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Implications of an η–Baryon Octet for Quark Model Classification

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Abstract

Recent tantalizing experimental support for an η–baryon $J^P = 1/2^-$ **unmixed** octet challenges the conventional wisdom. Establishment of the $\Xi(1868)$ member of the η–baryon octet will give strong **affirmation** that negative parity baryon mass spectrum below say 2 GeV could be largely **mixing free**. Implications of the existence of such a baryon octet for the negative parity $(70,1^-)$ baryon mass spectrum classification of the quark model are briefly discussed.

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Historical Perspective

For a problem with a history of some 28 years, it is important to begin by evaluating the historical perspective of the situation as it unravels in time. In August (1964) there was a theoretical explosion of work on SU(6) symmetry classification of hadron states according to

$$[SU(3)_F,\ 2J+1] \tag{1}$$

breakdown following the seminal papers of Gürsey, Radicati, and Sakita [1]; here F denotes flavor and J the (mechanical) spin. The lowest SU(6) L = 0 states are given by

$$56^+ = (8,2) + (10,4)$$
$$35^- = (8,1) + (8,3) + (1,3) \tag{2}$$

where the (8,2) of the 56^+ is the well known $1/2^+$ octet baryon states [N(939), Λ(1115), Σ(1192), Ξ(1320)] while the decuplet (decimet) (10,4) includes the lowest lying $3/2^+$ states [Δ(1232), Σ(1385), Ξ(1530), Ω^-(1672)]; for the meson 35^- states the (8,1) is the basic 0^- octet pseudoscalar mesons (π, K, $\bar{K}$, η) while the (8,3) and (1,3) include the 1^- nonet vector meson set (ρ, K*, $\bar{K}$*, ω, ϕ). The meson classification was later modified to U(6) to include the (1,1) singlet pseudoscalar member η'(958).

Pais [2] then proposed that for the negative parity baryon states under SU(6) we deploy the next smallest representation, namely the 70 with negative parity (for L=0) essentially put in by hand, to wit

$$70^- = (1,2)^- + (8,2)^- + (10,2)^- + (8,4)^-. \tag{3}$$

Bég and Singh [3] worked out the detailed mass formula for 70^-, L = 0 in SU(6), **but where are these states?** Pais [2] knew that Λ(1405) with $J^P = 1/2^-$ could be the $(1,2)^-$ member.

I visited Brookhaven in August (1964) and was attracted by the Pais paper for admittedly rather personal reasons, namely the $(1,2)^-$ member was one whose physical

existence was predicted by Dick Dalitz and I [4] some five years earlier. Hence I was more than casually interested to help Bram Pais achieve his goal of filling out the remaining negative parity baryon states according to (3). I pointed out to him the following possibilities:-

1. The Glashow-Rosenfeld [5] postulate of a γ-octet of $3/2^-$ baryon states needs to follow the assignments of A. W. Martin [6] for an **unmixed** octet satisfying the Gell-Mann-Okubo mass formula, namely

$$N_\gamma(1512),\ \Lambda_\gamma(1661),\ \Sigma_\gamma(1660),\ \Xi_\gamma(1810), \qquad (4)$$

from the $[3\Lambda + \Sigma]/4 = [N + \Xi]/2$ octet formula. One must remember that back in 1964, there was only very fragmentary evidence for the $\Sigma_\gamma(1660)$ and $\Xi_\gamma(1810)$ and no evidence at all for the $\Lambda_\gamma(1661)$! Hence as we shall see below Arthur W. Martin deserves a great deal of credit for his bold hypothesis.

2. We leave open the status of $\Lambda_\gamma(1520)$ with $J^P = 3/2^-$ which was assigned by Glashow-Rosenfeld [5] to the γ-octet, but was argued from dynamical grounds [6] to be an unitary singlet (1,4) even in the early days of 1964.

3. We postulate the existence of an η-baryon octet set of states with $J^P = 1/2^-$ associated with **S-wave** $\eta + N$, $\eta + \Lambda$, $\eta + \Sigma$, and $\eta + \Xi$ threshold interactions. Hence such states are expected within say 50 MeV of the appropriate threshold, i.e. they satisfy the Gell-Mann-Okubo octet mass formula to an accuracy of about 3%, **shifted by the η-mass scale** from the canonical $J^P = 1/2^+$ baryon octet [N(939), Λ(1115), Σ(1192), Ξ(1320)]. In 1964, S-wave "resonances" near $N + \eta$, $\Lambda + \eta$ thresholds were hinted by a number of experiments [7], hence Pais thought conjecture 3 was an "useful piece of physical speculation" and proceeded to name it the **η-octet.**

Pragmatically, from the above hypotheses the six mass inputs from Λ(1405) as (1,2), $N + \eta$ and $\Lambda + \eta$ as members of (8,2), and N_γ, Σ_γ, and Ξ_γ as members of (8,4) for which some experimental evidence for their existence can be argued, enable the remaining

seven masses of 70^-, L = 0 to be computed from the 7 Bég–Singh mass formula equations [3]. This was done by I. P. Gyuk and I [8] and in fact some of the solutions found, supported the η–octet hypothesis.

Nevertheless by (1965), the existence of $\Sigma(1775)$ with $J^P = 5/2^-$ became known experimentally. Furthermore $\Lambda(1520)$ needs to be accomodated as a $J^P = 3/2^-$ state in (1,4) which does not exist in the Pais 70^-, L = 0 scheme as evident from Eq. (3). Here Dalitz [9] made a brilliant generalization to the three quark model with internal orbital excitation L = 1 for the 70 representation, leading to 70 x 3 [2L+1 = 3] entries and decomposition into flavor SU(3) and spin subsets as follows:–

$$(70,\ L = 1) = (8,6)^- + (10+8+8+1,4)^- + (10+8+8+1,2)^-. \qquad (5)$$

Negative parity (–) is natural from L = 1 orbital amongst the qqq quark system; (8,6) accomodates the $\Sigma(1775)$ with $J^P = 5/2^-$; the $\Lambda(1520)$ fits nicely into the (1,4) slot of Eq. (5).

Consequence:

The 70^-, L = 0 SU(6) multiplet [2] together with the Bég–Singh mass formulae [3] were promptly abandoned by the world at large, and the Dalitz quark model with 70^-, L = 1 [9] became the standard model. We have been admonished in every day life not to "throw the baby out with the bath water". The η–octet and (to some extent) Martin's version of the γ–octet as possible assignments in SU(3) [logically a separate issue distinct from SU(6) classification] became the "baby" thrown out by association with the Pais–Bég–Singh work in 1964.

Some digressive remarks are appropriate here. Back in 1970, R. P. Feynman was already thinking along the lines of the relativistic harmonic oscillator model for baryon states. With his outstanding charisma, it was not too difficult for him to persuade yours truly of the following Feynman rule for $(\text{mass})^2$ of baryon states [10]

$$\text{Sign}\ [\Sigma^2 - \Lambda^2] = \text{Parity of the state.} \qquad (6)$$

The η-octet with $J^P = 1/2^-$ where $\Sigma > \Lambda$ violates this rule and must be discarded if one wishes to write a paper with Feynman and I confess that in my younger days I did have a weakness for collaborative papers with distinguished co-author(s)! One can also understand why Feynman did not believe in the MacDowell-Gribov parity doubling degeneracy for baryons, since it did not sit well with his rule (6). However I understand that parity doubling has again come back into fashion in certain aspects of supersymmetry.

Worse News to Come

For the η-octet hypothesis there was indeed worse news to come in the generation following 1970.

(a) Isgur and Karl [11] "canonized" the Feynman rule (6) through a QCD inspired Hamiltonian, deploying harmonic oscillator wave functions as a good approximation to the eigenfunctions of low-lying baryon states bound by Coulomb-plus-linear potentials. Not good for the η-octet hypothesis!

(b) The decomposition of 70^-, L = 1 into flavor SU(3)-spin states according to Eq. (5) affords plenty of opportunity for the η-octet and the γ-octet belonging to (8,2) and (8,4) respectively **to be mixed**, leading to appreciable distortion of the pattern of mass-values from that expected for isolated unitary multiplets. Hence significant departures from the unmixed Gell-Mann-Okubo octet mass formula could arise.

Indeed the era of 1970's and 1980's saw much detailed work [12] that **negative parity baryon states are mixed, from analysing decay data.** Thus the contradiction with η and γ octets which are hypothesized to be mixing free, has grown over the years.

The Resurrection

Renewed interest on my part in this topic occurred at the Hadron Spectroscopy Summer Colloquium (HSSC91) in August of 1991. In particular I was stimulated by the lectures of Hans Siebert on **Excited and Charmed Baryons.** I proceeded to apply the

principle of "seeking truth from facts" and ask what does the 1990 data **really** say about baryon mass spectrum, ignoring theoretical prejudices [another Feynman principle, though to my knowledge not published].

Back in 1964, workers in SU(3) symmetry have been accustomed to the following rule-of-thumb concerning SU(3) symmetry-breaking behavior pattern.

(i) Symmetry breaking in mass formula leads to the most accurate relationships. (ii) Symmetry breaking (e.g. mixing) in decay relationships are less accurate than mass formula predictions. (iii) Symmetry breaking scattering relationships are the least accurate when confronted with data.

Let us therefore analyse the data pattern under (i) above. From an experimental point of view and let us be current and use the Review of Particle Properties [Phys. Rev. D45, Part II, June 1 (1992)], the following facts can be gleaned:-

•Increasing support for an η-octet (8,2) associated with η + N [N(1535], η + Λ [Λ(1670)], η + Σ [Σ(1750)] S-wave threshold interactions {and within 50 MeV of their thresholds that we conjecture as acceptable}. These experimentally known $J^P = 1/2^-$ members all have significant coupling to the appropriate corresponding η + baryon channel, in the range 15% to 55% in decay partial width.

•The (8,4) $J^P = 3/2^-$ γ-octet [N(1520), Λ(1690), Σ(1670), Ξ(1820)] appears complete. Negative parity of Ξ(1820) is strongly indicated by the hyperon-beam experiment of S. F. Biagi et al. [13]. Here again an **unmixed** Gell-Mann-Okubo octet mass formula is satisfied to a **high degree** of accuracy, and incidentally this experimental γ-octet is only marginally different from Martin's original assignment [6] back in 1964.

Thus we could entertain the question whether negative parity baryon mass spectrum below say 2 GeV is largely mixing free. Phenomenologically we need to keep in mind the following:-

•The celebrated 70^-, L = 1 qqq quark model classification of baryon states is in fact not satisfactory in several respects. (α) Even the key assignments of $\Lambda(1520)$ to (1,4) and $\Lambda(1405)$ to (1,2) in (5) would suggest an **unattractive** large spin-orbit contribution to the model due to the size of the mass splitting here [10]. (β) The most serious candidate theory for $\Lambda(1405)$ is the chiral cloudy bag model [14]. This finds that $\Lambda(1405)$ is a superposition of three-quark and $\bar{K}N$ configurations, **but mostly (≅90%) the latter!** (γ) To circumvent the $\Lambda(1520)$ - $\Lambda(1405)$ large mass splitting problem for the standard quark model, R. L. Jaffe [15] has made the novel suggestion that such a splitting could be better understood by regarding $\Lambda(1405)$ $1/2^-$ state as an hybrid g(uds) state where (uds) is in $1/2^+$ and g is the gluon.

The **moral** we derive from the above is that if we do not even know the (1,2) and (1,4) members of 70^-, L = 1, how can we claim that the 70^-, L = 1 assignments are now "understood"? In revealing the η-baryon and γ-baryon octets to us, nature could be providing us with a **significant clue** - i.e. largely unmixed $1/2^-$ and $3/2^-$ baryon octets to guide future model building!

Experimental Test

Of course the "smoking gun" experimental test is the **establishment of the Ξ member of the η-octet which is expected in the neighborhood of the $\eta + \Xi$ threshold as a $J^P = 1/2^-$ $\Xi(1868)$ state with significant S-wave coupling to the $\eta + \Xi$ channel.** As an S = -2 baryon state, $\Xi(1868)$ can be searched for in production experiments involving three body final states like $K^- + p \rightarrow K^+ + \Xi(1868) \rightarrow K^+ + \eta^o + \Xi^-$ (from LASS or the future KAON at Triumf), $\bar{p} + p \rightarrow \bar{\Xi} + \Xi(1868) \rightarrow \bar{\Xi} + \eta^o + \Xi^-$ (from SUPER LEAR), and $\Xi^- + N \rightarrow \Xi(1868) + N \rightarrow \Xi^- + \eta^o + N$ (from CERN hyperon beam experiments). The challenge for production experiments is that in terms of current technology only narrow states (as peaks in the mass distributions) can be identified, furthermore overlaps are difficult to resolve, and spin-parity can be determined only in

exceptional cases. Nevertheless, the $\Xi(1868)$ may follow the pattern of other well established Ξ resonances in being relatively narrow. There is also the significant signature of being close to the $\Xi + \eta$ threshold as well as reasonably strongly coupled to this channel might help with the other difficulties mentioned.

For the spin-parity analysis of the $\Xi(1868)$, the formalism of Biagi et al. [13] (see particularly Section 5 and Appendix A therein) used to study $\Xi(1820) \rightarrow \Lambda \bar{K}^o$, with Λ decaying subsequently to $p + \pi^-$ and the analogous case of $\Xi(1960)$ is generally adequate for adaptation to our case. The method of analysis of Ref. [13] is based on earlier work of Chung [16] and Byers and Fenster [17]. In our situation the $\Xi(1868)$ should decay to $\Xi(1320)$ with $J^P = 1/2^+$ and η^o with $J^P = 0^-$. It is very important that the decay of the daughter baryon is not parity-conserving and thus allows one to determine the polarization of the daughter. The analysing power is given by the well-known α parameter, which is especially high in Λ decay (+0.64) but still large in Ξ decay (-0.46 for Ξ^-). Since one forms ratios of correlations, the value of α actually drops out, but the larger the α, the better the chances are to observe non-zero correlations.

Clearly development of adequate experimental search method for $\Xi(1868)$ is of greater relevance at this stage than a detailed theoretical quantitative analysis.

Theoretical Remarks:

(I) The dynamical basis for understanding these S-wave η-baryon interactions as virtual bound states or quasi-bound states (if $\Xi(1868)$ is below the $\Xi + \eta^o$ threshold) had been proposed by Frazer and Hendry, myself, and Dobson amongst others in Physical Review articles [18] of that early era when the experimental data on $\eta + N$ were beginning to surface. In current language this is the **molecular** approach emphasizing $q\bar{q}$ η-interaction with the qqq baryon, thus the η-octet would more naturally find its niche in a five quark configuration $q\bar{q}qqq$ under the classification of states. Hence this octet would not necessarily fit well with the 70^-, $L = 1$ qqq classification of conventional

wisdom. The situation is not necessarily shocking since Ron Longacre in his lectures at the Summer Colloquium (HSSC91) on **Quark Model and Beyond**, suggested a similar possibility for the meson spectra where the conventional wisdom is classification by $q\bar{q}$ with L-excitation. The suggestion here is that the well known E(1420) [now called $f_1(1420)$] with $J^{PC} = 1^{++}$ might also have a molecular structure $K\bar{K}\pi$ and/or $K^*\bar{K}$ and hence beyond the standard $q\bar{q}$ classification.

(II) The recent work of Morpurgo [19] on a new mass formula for octet baryons shifts our prediction for $\Xi(1868)$ to $\Xi(1872)$ and hence does not affect the overall picture presented here.

(III) There is an interesting paper by Hanqing ZHENG on "Chiral Theory with $1/2^-$ Octet Baryons" [20] where he independently identified the N(1535), $\Lambda(1670)$, and $\Sigma(1750)$ members of the η-octet. His emphasis is however on the parity doublet model that comes from the study of the EMC effects. Suffice for us to conclude here on an optimistic note that interest in this general area is picking up!

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References

[1] F. Gürsey and L. Radicati, Phys. Rev. Lett. **13**, 173 (1964);
B. Sakita, Phys. Rev. **136**, B1756 (1964).

[2] A. Pais, Phys. Rev. Lett. **13**, 175 (1964).

[3] M. A. B. Bég and V. Singh, Phys. Rev. Lett. **13**, 418 (1964).

[4] R. H. Dalitz and S. F. Tuan, Phys. Rev. Lett. **2**, 425 (1959).

[5] S. Glashow and A. Rosenfeld, Phys. Rev. Lett. **10**, 192 (1963).

[6] A. W. Martin, Nuovo Cimento **32**, 1645 (1964);
A. W. Martin and K. C. Wali, Nuovo Cimento **31**, 1324 (1964).

[7] See Refs. 15–22 in Gyuk and Tuan [8] below.

[8] I. P. Gyuk and S. F. Tuan, Phys. Rev. Lett. **14**, 121 (1965);
S. Pakvasa and S. F. Tuan, Nucl. Phys. **B8**, 95 (1968).

[9] R. H. Dalitz, Quark Models for the Elementary Particles, Chapter in **High Energy Physics** (Gordon and Breach, New York, 1966), p. 253.

[10] R. P. Feynman, S. Pakvasa, and S. F. Tuan, Phys. Rev. **D2**, 1267 (1970).

[11] N. Isgur and G. Karl, Phys. Lett. **72B**, 109 (1977);
N. Isgur and G. Karl, Phys. Rev. **D18**, 4187 (1978).

[12] A. J. G. Hey, P. J. Litchfield, and R. J. Cashmore, Nucl. Phys. **B95**, 516 (1975); see also A. J. G. Hey and R. L. Kelly, Phys. Rep. **96**, 75 (1983).

[13] S. F. Biagi et al., Z. Phys. **C34**, 175 (1987).

[14] R. H. Dalitz and A. Deloff, J. Phys. G: Nucl. Part. Phys. **17**, 289 (1991);
E. A. Veit et al., Phys. Rev. **D31**, 1033 (1985).

[15] R. L. Jaffe, private communication.

[16] S. U. Chung, CERN 71–8 (1971).

[17] N. Byers and S. Fenster, Phys. Rev. Lett. **11**, 52 (1963).

[18] W. R. Frazer and A. W. Hendry, Phys. Rev. **134**, B1307 (1964);
S. F. Tuan, Phys. Rev. **139**, B1393 (1965);
P. N. Dobson Jr., Phys. Rev. **146**, B1022 (1966).

[19] G. Morpurgo, Phys. Rev. Lett. **68**, 139 (1992).

[20] Hanqing ZHENG, CERN-TH.6522/92.

[21] S. F. Tuan, Phys. Rev. **D46**, No. 9, November 1 issue (1992).