Proposal for a new hadron nomenclature. I – Baryons

Gaëtan Landry* and others
Département de Physique et d'Astronomie, Université de Moncton, Moncton, NB, E1A 3E9, Canada.
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The current baryon nomenclature is based on the concept of isospin, introduced by Werner Heisenberg in 1932. In light of the quark model, introduced by Murray Gell-Mann in 1964, isospin (or rather its projections) is found to be a linear combination of the number of constituent up and down quarks. A historical review of particle physics prior to the advent of the quark model is given to help understand the basis of the nomenclature adopted by the Particle Data Group in 1986, with an overview of the various extensions needed to accommodate our current understanding of the six-quark universe. Because the current baryon nomenclature considers the up and down quarks to be more special than the other quarks, it clashes with the inherent (albeit broken) symmetries of the six-quark model. Several problems of clarity and conciseness are identified, and the concept of isospin is generalized to all quark symmetries. Finally, a greatly simplified baryon nomenclature is proposed to make baryon physics clearer to newcomers and experts alike, with a complete listing of current and proposed baryon names.

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I. INTRODUCTION

An essential aspects of science is how we name things. Nomenclatures, by their very nature, are designed to identify the various concepts and physical realities of science. The more a nomenclature is clear and rigorous, the more the communication of ideas is facilitated, as we can focus on the ideas themselves, rather than how to express them.

Enrico Fermi, once said to Leon Lederman, "Young man, if I could remember the names of these particles, I would have been a botanist."[1] But 58 years after his death, and 48 years after the advent of the quark model, Fermi's quote is still very much relevant. Few particle physicists could tell you *exactly* what a $\Xi_c'^+$ or Ω_b^- *is* without going back to the 1986 Review of Particle Properties from the Particle Data Group (PDG).[2] [3]

When the PDG formalized the current rules in 1986, the aim was to preserve the old names of particles as much as possible, rather than redesign them from scratch.[4] This conservatism, for lack of a better word, would come at a great cost of clarity and elegance, especially in the case of heavy baryons. Prior to the adoption of the current rules, and especially prior to the advent of the quark model, particles were viewed through the lens of isospin, an SU(2) symmetry involving the up and down quarks. While the every day universe is dominated by up and down quarks, particle physicists need to deal with all six of them.

When the quark model was proposed in 1964, there were only 18 baryons known; 8 baryons of spin-parity $J^P = \frac{1}{2}^+$, and 10 baryons of $J^P = \frac{3}{2}^+$.[5] With the prediction and subsequent discovery of the charm, bottom, and top quarks, the number of possible three-quark baryons increased from 18 to 126; 70 baryons of spin $\frac{1}{2}$, and 56 baryons of spin $\frac{3}{2}$. While isospin was an appropriate basis for the nomenclature of the known baryons in 1964, having such a nomenclature today leads to several problems of clarity and conciseness.

The situation is as if chemists, knowing only of hydrogen-1 and helium-4, decided that it was convenient to work with mass (i.e. number of nucleons), devised a chemical element nomenclature based on it, and who, for sake of tradition, kept using it long-after the discovery of isotopes and the other 118 or so elements. Chemists and non-chemists alike will agree that such a scenario is best left to fiction, and be glad that the chemical elements instead have a nomenclature based on the number of protons, which directly reflects the fundamental chemical properties of elements.

But for physicists, this is no fictional scenario, this is reality. We, knowing only of protons and neutrons, decided that it was convenient to work with mass (i.e. isospin), devised a baryon nomenclature based on it, and we, for sake of tradition, have kept using it long-after the discovery of quarks and the other 126 or so baryons. Hopefully we can collectively agree that we can (and should) do better, and move to a new nomenclature reflecting the constituent quarks, which directly reflects the fundamental properties of baryons.

II. THE ROAD TO THE QUARK MODEL:

*egl9818@umoncton.ca

FROM CHAOS TO ORDER

Hadron physics started in 1909 with the probing of gold atoms by Hans Geiger and Ernest Marsden, under the supervision of Ernest Rutherford.[6] These probing experiments led Rutherford to the discovery of the nucleus in 1911,[7] and to the discovery of the proton and prediction of the neutron in 1919.[8] Later, in 1932, James Chadwick discovered the neutron.[9] Soon after, Werner Heisenberg noticed that one could think of protons and neutrons as being two different states of a same particle, which he called nucleon (N).[10] The argument was that protons (N^+) and neutrons (N^0) behaved so similarly with respect to the strong interaction that they must have been the same particle, and that electric charge was the result of some unknown internal excitation. Not only did nucleons behaved nearly identically under the strong interaction, but they were nearly of the same mass as well (~ 940 MeV/c^2).[11]

Heisenberg thus lumped the “proton state” and “neutron state” of the “nucleon particle” together into an isospin doublet, based on the mathematics of spin. Since there were two nucleon states, one needed two isospin projections (I_z), and therefore an isospin vector ($\mathbf{I}$) of length $\frac{1}{2}$. The proton was arbitrarily assigned isospin *up* ($I_\mathrm{z} = +\frac{1}{2}$) and the neutron was assigned isospin *down* ($I_\mathrm{z} = -\frac{1}{2}$).[12]

As time progressed, particles were discovered in groups of mass, which gave further legitimacy to the concept of isospin. For example, three baryonic states with a mass of ~ 1190 MeV/c^2 were discovered in 1953 (Σ^+, Σ^-)[13] and 1956 (Σ^0).[14]. Although we now consider them to be three distinct particles, at the time of their discovery, they were thought to be three states of a single particle. These could be accommodated by an isospin vector of length 1, which would have the three isospin projections required to “explain” the three different charges. The Σ^+ was assigned $I_\mathrm{z} = +1$, the Σ^0 was assigned $I_\mathrm{z} = 0$, and the Σ^- was assigned $I_\mathrm{z} = -1$.[11] Other similar patterns appeared and were treated with the same mindset. For example, the Λ^0 of mass ~ 1115 MeV/c^2, discovered in 1951,[15, 16] was treated as an isospin singlet, and the Ξ^- and Ξ^0, discovered in 1952[17] and 1959[18] respectively, of mass ~ 1320 MeV/c^2, were treated as an isospin doublet.

In 1955, Kazuhiko Nishijima introduced the concept of η-charge,[19] which was also independently proposed by Murray Gell-Mann as *strangeness* in 1956,[20] a property related to the mass and lifetime of baryons. Plotting the light baryons in terms of mass vs isospin projection (see Figure 1), or similarly in terms of strangeness vs isospin projection (see Figure 2) would reveal a certain structure, known as the *Eightfold Way*, formalized as a broken SU(3) symmetry by Gell-Mann over the course of 1961–64,[21] and independently by Yuval Ne’eman in 1961.[22]

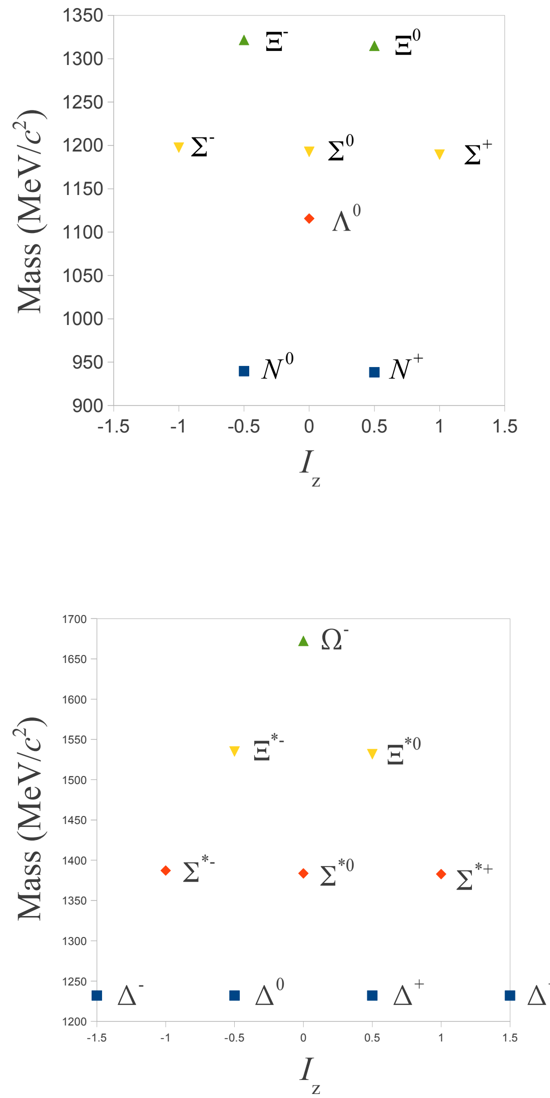

FIG. 1. The uds baryons octet (top) and decuplet (bottom).

This formalism successfully reproduced the patterns observed, which until then could only be understood via empirical formulas such as the Gell-Mann–Nishijima formula, which in 1964, looked like:

$$Q = I_\mathrm{z} + \frac{1}{2}\left(\tilde{B} + S\right) \tag{1}$$

where Q is the electric charge, I_z is the isospin projection, $\tilde{B}$ is the baryonic number (with $\tilde{B} = 1$ for all baryons), as well as related quantities, such as the hypercharge (Y):

$$Y = \left(\tilde{B} + S\right) \tag{2}$$

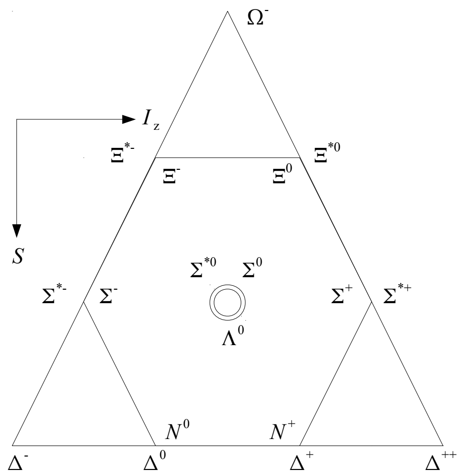

FIG. 2. The *Eightfold Way* scheme.

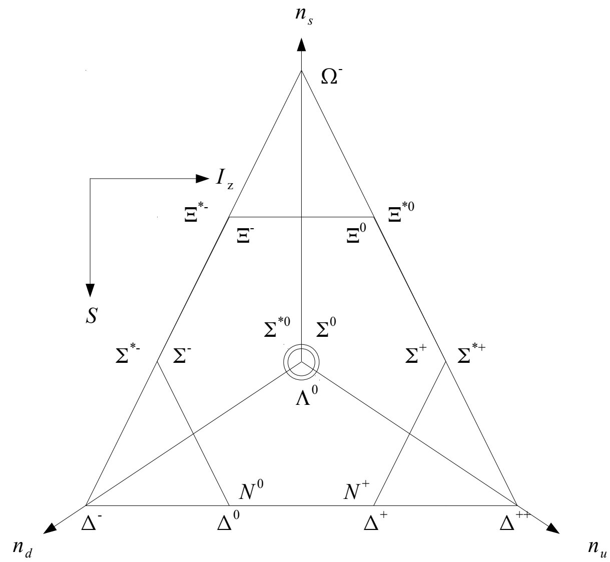

FIG. 3. The quark model scheme.

It also famously predicted the existence of the Ω^-, discovered in 1964.[23]

Soon after the discovery of the Ω^-, the quark model was proposed by Gell-Mann,[24] and independently by George Zweig[25] (who used the term *ace* instead of *quark*), to explain the physical basis behind the Eightfold Way in terms of three elementary fermions: the up, down, and strange quarks (see Figure 3). The previous formulae would, under the quark model, become:

$$\tilde{B} = \frac{1}{3}\left(n_{\mathrm{u}} + n_{\mathrm{d}} + n_{\mathrm{s}}\right) \tag{3}$$

$$S = -n_{\mathrm{s}} \tag{4}$$

$$I_{\mathrm{z}} = \frac{1}{2}\left(n_{\mathrm{u}} - n_{\mathrm{d}}\right) \tag{5}$$

where the various n_q refer to the number of quark of flavor $q \in \{\mathrm{u}, \mathrm{d}, \mathrm{s}\}$. The above, when substituted in the Gell-Mann–Nishijima formula, would give

$$Q = +\frac{2}{3}\left(n_{\mathrm{u}}\right) - \frac{1}{3}\left(n_{\mathrm{d}} + n_{\mathrm{s}}\right) \tag{6}$$

In the isospin scheme, what we now call the two nucleons are considered to be the excited states of a single "nucleon particle" (likewise for what we now call the four Δ baryons, which were seen as one single "Δ particle"). However, in light of the quark model, the four Δ baryons are better seen as excited nucleons.[26]

At this point in history, mass groups were understood to be due to the nearly equal contribution of both the up and down quarks to the mass of hadrons. What distinguished the Σ^0 baryon from the Λ^0 was an excitation related to the electroweak interaction. However, as people were used to the notion of isospin, and that isospin could be explained within the quark model, it was kept as the basis of baryon nomenclature. In a three-quark universe, which was the understanding at the time, this scheme worked very well, and had no major problems, if any.

For a more complete history of particle physics discoveries during the twentieth-century, readers are referred to [27].

III. FROM THREE TO SIX QUARKS: THE ROAD TO THE CURRENT NOMENCLATURE

If we were to restrain ourselves to a universe made only of the light quarks, as was the situation when the quark model was proposed, the current rules for the main symbols could be summarized as in Table I, with $n_{\mathrm{c}} = n_{\mathrm{b}} = n_{\mathrm{t}} = 0$.[11] In addition to these rules, charge is indicated in superscript, and the mass of strongly-decaying baryons (in MeV/c^2) is indicated in parenthesis (e.g. $\Sigma^+(1385)$). Although unofficial, it is common to place a superscript star on $J^P = \frac{3}{2}^+$ baryons which have a $J^P = \frac{1}{2}^+$ counterpart (e.g. Σ^{*+} instead of $\Sigma^+(1385)$).

The quark model gave a physical basis to the concepts of mass groups, which until then had no rigorous definition, and isospin, which until then only had an unclear link to mass groups. In the case of the original three-quark model, a mass group can be defined as a group containing all the particles of a particular J^P configuration, of a particular flavor configuration (e.g. the mixed-symmetry Σ^0 vs. the completely antisymmetric Λ^0), of a particular number of strange quarks (n_s). The length of the isospin vector for a mass group is, as before, related to the number of particle in the mass group (n_mg):

$$I = \frac{n_\mathrm{mg} - 1}{2} \tag{7}$$

with its projection related to the number of up and down quarks:

$$I_\mathrm{z} = \frac{1}{2}\left(n_\mathrm{u} - n_\mathrm{d}\right) \tag{8}$$

The current PDG rules are heavily-based on this subset of rules, which evolved gradually over the 1960s and 1970s, as the PDG generally sought to preserve the historical names.[4] In 1986, taking heavy inspiration from previous work by Archibald Hendry and Don Lichtenberg,[28] the rules were generalized to cover baryons containing heavy quarks as in Table I.[2] In addition to previous rules related to charge and mass/superscript stars, heavy baryons have their charm, bottom, and top quark content explicitly indicated by subscripts (e.g. Ω^-_{bb}). The rules allow for some baryons made of three different quarks to have the same symbol. When this is the case, a prime is added to the heaviest baryon (e.g. Ξ'^+_c and Ξ^+_c, which are the usc counterparts of the uds Σ^0 and Λ^0, respectively).

TABLE I. Current PDG symbols for all baryons

Symbol	Isospin (I)	$n_\mathrm{s} + n_\mathrm{c} + n_\mathrm{b} + n_\mathrm{t}$
N	1/2	0
Δ	3/2	0
Σ	1	1
Λ	0	1
Ξ	1/2	2
Ω	0	3

The concept of mass groups needed to be slightly redefined to be a group containing all the particles of a particular J^P configuration, of a particular flavor configuration, of a particular combination of strange, charm, bottom and top quark. In the six-quark model, the various equations are extended to the following:

$$Q = I_\mathrm{z} + \frac{1}{2}\left(\tilde{B} + S + C + B + T\right) \tag{9}$$

$$I_\mathrm{z} = \frac{1}{2}\left(n_\mathrm{u} - n_\mathrm{d}\right) \tag{10}$$

$$\tilde{B} = \frac{1}{3}\left(n_\mathrm{u} + n_\mathrm{d} + n_\mathrm{s} + n_\mathrm{c} + n_\mathrm{b} + n_\mathrm{t}\right) \tag{11}$$

$$Y = \left(\tilde{B} + S + C + B + T\right) \tag{12}$$

$$S = -n_\mathrm{s};\ C = +n_\mathrm{c};\ B = -n_\mathrm{b};\ T = +n_\mathrm{t} \tag{13}$$

where, C is charm, B is bottomness, T is Topness, and n_q is the number of quark of flavor $q \in \{\mathrm{u}, \mathrm{d}, \mathrm{s}, \mathrm{c}, \mathrm{b}, \mathrm{t}\}$.

Ultimately, this is nothing but a fancy way of saying that the electric charge of a baryon is due to the sum of the electric charge of its constituent quarks:

$$Q = +\frac{2}{3}\left(n_\mathrm{u} + n_\mathrm{c} + n_\mathrm{t}\right) - \frac{1}{3}\left(n_\mathrm{d} + n_\mathrm{s} + n_\mathrm{b}\right) \tag{14}$$

and that all quantum numbers can be explain in terms of the number of constituent quarks of different flavors.

IV. PROBLEMS AND GENERALIZATION OF ISOSPIN

As heavy quarks were discovered, the baryon nomenclature was extended with the goal of preserving what was already done rather than with the goal of reflecting their physics.[4] This meant extending rules based on a two-quark symmetry to a six-quark universe, rather than redesigning them from the ground up to accommodate six-quark symmetries. This leads to several problems concerning physics, and others concerning clarity.

A. Generalized isospin and mass groups

Firstly, the concept of mass groups is only well-defined for SU(3) projections involving both up and down quarks, and some other quark. But looking at the data, one can easily argue that the concept of mass groups can be extended to other symmetries such as the SU(2) symmetry between up and strange quarks, in the SU(3) projection involving up, strange, and charm quarks (see the usc octet in Figure 5 for example).

One could easily advance the concept of "generalized isospin", defined as

$$I_{ij} = \frac{1}{2}\left(n_i - n_j\right) \tag{15}$$

where n_i and n_j are the number of constituent quarks of flavor i and j, with $i \neq j$.[29] One could thus speak of the usc mass group of Ω^0_c, Ξ'^+_c, and Σ^{++}_c (analogous to the uds mass group of Σ^+, Σ^0, and Σ^-), and we could then devise quantitative descriptors of the absolute ($Q^\mathrm{ijk}_\mathrm{abs}$) and

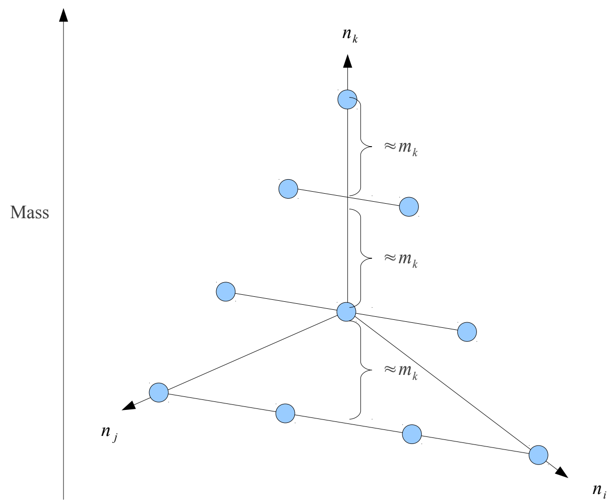

FIG. 4. Baryon mass hierarchy for baryons made of the ijk quarks, assuming $m_i < m_j < m_k$. $Q_{\rm abs}^{\rm ijk}$ represents the average slope while $Q_{\rm rel}^{\rm ijk}$ is the average slope scaled against the ijk triangle height along the $I_{ij} = 0$ axis.

relative quality ($Q_{\rm rel}^{\rm ijk}$) of the symmetry between quarks (see Figure 4).

$$Q_{\rm abs}^{\rm ijk} \equiv \langle \text{Slope} \rangle \approx m_i - m_j \tag{16}$$

$$Q_{\rm rel}^{\rm ijk} \equiv \frac{\langle \text{Slope} \rangle}{\text{Height}\,(ijk)} \approx \frac{m_i - m_j}{3m_k} \tag{17}$$

where $i \neq j \neq k \in \{\rm u, d, s, c, b, t\}$. The approximations assume that $m_{\rm baryon} = m_{\rm interaction} + m_{\rm quarks}$, where $m_{\rm interaction}$ is a constant specific to the ijk octet or decuplet of a particular J^P.

For example, using the most recent PDG values for the mass of quarks,[11] one finds that the estimates for $Q_{\rm abs}^{\rm ijk}$ and $Q_{\rm rel}^{\rm ijk}$, however crude and naïve they might be, compare well (within 15–20%, see Table II) to values calculated directly from the baryon masses, especially when considering the large relative errors on the mass of these quarks.

We also see that the quality of the us symmetry of in usc octet is very comparable to the quality of the ud symmetry in the uds octet, meaning that the notion of $I_{\rm us}$ mass groups for the usc octet is physically sound ($Q_{\rm abs}^{\rm usc} \ll 1$). Similar analyses can be done for other octets and decuplets, and will always lead to meaningful ($Q_{\rm abs}^{\rm ijk} \ll 1$) I_ij mass groups for ijk octets and decuplets as long as i and j are chosen so that m_i and m_j are both smaller than m_k.

TABLE II. Absolute and relative quality of the uds and usc mass groups symmetries

Quantity	Using $m_{\rm quarks}$	Using $m_{\rm baryons}$	Notes
$Q_{\rm abs}^{\rm uds}$ $\left(\text{MeV}/c^2\right)$	2.5 ± 1.5	4.1	a
$Q_{\rm rel}^{\rm uds}$	$8.3^{+6.7}_{-7.5} \times 10^{-3}$	7.2×10^{-3}	b
$Q_{\rm abs}^{\rm usc}$ $\left(\text{MeV}/c^2\right)$	97.5^{+31}_{-21}	123.6	c
$Q_{\rm rel}^{\rm usc}$	$2.5^{+1.0}_{-0.9} \times 10^{-3}$	3.1×10^{-2}	d

[a] Using the masses of N^+, N^0, Σ^+, Σ^0, Σ^-, Ξ^0, and Ξ^-.
[b] Height(uds) $= \frac{3}{2}\left(\langle m_{\Xi^0}, m_{\Xi^-}\rangle - \langle m_{N^+}, m_{N^0}\rangle\right)$
[c] Using the masses of Σ^+, Ξ^0, Σ_c^{++}, $\Xi_c'^{+}$, Ω_c^0.
[d] Height(usc) $= 3\left(\langle m_{\Omega_c^0}, m_{\Xi_c^+}, m_{\Sigma_c^{++}}\rangle - \langle m_{\Xi^0}, m_{\Sigma^+}\rangle\right)$

Strictly speaking, the concept of generalized isospin and the analysis of its associated mass groups is possible within the current nomenclature, but the current nomenclature is not friendly to these. $I_{\rm ud}$ and its associated mass groups are put on a pedestal, while the other I_{ij} and their associated mass groups are completely ignored. Though one could certainly argue that $I_{\rm ud}$ is the most used quantity, especially in low-energy particle physics, one should not forget the other symmetries. As of writing, nearly all of the $J^P = \frac{1}{2}^+$ and $J^P = \frac{3}{2}^+$ baryons involving any combination of up, down, strange and charm quarks were discovered; only the Ξ_c^{++} and Ω_{cc}^{++} are missing for the $J^P = \frac{1}{2}^+$ octets, and only the Ξ_c^{*++}, Ω_{cc}^{*++} and Ω_{ccc}^{++} are missing for the $J^P = \frac{3}{2}^+$ decuplets. It is only a matter of time for octets and decuplets involving the bottom quarks to be similarly complete.[30]

B. Lack of clear pattern

Secondly, there are 20 sets of three distinct axes possible for representing baryons in SU(3) diagrams, but the current nomenclature only works well for 4 of them: *uds*, *udc*, *udb*, and *udt*. For the 16 others, the projections take completely different forms (see Figure 5), and while certain patterns emerge, none are tied to any symmetry or fundamental properties.

On top of the lack of clear pattern in the main symbols, we also see some inconsistencies in the patterns related to the superscript stars (or officially, masses). Superscript stars only appear in the spin 3/2 decuplet, indicating excitations, but do not appear for the Δ^+ and Δ^0, despite being excited nucleons. If going by the official rules, only strongly-decaying particles should have mass indicated in parentheses. This means that the four Δ should formally be referred to as Δ^{++}, $\Delta^+(1232)$, $\Delta^0(1232)$, and Δ^- instead of the usual $\Delta^{++}(1232)$, $\Delta^+(1232)$, $\Delta^0(1232)$, and $\Delta^-(1232)$ (if one is of the mindset that the four Δ are excited nucleons) or Δ^{++}, Δ^{+}, Δ^{0}, and Δ^{-} (if one is of the mindset that the four Δ represent the ground state of a Δ particle).

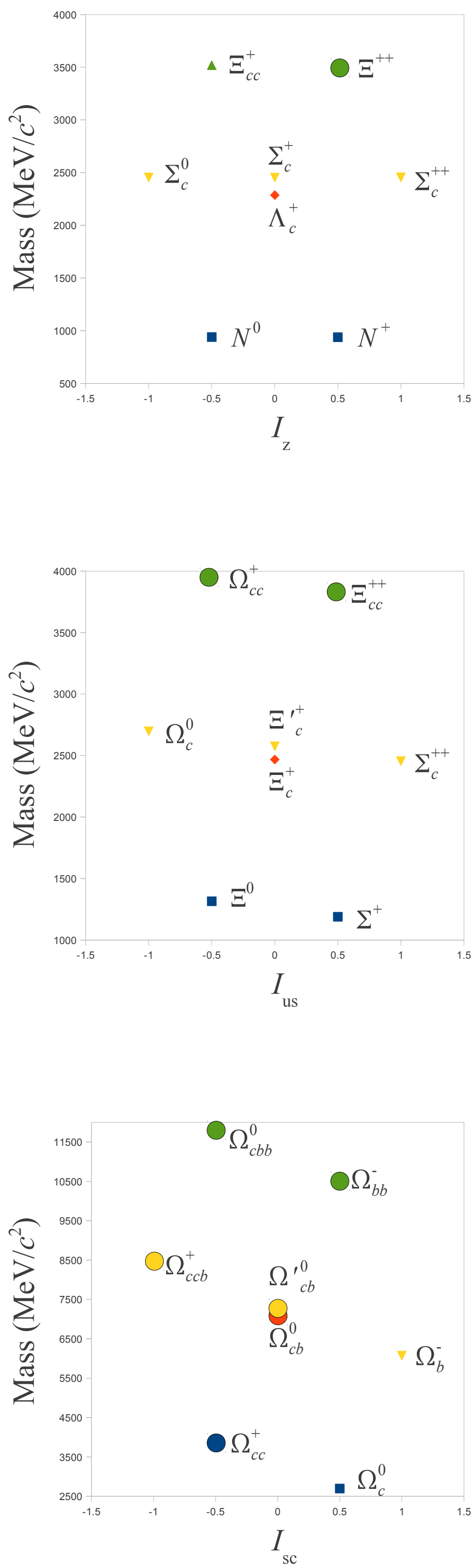

FIG. 5. The udc (top), usc (middle), and scb (bottom) octets. Circles denotes mass estimates. Note the lack of clear patterns in the symbols when one changes the axes.

C. Lack of simplicity

Thirdly, to pin down the exact quark content and symmetries of a baryon, one has to go through a long list of steps. Taking the $\Xi_c'^{+}$ as an example, the steps required to determine the quark content are:

1. The Ξ indicates that this baryon has isospin $\frac{1}{2}$, and that the sum of its non-up and non-down quarks is equal to 2.
2. The c subscript explicitly indicates that it has one charm quark, and implicitly that it has one strange quark (if it had a bottom quark instead, it would be explicitly indicated in subscript).
3. Knowing that it has one charm quark and one strange quark, the + charge indicates that the remaining quark is an up quark, via the Gell-Mann–Nishijima formula.

and the steps required to determine the symmetries are:

1. The lack of either the parenthetical mass or the presence of a * indicates a ground-state baryon. Is the ground state of a usc baryon in the $J^P = \frac{1}{2}^+$ octet or in the $J^P = \frac{3}{2}^+$ decuplet?
   - $J^P = \frac{1}{2}^+$ octet
2. Where in the SU(3) diagram is the usc located?
   - In the middle.
3. If it is in the middle of the octet, it is the Σ^0-like (part of the generalized isospin triplet) or the Λ^0-like (part of the generalized isospin singlet)?
   - There is a prime, so it is the most massive one (i.e. the Σ^0-like, part of the generalized isospin triplet).

D. Unfortunate convention for primes

Fourthly, the prime is put on the spin-1/2 ijk baryon that is part of the generalized isospin triplet. But the logic in the case of the ud$k$ baryons was to distinguish the isospin singlet (Λ^0) from the triplet (Σ^0). Thus in the case of $\Xi_c^{+}/\Xi_c'^{+}$ one would expect the prime to be placed on *least*-massive baryon, to indicate the generalized isospin *singlet* state.

It is interesting to note that Hendry and Lichtenberg denoted the Λ^0-likes with a superscript "A", to indicate the antisymmetric nature of the flavor-part of these baryons' wavefunction.[28]

E. Dependency on experimental results

Fifthly, the nomenclature relies on some experimental measurements. Specifically, the formal name of a certain baryon cannot be known until it is discovered, and the uncertainties in mass measurement can lead to a formal name that will become out-of-sync with data as experiments improve the mass accuracy. For example, the formal names of the spin-$\frac{3}{2}$ Σ^* are $\Sigma^+(1385)$, $\Sigma^0(1385)$, and $\Sigma^-(1385)$, despite their masses being 1382.8 ± 0.4 MeV/c^2, 1383.7 ± 1.0 MeV/c^2, and 1387.2 ± 0.5 MeV/c^2 respectively.[11] This also makes it impossible to formally identify baryons without consulting the latest PDG review, unless one wishes to memorize the approximate masses used by the PDG.

F. Exotic baryons

And lastly, while there is little experimental evidence for the existence of exotic baryons such as pentaquarks, heptaquarks, etc., it has not been theoretically ruled out. This means that in the event that exotic baryons are found to exist, the need would arise to have a nomenclature for them as well. While one could (at least in theory) extend an isospin-based nomenclature to isospin pentets, hexets, and so on, doing so would only amplify the existing problems.

V. PROPOSED NOMENCLATURE

Given that baryons are SU(3) objects, it is natural to devise an SU(3)-based nomenclature (see Figure 6). We propose the following rules for a new nomenclature, designed to directly reflect their various symmetries, as well as their quark content.[31]

- Baryons on the summits of the triangle (iii) are named ϵ_{iii}
- Baryons on the hexagon (iij) are named ζ_{iij}
- Baryons in the center (ijk) are named κ_{ijk}
- Quark content is explicitly indicated in subscript
- Charge is explicitly indicated in superscript
- Decuplet baryons are starred

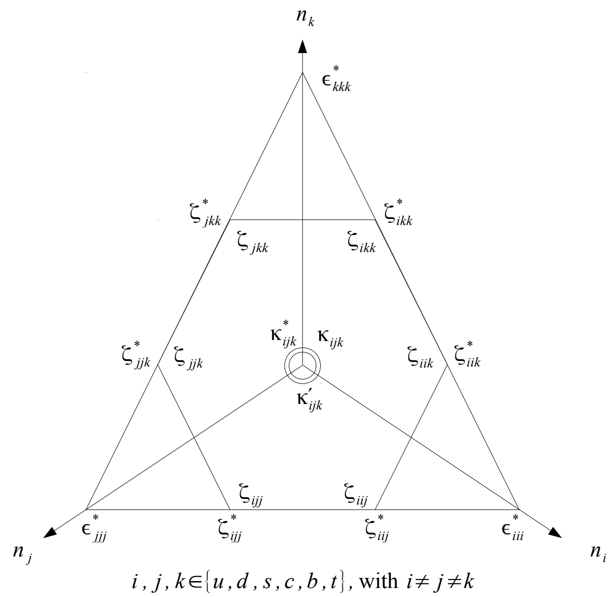

FIG. 6. Proposed baryon nomenclature. Starred baryons belong to the decuplet. The primed baryons refer to the Λ^0-like.

- Generalized isospin singlet baryons are primed
- J^P is indicated explicitly in parentheses, alternatively mass
  - If J^P is omitted, X_{qqq} and X^*_{qqq} refer to $X_{qqq}\left(\frac{1}{2}^+\right)$ and $X_{qqq}\left(\frac{3}{2}^+\right)$ baryons respectively

The rules are vastly simpler and not prone to any of the problems discussed in the previous section. For example, the baryon currently named Ξ'^+_c would now be named κ^+_{usc}. This displays nearly all the information about this baryon in explicit form. The quark content is directly indicated (usc), and so is charge (+). The main symbol (κ) tells you where on the SU(3) weight diagrams the baryon is located (although this is technically redundant with the explicit quark content). The superscript star (or lack thereof) tells you the baryon has decuplet (or octet) symmetries, and the prime (or lack therefore) tells you the baryon is part of a generalized isospin singlet (or triplet). As the nomenclature is inherently SU(3)-based, changing the choice of n_q axes on which to project baryons will not result in completely different naming patterns.[32] The only implicit property is I_{ij}, which can be determined via Table III.

The proposed rules also allow to easily identify and summarize the interaction involved in the various processes:

- $X_{qqq} \leftrightarrow X^*_{qqq}$ are strong processes (g)

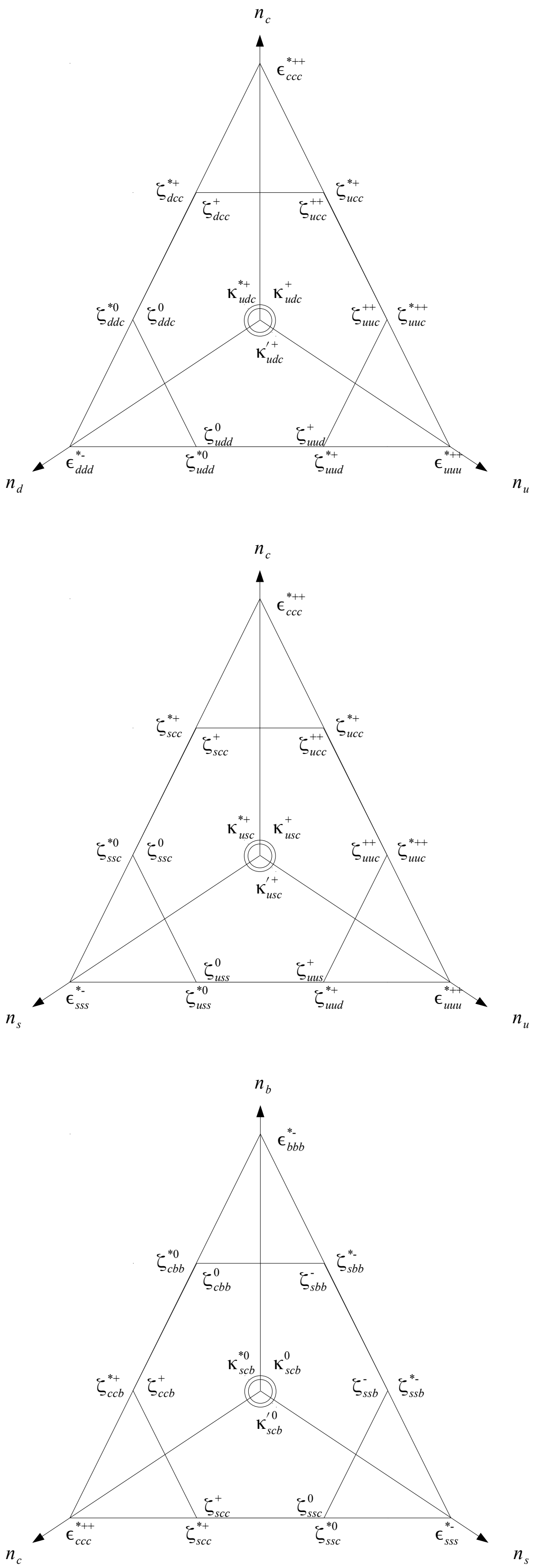

FIG. 7. The udc (top), usc (middle), and scb (bottom) octets and decuplets with the proposed names. Note how only the charge and quark content change when different axes are chosen.

TABLE III. How to determine I_{ij} from the proposed names

Symbol		I_{ij}
X_{qqq}	$n_k \neq 1$	$\frac{1}{2}$
	$n_k = 1$	1
X'_{qqq}	always	0
X^*_{qqq}	always	$\frac{1}{2}(n_i + n_j)$

- $X_{qqq} \leftrightarrow X_{qq\tilde{q}}$ and $X^*_{qqq} \leftrightarrow X^*_{qq\tilde{q}}$ are weak processes ($W^{\pm}$)
- $X_{qqq} \leftrightarrow X'_{qqq}$ are electroweak processes (γ^0, Z^0)

The cost of this nomenclature is that one needs to be slightly more verbose in the low-energy cases. For example, instead of saying "the three $\Sigma\,(1385)$ baryons" or "the three Σ^* baryons" , one would need to say "the $I_{\mathrm{ud}}\left(\frac{3}{2}^+\right)$ baryons" or "the $I_{\mathrm{ud}}\,(1385)$ baryons". But this change in language will pay off when one will want to speak of "the $I_{\mathrm{us}}\left(\frac{3}{2}^+\right)$ baryons" or "the $I_{\mathrm{us}}\,(2643)$ baryons", rather than having to find awkward phrasing such as "the mass group formed by Δ^{++}, Σ^{*+}, Ξ^{*0}, and Ω^-", which goes against the conventional idea that these particles do not form a mass group.

VI. PRELIMINARY REACTIONS

The proposed baryon nomenclature has been presented in preliminary form in a conference talk given at the 2009 Canadian Association of Physicists Congress.[33]

Reactions were mostly positive, with many, including particle physicists, saying that they never gave much thought about the logic behind the names of baryons before. Two reasons were cited for this lack of interest. Most non-experts, and many experts, felt that the current baryon nomenclature was intimidating, especially in the case of heavy baryons, and had a hard time making the connection between the current baryon names and the physical entities they were meant to represent. Most experts also said they never really bothered understanding the current nomenclature, and just used whatever names the PDG used.

Some experts expressed reservations about losing the current connection between baryon names and isospin, although at the time generalized isospin had not yet been introduced. Some experts also expressed concerns about the required transition period and continuity in the literature, assuming the proposed nomenclature were to be adopted. However, all felt that the proposed nomenclature was conceptually much simpler and would be much easier to teach and learn than the current one.

VII. CONCLUSION

If the proposed nomenclature is adopted (in current or modified form), some will worry about the transition period involved. These concerns are perfectly valid, since changing something as fundamental as a nomenclature requires an entire scientific community to reorganize itself, and such a reorganization should not be done lightly. But one must remember that keeping old ideas for sake of tradition also has a great impact on a community. And one should also remember that the adoption of the current nomenclature required a transition at the time of its adoption, and there is no reason to believe that such a transition would be any less successful today than it was in 1986.

Others will be more concerned with the nostalgia factor, saying this is equivalent to turning our back on the rich history and excitement of early particle physics. We argue that this should not be seen as abandoning history, but rather as a celebration of our modern understanding to ensure that the future generations are not needlessly encumbered by tradition, and let them stand on the shoulders of giants rather than on their scaffolds.

As the authors of this article have neither the authority nor resources to centralize and coordinate discussion related to the adoption (or rejection) of this proposal, it is hoped that the PDG will consider re-examining the issue, as they once did 24 years ago.

VIII. ACKNOWLEDGMENTS

We would like to acknowledge the excellent feedback and criticism of Jonathan Blanchard and Marc Collette.

Appendix: Correspondence tables

In the event that the proposed nomenclature is adopted (in current or modified form), Tables IV and V would prove useful in making the correspondence between the current and proposed baryon names.

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[2] M. Aguilar-Benítez *et al.*, Physics Letters B **170**, 1 (1986).
[3] To the best of this author's knowledge, no textbook contain the full set of rules, nor do any of the post-1986 Reviews of Particle Physics, and most introductory textbook, such as [34], will only summarize the rules for the light baryons.
[4] R. M. Barnett *et al.*, AIP Conference Series **32**, 474 (1985).
[5] Counting baryons is a tricky business and can be done in several ways. In this article, we count the different baryon states in the lowest-energy octet ($J^P = \frac{1}{2}^+$) and lowest-energy decuplet ($J^P = \frac{3}{2}^+$) configurations.
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[10] W. Heisenberg, Zeitschrift für Physik **77**, 1 (1932); **78**, 156 (1932); **80**, 587 (1932).
[11] K. Nakamura *et al.*, Journal of Physics G **37**, 075021 (2010) and 2011 partial update for the 2012 edition available at http://pdg.lbl.gov.
[12] These assignments are the reason why the *up* and *down* quarks are named such.[35].
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[23] V. E. Barnes *et al.*, Physical Review Letters **12**, 204 (1964).
[24] M. Gell-Mann, Physics Letters **8**, 214 (1964).
[25] G. Zweig, *Model for Strong Interaction Symmetry and Its Breaking*, Tech. Rep. 8182 (CERN, 1964); *Model for Strong Interaction Symmetry and Its Breaking II*, Tech. Rep. 8419 (CERN, 1964).
[26] The Δ^{++} and Δ^- do not have corresponding nucleons, as these are forbidden by the Pauli exclusion principle, much like the spin-$\frac{1}{2}$ Ω^- baryon is forbidden.
[27] COMPAS Collaboration, *Chronology of Particle Physics Discoveries* (Hallym University, Department of Physics). Available at http://web.hallym.ac.kr/~physics/education/hep/discovery.html, accessed on 2012-03-30. This is a mirror of the original http://wwwppds.ihep.su:8001/discovery.html.
[28] A. W. Hendry and D. B. Lichtenberg, Reports on Progress in Physics **41**, 1707 (1978).
[29] Obviously, for the choice of $i = \mathrm{u}$ and $j = \mathrm{d}$, $I_{\mathrm{ud}} = I_{\mathrm{z}}$.

[30] Because of the top quark's extremely short lifetime, no members of any octet or decuplets involving top quarks are expected to ever be observed, as they do not have time to hadronize.[36].

[31] The symbols ϵ, ζ, and κ were chosen carefully to create no confusion between the current and proposed nomenclature, both in written and oral forms. The upper or lowercase α, β, γ, Δ, η, both θ and Θ, Λ, μ, ν, Ξ, π, ρ, Σ, τ, Υ, ϕ, χ, Ψ, and both ω and Ω were already used for particle names. This left ϵ, ζ, ι, κ, and o available. ι (iota) and o (omicron) were ruled out as potentially confusing with i or o, leaving only ϵ, ζ, and κ available from the Greek alphabet.

[32] The same applies to SU(4) projections, as the faces of the $J^P = \frac{1}{2}^+$ truncated tetrahedrons and of the $J^P = \frac{3}{2}^+$ tetrahedrons are SU(3) octets and decuplets. It would also apply to SU(5) and SU(6) diagrams, assuming one found a way to project 5 or 6 dimensions on paper.

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TABLE IV. Correspondence between the current and proposed nomenclature for octet baryons

Curr.	Prop.	Curr.	Prop.	Curr.	Prop.	Curr.	Prop.	Curr.	Prop.	Curr.	Prop.	Curr.	Prop.
N^+	ζ^+_{uud}	Σ^+_c	κ^+_{udc}	Ξ^+_c	κ'^+_{usc}	Ξ^{++}_{ct}	κ'^{++}_{uct}	Ξ'^0_b	κ^0_{usb}	Ω^0_c	ζ^0_{ssc}	Ω^{++}_{cct}	ζ^{++}_{cct}
N^-	ζ^-_{udd}	Σ^0_c	ζ^0_{ddc}	Ξ^0_c	κ'^0_{dsc}	Ξ^+_{ct}	κ'^+_{dct}	Ξ'^-_b	κ^-_{dsb}	Ω^-_b	ζ^-_{ssb}	Ω^0_{cbb}	ζ^0_{cbb}
Λ^0	κ'^0_{uds}	Σ^+_b	ζ^+_{uub}	Ξ^0_b	κ'^0_{dsb}	Ξ^0_{bb}	ζ^0_{ubb}	Ξ'^+_t	κ^+_{ust}	Ω^0_t	ζ^0_{sst}	Ω^+_{cbt}	κ'^+_{cbt}
Λ^+_c	κ'^+_{uds}	Σ^0_b	κ^0_{udb}	Ξ^-_b	κ'^-_{dsb}	Ξ^-_{bb}	ζ^-_{dbb}	Ξ'^0_t	κ^0_{dst}	Ω^+_{cc}	ζ^+_{scc}	Ω^{++}_{ctt}	ζ^{++}_{ctt}
Λ^0_b	κ'^0_{udb}	Σ^-_b	ζ^-_{ddb}	Ξ^+_t	κ'^+_{ust}	Ξ^+_{bt}	κ'^+_{ubt}	Ξ'^+_{cb}	κ^+_{ucb}	Ω^0_{cb}	κ'^0_{scb}	Ω^0_{bbt}	ζ^0_{bbt}
Λ^+_t	κ'^+_{udt}	Σ^{++}_t	ζ^{++}_{uut}	Ξ^0_t	κ'^0_{dst}	Ξ^0_{bt}	κ'^0_{dbt}	Ξ'^0_{cb}	κ^0_{dcb}	Ω^+_{ct}	κ'^+_{sct}	Ω^+_{btt}	ζ^+_{btt}
Σ^+	ζ^+_{uus}	Σ^+_t	κ^+_{udt}	Ξ^{++}_{cc}	ζ^{++}_{ucc}	Ξ^{++}_{tt}	ζ^{++}_{utt}	Ξ'^{++}_{ct}	κ^{++}_{uct}	Ω^-_{bb}	ζ^-_{sbb}	Ω'^0_{cb}	κ^0_{scb}
Σ^0	κ^0_{uds}	Σ^0_t	ζ^0_{ddt}	Ξ^+_{cc}	ζ^+_{dcc}	Ξ^+_{tt}	ζ^+_{dtt}	Ξ'^+_{ct}	κ^+_{dct}	Ω^0_{bt}	κ'^0_{sbt}	Ω'^+_{ct}	κ^+_{sct}
Σ^-	ζ^-_{dds}	Ξ^0	ζ^0_{uss}	Ξ^+_{cb}	κ'^+_{ucb}	Ξ'^+_c	κ^+_{usc}	Ξ'^+_{bt}	κ^+_{ubt}	Ω^+_{tt}	ζ^+_{stt}	Ω'^0_{bt}	κ^0_{sbt}
Σ^{++}_c	ζ^{++}_{uuc}	Ξ^-	ζ^-_{dss}	Ξ^0_{cb}	κ'^0_{dcb}	Ξ'^0_c	κ^0_{dsc}	Ξ'^0_{bt}	κ^0_{dbt}	Ω^+_{ccb}	ζ^+_{ccb}	Ω'^+_{cbt}	κ^+_{cbt}

TABLE V. Correspondence between the current and proposed nomenclature for decuplet baryons

Curr.	Prop.	Curr.	Prop.	Curr.	Prop.	Curr.	Prop.	Curr.	Prop.	Curr.	Prop.	Curr.	Prop.
Δ^{++}	ϵ^{*++}_{uuu}	Σ^{*+}_c	κ^{*+}_{udc}	Ξ^{*0}	ζ^{*0}_{uss}	Ξ^{*++}_{cc}	ζ^{*++}_{ucc}	Ξ^{*+}_{bt}	κ^{*+}_{ubt}	Ω^{*+}_{cc}	κ^{*+}_{scc}	Ω^{*++}_{cct}	κ^{*++}_{cct}
Δ^+	ζ^{*+}_{uud}	Σ^{*0}_c	ζ^{*0}_{ddc}	Ξ^{*-}	ζ^{*-}_{dss}	Ξ^{*+}_{cc}	ζ^{*+}_{dcc}	Ξ^{*0}_{bt}	κ^{*0}_{dbt}	Ω^{*0}_{cb}	κ^{*0}_{scb}	Ω^{*0}_{cbb}	κ^{*0}_{cbb}
Δ^0	ζ^{*0}_{udd}	Σ^{*+}_b	ζ^{*+}_{uub}	Ξ^{*+}_c	κ^{*+}_{usc}	Ξ^{*+}_{cb}	κ^{*+}_{ucb}	Ξ^{*++}_{tt}	ζ^{*++}_{utt}	Ω^{*+}_{ct}	κ^{*+}_{sct}	Ω^{*+}_{cbt}	κ^{*+}_{cbt}
Δ^-	ϵ^{*-}_{ddd}	Σ^{*0}_b	κ^{*0}_{udb}	Ξ^{*0}_c	κ^{*0}_{dsc}	Ξ^{*0}_{cb}	κ^{*0}_{dcb}	Ξ^{*+}_{tt}	ζ^{*+}_{dtt}	Ω^{*-}_{bb}	κ^{*-}_{sbb}	Ω^{*++}_{ctt}	κ^{*++}_{ctt}
Σ^{*+}	ζ^{*+}_{uus}	Σ^{*-}_b	ζ^{*-}_{ddb}	Ξ^{*0}_b	κ^{*0}_{usb}	Ξ^{*++}_{ct}	κ^{*++}_{uct}	Ω^-	ϵ^{*-}_{sss}	Ω^{*0}_{bt}	κ^{*0}_{sbt}	Ω^-_{bbb}	ϵ^{*0}_{bbb}
Σ^{*0}	κ^{*0}_{uds}	Σ^{*++}_t	ζ^{*++}_{uut}	Ξ^{*-}_b	κ^{*-}_{dsb}	Ξ^{*+}_{ct}	κ^{*+}_{dct}	Ω^{*0}_c	κ^{*0}_{ssc}	Ω^{*+}_{tt}	κ^{*+}_{stt}	Ω^{*0}_{bbt}	κ^{*0}_{bbt}
Σ^{*-}	ζ^{*-}_{dds}	Σ^{*+}_t	κ^{*+}_{udt}	Ξ^{*+}_t	κ^{*+}_{ust}	Ξ^{*0}_{bb}	ζ^{*0}_{ubb}	Ω^{*-}_b	κ^{*-}_{ssb}	Ω^{++}_{ccc}	ϵ^{*++}_{ccc}	Ω^{*0}_{btt}	κ^{*0}_{btt}
Σ^{*++}_c	ζ^{*++}_{uuc}	Σ^{*0}_t	ζ^{*0}_{ddt}	Ξ^{*0}_t	κ^{*0}_{dst}	Ξ^{*-}_{bb}	ζ^{*-}_{dbb}	Ω^{*0}_t	κ^{*0}_{sst}	Ω^{*+}_{ccb}	κ^{*+}_{ccb}	Ω^{++}_{ttt}	ϵ^{*++}_{ttt}