CHARMED BARYONS

Revised March 2012 by C.G. Wohl (LBNL).

(Note added November 2015.) Since the 2014 *Review*, there have been three papers that improved the values of the masses and/or widths of the $\Sigma(2455)$, $\Sigma(2520)$, Ξ_c^+, Ξ_c^0, $\Xi_c(2645)$, $\Xi_c(2970)$, $\Xi_c(3055)$, and $\Xi_c(3080)$. See the Listings for those particles.

But far and away the most important advance for c-baryons this edition is the first ever (!) model-independent measurement of a Λ_c^+ branching fraction. The anchor for all the other Λ_c^+ fractions is the $pK^-\pi^+$ fraction. Our value for many editions, $(5.0 \pm 1.3)\%$, was cobbled together from two ancient model-dependent measurements. Now, thanks to the Belle experiment, it is $(6.84 \pm 0.24^{\pm 0.21}_{\pm 0.27})\%$. This fraction is 37% larger than the old fraction, and its error is only 27% as large as the old error.

There are 18 known charmed baryons, and four other candidates not well enough established to be promoted to the Summary Tables.* Fig. 1(a) shows the mass spectrum, and for comparison Fig. 1(b) shows the spectrum of the lightest strange baryons. The Λ_c and Σ_c spectra ought to look much like the Λ and Σ spectra, since a Λ_c or a Σ_c differs from a Λ or a Σ only by the replacement of the s quark with a c quark. However, a Ξ or an Ω has more than one s quark, only *one* of which is changed to a c quark to make a Ξ_c or an Ω_c. Thus the Ξ_c and Ω_c spectra ought to be richer than the Ξ and Ω spectra.**

Before discussing the observed spectra, we review the theory of SU(4) multiplets, which tells what charmed baryons to expect; this is essential, because few of the spin-parity values given in Fig. 1(a) have been measured. Rather, they have been assigned in accord with expectations of the theory. However, they are all very likely as shown (see below).

SU(4) multiplets—Baryons made from u, d, s, and c quarks belong to SU(4) multiplets. The multiplet numerology, analogous to $3 \times 3 \times 3 = 10 + 8_1 + 8_2 + 1$ for the subset of baryons made from just u, d, and s quarks, is $4 \times 4 \times 4 = 20 + 20'_1 + 20'_2 + \bar{4}$. Figure 2(a) shows the 20-plet whose bottom level is an SU(3) decuplet, such as the decuplet that includes the $\Delta(1232)$. Figure 2(b) shows the $20'$-plet whose bottom level is an SU(3) octet, such as the octet that includes the nucleon. Figure 2(c) shows the $\bar{4}$ multiplet, an inverted tetrahedron. One level up

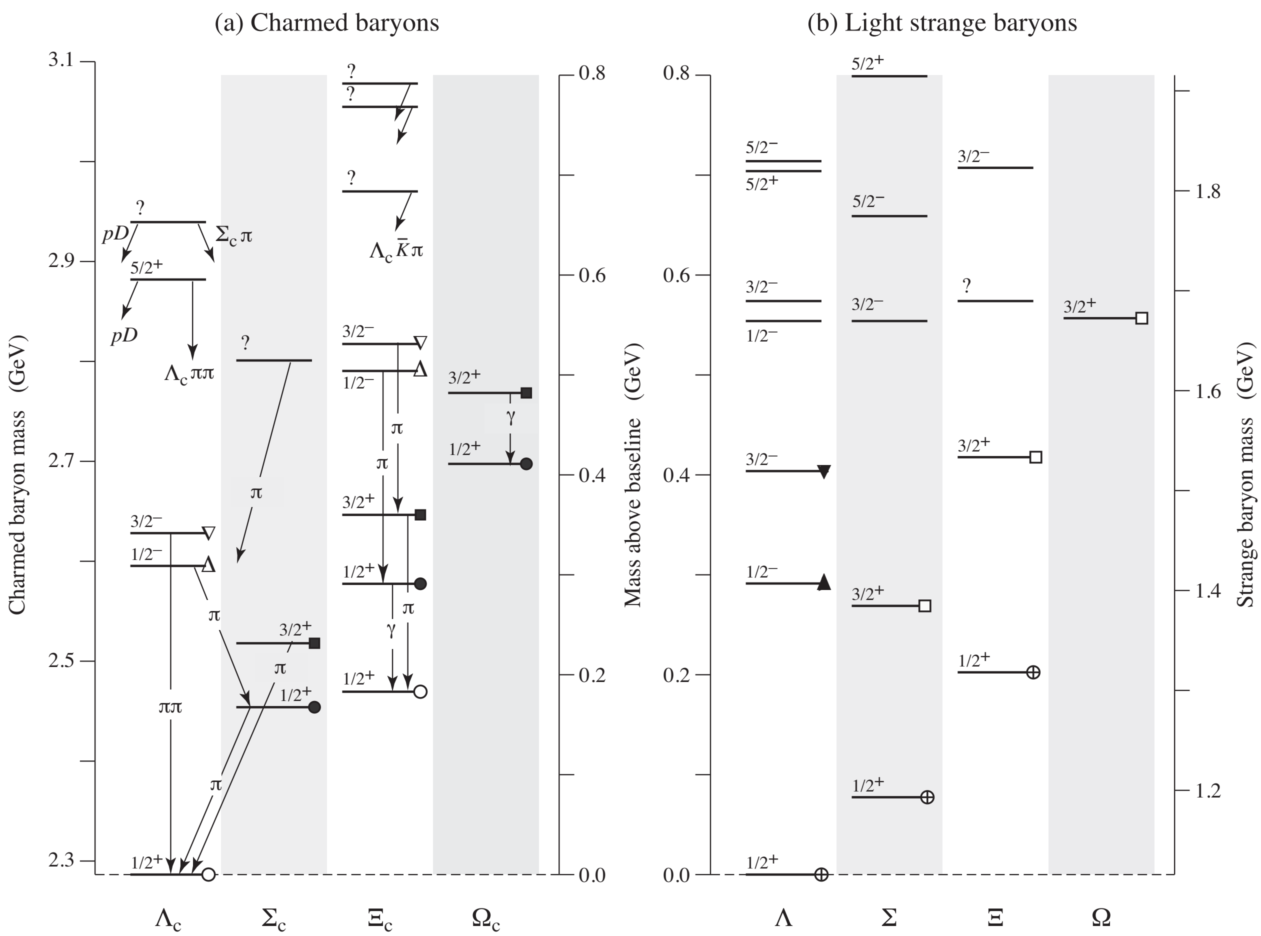

Fig. 1. (a) The known charmed baryons, and (b) the lightest "4-star" strange baryons. Note that there are two $J^P = 1/2^+$ Ξ_c states, and that the lightest Ω_c does not have $J = 3/2$. The $J^P = 1/2^+$ states, all tabbed with a circle, belong to the SU(4) multiplet that includes the nucleon; states with a circle with the same *fill* belong to the same SU(3) multiplet within that SU(4) multiplet. Similar remarks apply to the other states: same shape of tab, same SU(4) multiplet; same fill of that shape, same SU(3) multiplet. The $J^P = 1/2^-$ and $3/2^-$ states tabbed with triangles complete two SU(4) $\bar{4}$ multiplets.

from the bottom level of each multiplet are the baryons with one c quark. All the baryons in a given multiplet have the same spin and parity. Each N or Δ or SU(3)-singlet-Λ resonance calls for another $20'$- or 20- or $\overline{4}$-plet, respectively.

The flavor symmetries shown in Fig. 2 are of course badly broken, but the figure is the simplest way to see what charmed baryons should exist. For example, from Fig. 2(b), we expect to find, in the same $J^P = 1/2^+$ $20'$-plet as the nucleon, a Λ_c, a Σ_c, *two* Ξ_c's, and an Ω_c. Note that this Ω_c has $J^P = 1/2^+$ and is not in the same SU(4) multiplet as the famous $J^P = 3/2^+$ Ω^-.

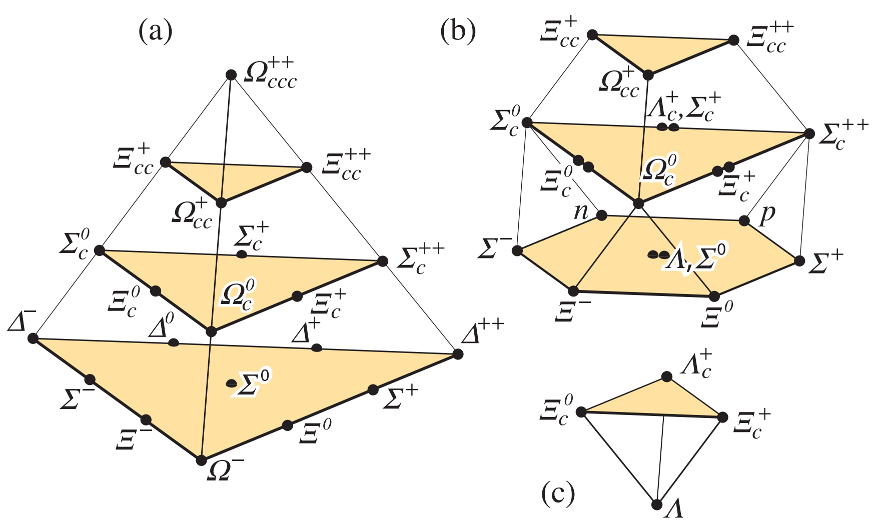

Figure 2: SU(4) multiplets of baryons made of u, d, s, and c quarks. (a) The 20-plet with an SU(3) decuplet on the lowest level. (b) The $20'$-plet with an SU(3) octet on the lowest level. (c) The $\overline{4}$-plet. Note that here and in Fig. 3, but not in Fig. 1, each charge state is shown separately.

Figure 3 shows in more detail the middle level of the $20'$-plet of Fig. 2(b); it splits apart into two SU(3) multiplets, a $\overline{3}$ and a 6. The states of the $\overline{3}$ are antisymmetric under the interchange of the two light quarks (the u, d, and s quarks), whereas the states of the 6 are symmetric under this interchange. We use a prime to distinguish the Ξ_c in the 6 from the one in the $\overline{3}$.

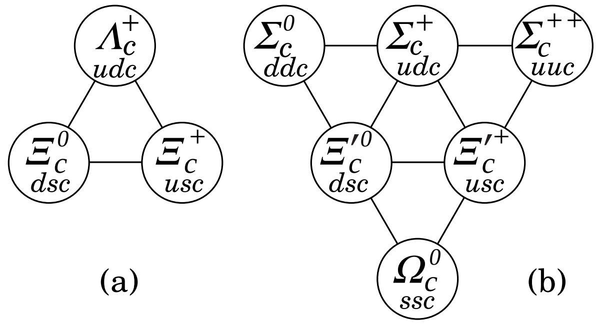

Figure 3: The SU(3) multiplets on the second level of the SU(4) multiplet of Fig. 2(b). The Λ_c and Ξ_c tabbed with open circles in Fig. 1(a) complete a $J^P = 1/2^+$ SU(3) $\overline{3}$-plet, as in (a) here. The Σ_c, Ξ_c, and Ω_c tabbed with closed circles in Fig. 1(a) complete a $J^P = 1/2^+$ SU(3) 6-plet, as in (b) here. Together the nine particles complete the charm $= +1$ level of a $J^P = 1/2^+$ SU(4) $20'$-plet, as in Fig. 2(b).

The observed spectra—(1) The parity of the lightest Λ_c is defined to be positive (as are the parities of the p, n, and Λ); the limited evidence about its spin is consistent with $J = 1/2$. However, few of the J^P quantum numbers given in Fig. 1(a) have been measured. Models using spin-spin and spin-orbit interactions between the quarks, with parameters determined using a few of the masses as input, lead to the J^P assignments shown.[†] There are no surprises: the $J^P = 1/2^+$ states come first, then the $J^P = 3/2^+$ states . . .

(2) There is, however, evidence that many of the J^P assignments in Fig. 1(a) must be correct. As is well known, the successive mass differences between the $J^P = 3/2^+$ particles, the $\Delta(1232)^-$, $\Sigma(1385)^-$, $\Xi(1535)^-$, and Ω^-, which lie along the lower left edge of the 20-plet in Fig. 2(a), should according to SU(3) be about equal; and indeed experimentally they nearly are. In the same way, the mass differences between the $J^P = 1/2^+$ $\Sigma_c(2455)^0$, $\Xi_c'^0$, and Ω_c^0,[‡] the particles along the left edge of Fig. 3(b), should be about equal—assuming, of course, that they *do* all have the same J^P. The measured differences are 125.0 ± 2.9 MeV and 117.3 ± 3.4 MeV—not perfect, but close. Similarly, the mass differences between the presumed

$J^P = 3/2^+$ $\Sigma_c(2520)^0$, $\Xi_c(2645)^0$, and $\Omega_c(2770)^0$ are 127.1 ± 0.8 MeV and 120.0 ± 2.1 MeV. In Fig. 1(a), these two sets of charm particles are tabbed with solid circles and solid squares.

(3) Other evidence comes from the decay of the $\Lambda_c(2593)$. The only allowed strong decay is $\Lambda_c(2593)^+ \to \Lambda_c^+ \pi\pi$, and this appears to be dominated by the submode $\Sigma_c(2455)\pi$, despite little available phase space for the latter (the "Q" is about 2 MeV, the c.m. decay momentum about 20 MeV/c). Thus the decay is almost certainly s-wave, which, assuming that the $\Sigma_c(2455)$ does indeed have $J^P = 1/2^+$, makes $J^P = 1/2^-$ for the $\Lambda_c(2593)$.

Footnotes:

* The unpromoted states are a $\Lambda_c(2765)^+$, a $\Xi_c(2930)$, and a $\Xi_c(3123)$. There is also very weak evidence for a baryon with *two* c quarks, a Ξ_{cc}^+ at 3519 MeV. See the Particle Listings.

** For example, there are three Ω_c^0 states (properly symmetrized states of ssc, scs, and css) corresponding to each Ω^- (sss) state.

† This is not the place to discuss the details of the models, nor to attempt a guide to the literature. See the discovery papers of the various charmed baryons for references to the models that lead to the quantum-number assignments.

‡ A reminder about the Particle Data Group naming scheme: A particle has its mass as part of its name if and only if it decays strongly. Thus $\Sigma(1385)$ and $\Sigma_c(2455)$ but Ω^- and Ξ_c'.