feel a rotationally invariant potential resulted in a $SU(6) \otimes O(3)$ pattern. Mass differences inside the (N, L^P) multiplets (N standing for the $SU(6)$ multiplet) pointed out the need to implement a symmetry breaking in the dynamics. The inclusion of a one gluon exchange chromomagnetic quark-quark interaction allowed for a correct description of the observed mass splitting [2].

When going to higher energy states the ascription of resonances to multiplets becomes much more difficult because of the different spin-orbital structures entering as resonance components. Furthermore the same validity of $SU(6) \otimes O(3)$ as a symmetry group may be under suspicion if relativistic effects, mixing orbital and spin degrees of freedom, becomes relevant. An unambiguous baryon quantum number assignment demands in practice two conditions to be satisfied: first the use of a complete data set and second the use of a dynamical model being able to reproduce the number and ordering of known resonances. These conditions can be rather well satisfied for the lightest-quark (u, d)-baryon spectrum to which we shall restrict hereforth. This (N, Δ) spectrum, containing 45 known

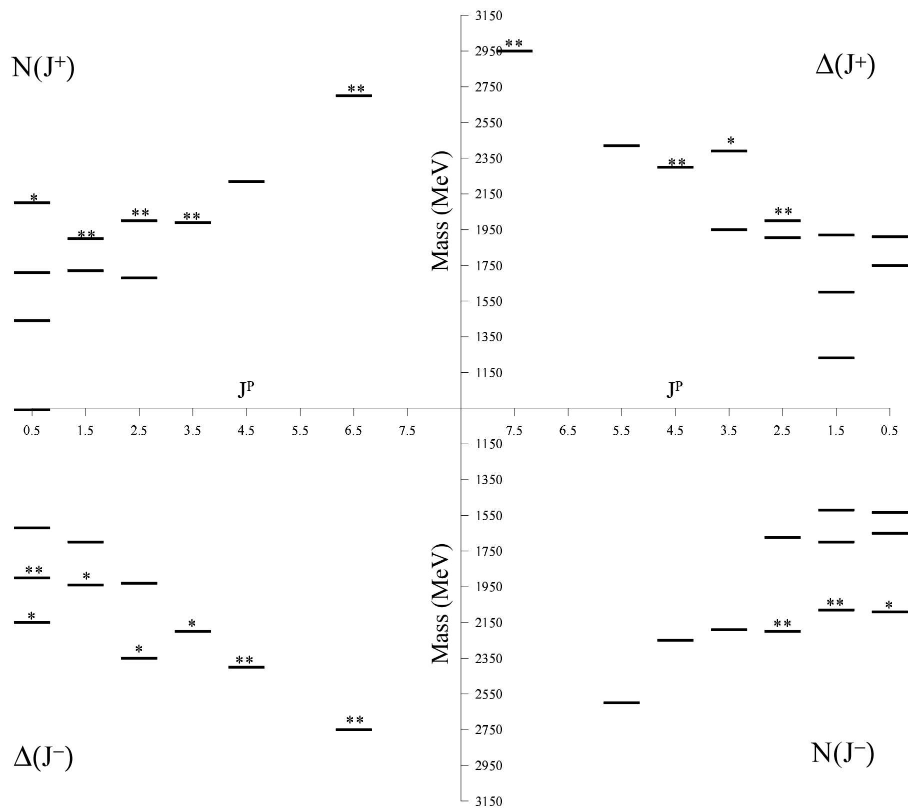

Figure 1. Nucleon and Δ spectra from PDG [1]. Stars have been omitted for four and three star resonances.

resonances, 25 of them well established experimentally, is represented in Fig. 1.

2. Dynamical model and the symmetry pattern

A dynamical model satisfying the second condition above can be built from a minimal quark potential model (containing a linear confinement plus a hiperfine one gluon exchange interaction) by incorporating screening as an effective mechanism to take, at least partially into account, the effect derived from the opening of decay channels. Screening can be put in the form of a saturating distance beyond which the quark-quark potential becomes a constant [3]. Except for the spin-spin piece the model is approximately $SU(4)(\supset SU(2)_{\rm spin} \otimes SU(2)_{\rm isospin}) \otimes O(3)$ symmetric. Hence we expect the baryons to be classified according to $SU(4)$ 20plets (since $4 \otimes 4 \otimes 4 = 20_S \oplus 20_M \oplus 20_M \oplus \overline{4}$) with defined orbital angular momentum L and parity P. This is confirmed by the analysis of the dominant configurations for the ground and first non-radial excited states of any J^Presonance up to a mass of 3 GeV [3]. The multiplet pattern appears in Tables 1 and 2.

The subindexes S and M indicate multiplet states that mix to give rise to experimental resonances (nonetheless when one of the configurations (S or M) is clearly dominant we have assigned to it the experimental mass: $N_S(1/2^+)(940), N_M(1/2^+)(1710), ...$). Thus for example $N(5/2^+)(1680)$ gets in our model a 62% of $N_S(5/2^+)$ and a 34% of $N_M(5/2^+)$ whereas $N(5/2^+)(2000)$ gets 35% of $N_S(5/2^+)$ and 64% of $N_M(5/2^+)$. A comparative

Table 1
Positive parity N and Δ states classified in multiplets of $SU(4) \otimes O(3)$ (up to $\simeq 3000$ MeV mass). Experimental data are from PDG [1]. Stars have been omitted for four-star resonances. States denoted by a question mark correspond to predicted resonances, Fig. 2, that do not appear in the PDG.

(N, L^P)	$S = 1/2$	$S = 3/2$
$(20_S, 0^+)$	$N_S(1/2^+)(940)$	$\Delta(3/2^+)(1232)$
$(20_S, 2^+)$	$N_S(5/2^+)$	$\Delta(7/2^+)(1950)$
$(20_S, 4^+)$	$N_S(9/2^+)$	$\Delta(11/2^+)(2420)$
$(20_S, 6^+)$	$N_S(13/2^+)$	$\Delta(15/2^+)(2950)(**)$
$(20_M, 0^+)$	$N_M(1/2^+)(1710), \Delta(1/2^+)(1750)$	$N_M(3/2^+)$
$(20_M, 2^+)$	$N_M(5/2^+), \Delta(5/2^+)(1905)$	$N(7/2^+)(1990)(**)$
$(20_M, 4^+)$	$N_M(9/2^+), \Delta(9/2^+)(2300)(**)$	$N(11/2^+)(?)$
$(20_M, 6^+)$	$N_M(13/2^+), \Delta(13/2^+)(?)$	$N(15/2^+)(?)$

Table 2
Same as Table 1 for negative parity N and Δ states.

(N, L^P)	$S = 1/2$	$S = 3/2$
$(20_M, 1^-)$	$N_M(3/2^-)(1520), \Delta(3/2^-)(1700)$	$N(5/2^-)(1675)$
$(20_M, 3^-)$	$N_M(7/2^-), \Delta(7/2^-)(2200)(*)$	$N(9/2^-)(2250)$
$(20_M, 5^-)$	$N_M(11/2^-), \Delta(11/2^-)(?)$	$N(13/2^-)(?)$
$(20_S, 1^-)$	$N_S(3/2^-)$	$\Delta(5/2^-)(1930)(***)$
$(20_S, 3^-)$	$N_S(7/2^-)$	$\Delta(9/2^-)(2400)(**)$
$(20_S, 5^-)$	$N_S(11/2^-)$	$\Delta(13/2^-)(2750)(**)$

analysis between the model masses and data might even indicate less mixing than calculated by the model, what would make the symmetry scheme more predictive. This seems to be confirmed by the spectral regularities observed for $J \geq 5/2$ when one identifies multiplet states with known resonances, for instance $N_S(5/2^+) \approx N(5/2^+)(1680)$, $N_M(5/2^+) \approx N(5/2^+)(2000)$ and so on (one exception is $N(3/2^+)(1720)$ with the same dominant configuration than $N(5/2^+)(1680)$ due to the spin-spin interaction). These spectral regularities can be summarized as:

i) Intermultiplet energy difference: $E_{N,\Delta}(J+2) - E_{N,\Delta}(J) \approx 400 - 500$ MeV.

ii) $N - \Delta$ ground state degeneracies: $N(J^\pm) \approx \Delta(J^\pm)$ for $J = \frac{4n+3}{2}$, $n = 1, 2....$

iii) N ground state parity doublets: $N(J^+) \approx N(J^-)$ for $J = \frac{4n+1}{2}$, $n = 1, 2....$

iv) First non-radial excitations: $(N(J), \Delta(J))^\bullet \approx (N(J+1), \Delta(J+1))$.

The extension of this pattern up to 3 GeV drives to the prediction of until now undetected resonances as shown in Fig. 2, containing the $[J = 5/2 - J = 15/2]$ ground and first non-radial excitations. It is worth to mention that the existence of nucleon parity doublets is a

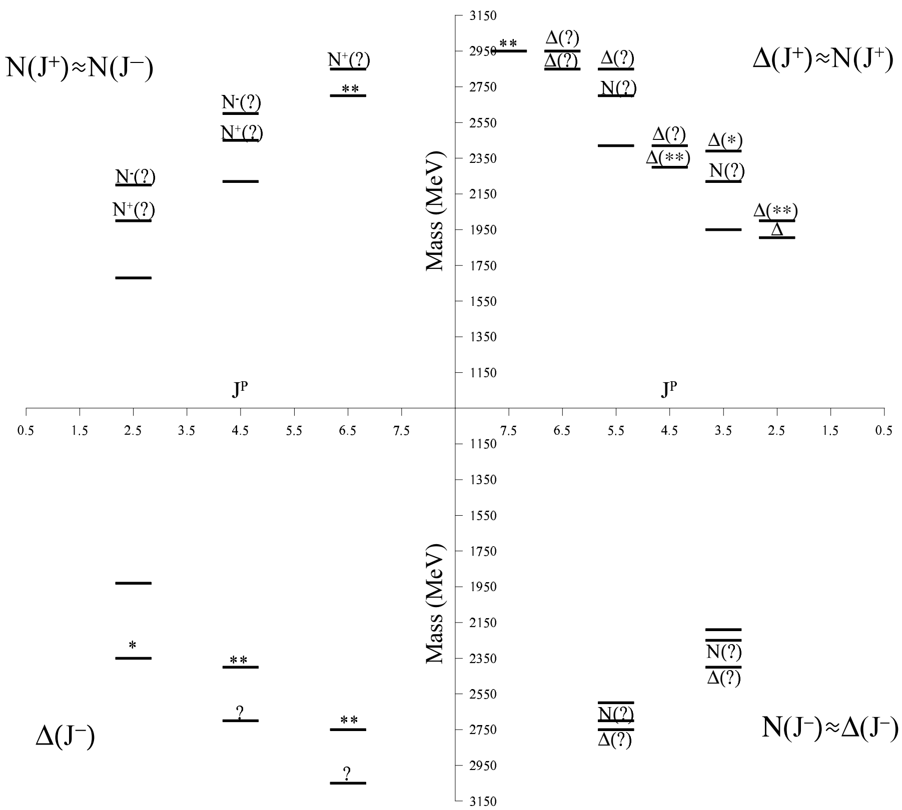

Figure 2. Nucleon and Δ spectrum (data and predictions) for $J \geq 5/2$. Predicted states are indicated by a question mark. Those Δ's ground state not degenerate with N's as well as first non-radial excited states for Δ's and N's are explicitly indicated by a corresponding Δ or N symbol.

consequence of the almost exact cancellation of a bigger repulsion (due to a bigger K and L) and a bigger attraction (due to $S = 1/2$) for N^+ states. No parallel degeneracy for Δ's is found against theoretical proposals [4] that have been questioned recently [5]. Though new experimental data, to confirm or discard the validity of our predictions, are definitely needed we think the *symmetry way* can be of great interest to guide experimental searches.

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