The η-baryon octet

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The recent tantalizing experimental support for an η-baryon $J^P=\frac{1}{2}^-$ unmixed octet challenges conventional model wisdom. The establishment of the $\Xi(1868)$ member of the η octet will give strong affirmation that the negative-parity baryon mass spectrum could be mixing-free.

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More than a quarter of a century ago, Gyuk and I postulated the existence of an η-baryon octet [1] of $J^P=\frac{1}{2}^-$ states associated with the 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 thresholds, and satisfy to an accuracy of order 3% in mass, the *unmixed* Gell-Mann–Okubo octet mass formula $[3\Lambda+\Sigma]/4=[N+\Xi]/2$. The η-baryon octet, shifted by the mass scale of the η meson from the canonical $J^P=\frac{1}{2}^+$ baryon octet, are predicted to have the characteristic experimental signature of *significant* strong decay couplings to the associated $\eta+$baryon channels. A dynamical basis for understanding these η-baryon S-wave interactions as virtual states [2] was proposed. In current language this would emphasize the primary $(q\bar{q})$ η interaction with the (qqq) baryon akin to a $(q\bar{q}qqq)$ system of classification; hence, it would not necessarily fit well with a 3-quarks (qqq) interpretation of conventional wisdom. We also endorsed the proposal of Glashow and Rosenfeld [3] for an *unmixed* Gell-Mann–Okubo γ octet with $J^P=\frac{3}{2}^-$. However, for dynamical reasons, we favored the assignment of Martin [4] that the γ octet is the set $[N_\gamma(1512), \Lambda_\gamma(1661), \Sigma_\gamma(1660), \Xi_\gamma(1810)]$ with $\Lambda(1520)$ regarded as a unitary singlet rather than as a member of the γ octet.

Our *unmixed* negative-parity baryon states hypothesis was quickly ignored with the advent of the $(70,1^-)$ three-quark model of Dalitz [5]. Here it was pointed out that both the η octet and the γ octet must belong to the (8,2) and (8,4) members of the $(70,1^-)$ decomposition into SU(3) and spin subsets, to wit $(70,1^-)=(8,6)+(10+8+8+1,4)+(10+8+8+1,2)$. Hence η and γ octets of given J^P may be mixed by the SU(3) symmetry-breaking interactions. This could lead to appreciable distortion of the pattern of mass values from that expected for isolated unitary multiplets. There could arise significant departures from the Gell-Mann–Okubo octet mass formula for instance, and this could lead to quite a complex situation to disentangle. Indeed the era of the 1970s saw much detailed work that the negative-parity baryon states *are mixed*, both from analyzing decay data [6] and through the predictions of a QCD-inspired Hamiltonian [7] based on the importance of hyperfine interaction (and *lack of importance of spin-orbit coupling*). This latter approach of Isgur and Karl [7] deploys harmonic oscillator wave functions as a good approximation to the eigenfunctions of low-lying baryon states of a QCD-type system bound by Coulomb-plus-linear potentials. In particular the Λ member of the negative-parity baryon octet is expected to lie *higher* in mass than the Σ member—contrary to the η octet hypothesis.

Yet from a theoretical point of view, the situation with the $(70,1^-)$ negative-parity baryon states in standard three-quark language has been less than totally satisfactory. For instance, the key assignments of the $\Lambda(1520)$ to (1,4) and $\Lambda(1405)$ to the (1,2) of $(70,1^-)$ would suggest a *large* spin-orbit contribution due to the size of the mass splitting [8]. Furthermore the most serious candidate theory is the chiral cloudy bag model [9], which finds that $\Lambda(1405)$ is a superposition of three-quark and $\bar{K}N$ configurations, *but mostly (≅90%) the latter.* Indeed Jaffe [10] has suggested that the large mass splitting with $\Lambda(1520)$ could be better understood if the $\Lambda(1405)$ $\frac{1}{2}^-$ state is regarded as a hybrid $g(uds)$ state where (uds) is in $\frac{1}{2}^+$ and g is the gluon. There is increasing evidence recently that the hadron mass spectra are both richer and more complex than can be handled by the accepted classification schemes even at relatively low energies. From an experimental viewpoint the Particle Data Group (PDG) [J. J. Hernández *et al.*, Phys. Lett. B **239**, 1 (1990)] give increasing support for an (8,2) η octet associated with $\eta+N[N(1535)]$, $\eta+\Lambda[\Lambda(1670)]$, $\eta+\Sigma[\Sigma(1750)]$ S-wave threshold interactions. These experimentally known members all have significant coupling to the appropriate $\eta+$baryon channel, in the range 15 to 55 % in decay partial width. Of course, the (8,4) $J^P=\frac{3}{2}^-$ γ octet $[N(1520), \Lambda(1690), \Sigma(1670), \Xi(1820)]$ appears complete [negative parity of the $\Xi(1820)$ is indicated by the hyperon-beam experiment of Biagi *et al.* [11]]. Here again an *unmixed* Gell-Mann–Okubo octet mass formula is satisfied to a high degree of accuracy, and is incidentally only marginally different from Martin's original assignment [4]. Hence unlike the meson spectra, the negative-parity baryon mass spectrum could be largely free from mixing. My *purpose* here is therefore to affirm that nature is giving us a significant clue, which needs to be deployed as input into future theoretical discussions about baryon states.

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*

$J^P=\frac{1}{2}^-$ *Ξ(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 such as $K^-+p\rightarrow K^+ +\Xi(1868)\rightarrow K^+ +\eta^0+\Xi^-$ (from LASS or the future KAON factory at TRIUMF), $\bar{p}+p\rightarrow\bar{\Xi}+\Xi(1868)\rightarrow\bar{\Xi}+\eta^0+\Xi^-$ (from Super LEAR at CERN?), and $\Xi^-+N\rightarrow\Xi(1868)+N\rightarrow\Xi^-+\eta^0+N$ (from CERN hyperon beam experiments). Production experiments in current technology have the disadvantage that only narrow states (as peaks in the mass distributions) can be identified, overlaps are difficult to resolve, and spin parity can be determined only in exceptional cases. Nevertheless the $\Xi(1868)$ may well follow the pattern of other well established Ξ resonances of being relatively narrow, and the significant signature of being close to the $\Xi+\eta$ threshold and reasonably strongly coupled to this channel might help with the other difficulties mentioned. Development of adequate experimental search methods for such a state is evidently of greater relevance at this stage than a detailed theoretical quantitative analysis.

Remarks: (a) Though mixing seems to be established for the more prominent meson multiplets in the $(q\bar{q})$ L-excitation model, it remains to be seen whether even some reasonably well-confirmed mesonic states can be so interpreted in this framework. For instance Chung [12] pointed out that the $E(1420)$ is likely a $K^*\bar{K}$ molecule (hence $q\bar{q}q\bar{q}$ in quark model classification) with $J^{PC}=1^{++}$ according to the Longacre model. Hence even setting aside issues such as glueballs and hybrid $q\bar{q}g$, our knowledge of the mesonic spectrum below say 2 GeV, such as the baryon qqq case discussed above, is also quite incomplete based on the naive $q\bar{q}$ orbital and radial excitation model. (b) The recent work of Morpurgo [13] 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. (c) For the spin-parity analysis of the $\Xi(1868)$, the formalism of Biagi *et al.* [11] (see particularly Sect. 5 and Appendix A therein) used to study $\Xi(1820)$ to $\Lambda\bar{K}^0$, with Λ decaying to $p+\pi^-$ and the analogous $\Xi(1960)$ is generally adequate for adaptation to our case. The method of analysis of Ref. [11] is based on earlier work of Chung [14] and Byers and Fenster [15]. In our situation the $\Xi(1868)$ should decay to $\Xi(1320)(J^P=\frac{1}{2}^+)+\eta^0(J^P=0^-)$. 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 analyzing 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 $\Xi^-)$. 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 nonzero correlations.

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