On the nature of the lowest $1/2^-$ baryon nonet and decuplet

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1 Introduction

The classical simple 3q constituent quark model has been very successful in explaining the static properties, such as mass and magnetic moment, of the spatial ground states of the flavor SU(3) octet and decuplet baryons. Its predicted Ω baryon with mass around 1670 MeV was discovered by later experiments. However its predictions for the spatial ground states of the flavor SU(3) octet and decuplet baryons. Its predicted mass and magnetic moment, of the spatial ground states of the lowest spin-parity 1/2− baryons, N*(1535) and Δ*(1620), new pictures for the internal structure of the lowest 1/2− baryon octet and decuplet are proposed. While the lowest 1/2− baryon octet may have large diquark-diquark-antiquark component, the lowest 1/2− baryon decuplet is proposed to have large vector-meson-baryon components. Evidence for the “missing” members of the new pictures is pointed out and suggestions are made for detecting these predicted states from forthcoming experiments.

2 Nature of N*(1535) and its 1/2− nonet partners

Recently BES experiment at Beijing Electron-Positron Collider (BEPC) has been producing very useful information on N* resonances [6-8,9]. In J/ψ → ¯pπη, as expected, the N*(1535) gives the largest contribution [6]. In J/ψ → pK−A + c.c., a strong near-threshold enhancement is observed for KΛ invariant mass spectrum [7] as duplicated in Fig. 1. The KΛ threshold is 1609 MeV. The near-threshold enhancement is confirmed by J/ψ → nKSÅ + c.c. [9]. Since the mass spectrum divided by efficiency and phase space peaks at threshold, it is natural to assume it comes from the sub-threshold nearby N*(1535) resonance. Then from BES branching ratio results on J/ψ → ¯ppη [6] and ψ → pK−A + c.c. [7], the ratio between effective coupling constants of N*(1535) to KA and pn is deduced to be [10]

$$g_{N^*(1535)KA}/g_{N^*(1535)pn} = 1.3 \pm 0.3$$

With previous known value of $g_{N^*(1535)Nn}$, the obtained new value of $g_{N^*(1535)KA}$ is shown to reproduce recent pp → pK−A near-threshold cross section data [11] as well. There are also indications for the large g_{N^*(1535)KA} from partial wave analysis of γp → KA reactions [12]. Taking into account this large N*KA coupling in the coupled channel Breit-Wigner formula for the N*(1535), its
Breit-Wigner mass is found to be around 1400 MeV, much smaller than previous value of about 1535 MeV obtained without including its coupling to $K\Lambda$. There is also evidence for large $g_{N^*(1535)N\eta'}$ coupling from $\gamma p \rightarrow p\eta'$ reaction at CLAS [13], and large $g_{N^*(1535)N\phi}$ coupling from $\pi^- p \rightarrow n\phi$ and $pp \rightarrow p\phi\phi$ reactions [14], but smaller coupling of $g_{N^*(1535)K\Sigma}$ from comparison of $pp \rightarrow pK^+\Lambda$ to $pp \rightarrow pK^+\Sigma^0$ [15].

The nearly degenerate mass for the $N^*(1535)$ and the $N^*(1440)$ resonances can be easily understood by considering 5-quark components in them [10,16]. The $N^*(1535)$ could be the lowest $L = 1$ orbital excited $|uud>$ state with a admixture of $|ud|<us|\bar{s}>$ pentaquark component having $|ud|$, $|us>$ and $\bar{s}$ in the ground state. The $N^*(1440)$ could be the lowest radial excited $|uud>$ state with a admixture of $|ud|<ud|\bar{d}>$ pentaquark component having two $|ud>$ diquarks in the relative P-wave. While the lowest $L = 1$ orbital excited $|uud>$ state should have a mass lower than the lowest radial excited $|uud>$ state, the $|ud|<us|\bar{s}>$ pentaquark component has a higher mass than $|ud|<ud|\bar{d}>$ pentaquark component. The large mixture of the $|ud|<us|\bar{s}>$ pentaquark component in the $N^*(1535)$ may also explain naturally its large couplings to the $N\eta$, $N\eta'$ and $K\Lambda$ meanwhile small couplings to the $N\pi$ and $K\Sigma$. In the decay of the $|ud|<us|\bar{s}>$ pentaquark component, the $|ud>$ diquark with isospin $I = 0$ is stable and keeps unchanged while the $|us>$ diquark is broken to combine with the $\bar{s}$ to form either $K^-<us|\Lambda(|ud|s)$ or $\eta(s\bar{s})\rho(<ud|u>)$.

The lighter $\Lambda^*(1405)1/2^-$ is also understandable in this picture. Its main 5-quark configuration is $|ud|<us|\bar{s}>$ which is lighter than the corresponding 5-quark configuration $|ud|<us|\bar{s}>$ in the $N^*(1535)1/2^-$. If this picture of large 5-quark mixture is correct, there should also exist the SU(3) nonet partners of the $N^*(1535)$ and $\Lambda^*(1405)$, i.e., an additional $\Lambda^* 1/2^-$ around 1570 MeV, a triplet $\Sigma^* 1/2^-$ around 1360 MeV and a doublet $\Xi^* 1/2^-$ around 1520 MeV [16]. There is no hint for these baryon resonances in the PDG tables [1]. However, as pointed out in Ref. [2], there is in fact evidence for all of them in the data of $J/\psi$ decays. According to PDG [1], the branching ratios for $J/\psi \rightarrow \Sigma^-\Sigma^0(1385)^+$ and $J/\psi \rightarrow \Xi^+\Xi^-(1530)^0$ are $(3.1 \pm 0.5) \times 10^{-4}$ and $(5.9 \pm 1.5) \times 10^{-4}$, respectively. These two processes are SU(3) breaking decays since $\Sigma$ and $\Xi$ belong to SU(3) 1/2 + octet while $\Sigma^0(1385)$ and $\Xi^-(1530)$ belong to SU(3) 3/2+ decuplet. Comparing with the similar SU(3) breaking decay $J/\psi \rightarrow \bar{p}\Delta^+$ with branching ratio of less than $1 \times 10^{-4}$ and the SU(3) conserved decay $J/\psi \rightarrow \bar{p}N^*(1535)^+$ with branching ratio of $(10 \pm 3) \times 10^{-4}$, the branching ratios for $J/\psi \rightarrow \Sigma^-\Sigma^+(1385)^+$ and $J/\psi \rightarrow \Xi^+\Xi^-(1530)^-$ are puzzling too high. A possible explanation for this puzzling phenomena is that there were substantial components of $1/2^-$ under the 3/2 + peaks but the two branching ratios were obtained by assuming pure 3/2 + contribution. This possibility should be easily checked with the high statistics BESIII data in near future.

3 Nature of $\Delta^{++}(1620)$ and its $1/2^-$ decuplet partners

The spectrum of isospin 3/2 $\Delta^{++}$ resonances is of special interest since it is the most experimentally accessible system composed of 3 identical valence quarks. However, our knowledge on these resonances mainly comes from old $\pi N$ experiments and is still very poor [1]. A possible new excellent source for studying $\Delta^{++}$ resonances is $pp \rightarrow nK^+\Sigma^+$ reaction, which has a special advantage for absence of complication caused by $N^*$ contribution because of the isospin and charge conversation.

At present, little is known about the $pp \rightarrow nK^+\Sigma^+$ reaction. Experimentally there are only a few data points about its total cross section versus energy [17,18]. Theoretically a resonance model with an effective intermediate $\Delta^{++}(1920)$ resonance [19] and the Jülich meson exchange model [20] reproduce the old data at higher beam energy [17] quite well, but their predictions for the cross sections close to threshold fail by order of magnitude compared with very recent COSY-11 measurement [18]. Recently this reaction was restudied [21]. With an effective Lagrangian approach, contributions from a previous ignored sub-$K^+\Sigma^+$-threshold resonance $\Delta^{++}(1620)1/2^-$ are fully included in addition to those already considered in previous calculations. It is found that the $\Delta^{++}(1620)$ resonance gives an overwhelmingly dominant contribution for energies very close to threshold, with a very important contribution from the t-channel $\rho$ exchange as shown in Fig. 3. This solves the problem that all previous calculations seriously underestimate the near-threshold cross section by order(s) of magnitude.

Meanwhile the extra-ordinary large coupling of the $\Delta^{++}(1620)$ to $\rho N$ obtained from the $\pi^+p \rightarrow N\pi\pi$ [11,22] seems confirmed by the new study [21] of the strong near-threshold enhancement of $pp \rightarrow nK^+\Sigma^+$ cross section. Does the $\Delta^{++}(1620)$ contain a large $\rho N$ molecular component or relate to some $\rho N$ dynamical generated state? If so, where to search for its SU(3) decuplet partners? Sarkar et al. [23] have studied baryonic resonances from...
baryon decuplet and pseudoscalar meson octet interaction. It would be of interests to study baryonic resonances from baryon octet and vector meson octet interaction. In fact, from PDG compilation [1] of baryon resonances, there are already some indications for a vector-meson-baryon SU(3) decuplet. While the $\Delta^*(1620)1/2^−$ is about 85 MeV below the $N\rho$ threshold, there is a $\Sigma^*(1750)1/2^−$ about 70 MeV below the $NK^+$ threshold and there is a $\Xi^*(1950)?^−$ about 60 MeV below the $AK^+$ threshold. If these resonances are indeed the members of the $1/2^- SU(3)$ decuplet vector-meson-baryon S-wave states, we would expect also a $\Omega^*1/2^−$ resonance around 2160 MeV. All these baryon resonances can be searched for in high statistic data on relevant channels from vector charmonium decays by upcoming BES3 experiments in near future.

4 Conclusion

While the classical 3q constituent quark model works well in reproducing properties of baryons in the spatial ground states, the study of $1/2^- baryons seems telling us that the $qqqq$ in S-state is more favorable than $qq$ with $L = 1$. In other words, for excited baryons, the excitation energy for a spatial excitation could be larger than to drag out a $qq$ pair from gluon field.

Whether the $qqqq$ components are in penta-quark configuration or meson-baryon configuration depends on the strength of relevant diquark or meson-baryon correlations.

For $N^*(1535)$ and its $1/2^- SU(3)$ nonet partners, the diquark cluster picture for the penta-quark configuration gives a natural explanation for the longstanding mass-reverse problem of $N^*(1535)$, $N^*(1440)$ and $\Lambda^*(1405)$ resonances as well as the unusual decay pattern of the $N^*(1535)$ resonance. Its predictions of the existence of an additional $\Lambda^* 1/2^- \sim 1570$ MeV, a triplet $\Sigma^* 1/2^- \sim 1360$ MeV and a doublet $\Xi^* 1/2^- \sim 1520$ MeV [16] could be examined by forth coming experiments at BEPC2, CEBAF, JPARC etc..

For $\Delta^{++}(1620)$ and its $1/2^- SU(3)$ decuplet partners, their SU(3) quantum numbers do not allow them to be formed from two good scalar diquarks plus a $q$. Then their $qqqq$ components would be mainly in the meson-baryon configuration. This picture can be also examined by forth coming experiments.

Acknowledgements I would like to B.C.Liu, J.J.Xie and H.C.Chiang for collaborations on relevant issues. This work is partly supported by the National Natural Science Foundation of China under grants Nos. 10435080, 10521003 and by the Chinese Academy of Sciences under project No. KJCX3-SYW-N2.

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![Fig. 2. Total cross section vs kinetic energy of proton beam for the $pp \to nK^+ \Sigma^+$ reaction: data [17,18] and calculation (solid curve for sum of other curves) [21].](image)

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