CHARMED BARYONS

Revised February 2006 by C.G. Wohl (LBNL).

There have been twelve papers on charmed baryons since our 2004 *Review*. Probably the most important results are (1) the discovery of another Σ_c, at 2800 MeV, by the BELLE experiment, and (2) a very precise measurement of the Λ_c^+ mass by the BABAR experiment. This mass is 1.56 MeV and 2.6 (old) standard deviations higher than our 2004 value. We use the new measurement as our Λ_c^+ mass, and this increases all the other Λ_c^+ masses, as well as all Σ_c masses, a like amount.

There are twelve known charmed baryons, each with one c quark.* 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 is obtained from a Λ or a Σ by changing the s quark to 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 or Ω spectra.**

Before discussing the observed spectra, we review the theory of SU(4) multiplets, which tells us what charmed baryons we should expect to find; this is essential, because the spin-parity values given in Fig. 1(a) have not been measured but have been assigned in accord with expectations of the theory.

CITATION: W.-M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006) (URL: http://pdg.lbl.gov)

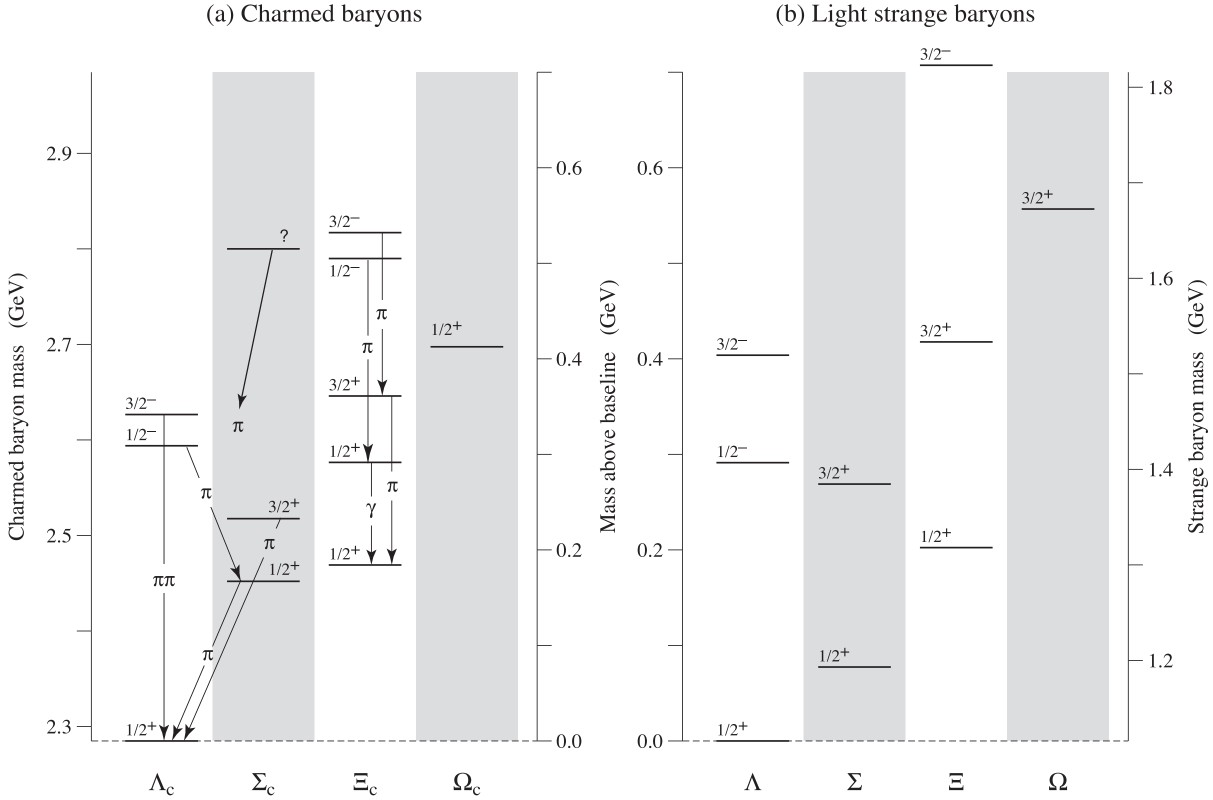

Fig. 1. (a) The known charmed baryons, and (b) the lightest strange baryons. Isospin splittings are not shown, and the only transitions shown are those between the charmed baryons. Note that there are two $J^P = 1/2^+$ Ξ_c states, and that the Ω_c does not have $J = 3/2$. Actually, none of the J^P values of the charmed baryons has been measured (except perhaps for the $1/2^+ \Lambda_c$), but they are all very likely as shown—see the discussion.

SU(4) multiplets—Baryons made from u, d, s, and c quarks belong to SU(4) multiplets. The multiplet numerology, analogous to $3\times3\times3 = 10+8_1+8_2+1$ 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 in 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 $\bar{4}$-plet, respectively.

The flavor symmetries shown in Fig. 2 are of course very 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 is not in the same SU(4) multiplet as the famous $J^P = 3/2^+$ Ω^-.

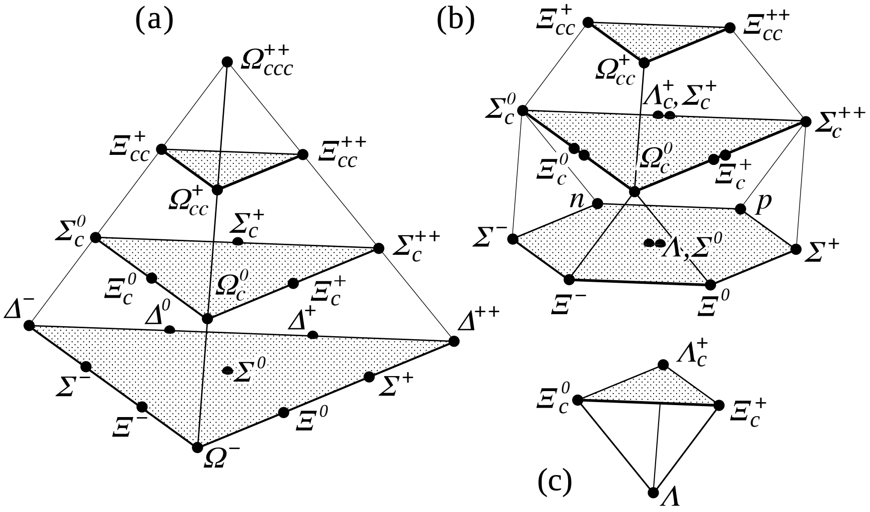

Figure 2: SU(4) multiplets of baryons made of u, d, s, and c quarks. (a) The 20-plet with an SU(3) decuplet on the lowest level. (b) The $20'$-plet with an SU(3) octet on the lowest level. (c) The $\bar{4}$-plet.

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 $\bar{3}$ and a 6. The states of the $\bar{3}$ 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 $\bar{3}$.

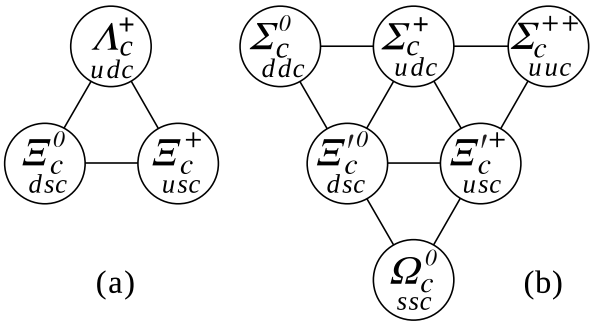

Figure 3: The SU(3) multiplets on the second level of the SU(4) multiplet of Fig. 2(b).

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, none of the other J^P quantum numbers given in Fig. 1(a) has 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, strong evidence that at least some of the J^P assignments in Fig. 1(a) are 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 be equal according to SU(3); and indeed experimentally they nearly are. Similarly, the successive 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 equal—assuming, of course, that they *do* all have the same J^P. And the observed differences are 124.2 ± 2.9 MeV and 119.5 ± 3.9 MeV—not perfect, but close. By the same reasoning, since the mass difference between the presumed $J^P = 3/2^+$ $\Sigma_c(2520)^0$ and $\Xi_c(2645)^0$ is 128.1 ± 1.3 MeV, the $3/2^+$ Ω_c^0 should be at about 2774 MeV.

(3) Other evidence comes from the decay of the $\Lambda_c(2593)$. The only allowed strong decay is $\Lambda_c(2593)^+ \rightarrow \Lambda_c^+\pi\pi$, 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 $\Lambda_c(2593)$.

(4) The heavier charmed baryons, such as the $J^P = 1/2^-$ and $3/2^-$ Λ_c's, have much narrower widths than do their strange counterparts, such as the $\Lambda(1405)$ and $\Lambda(1520)$. The clean Λ_c spectrum has in fact been taken to settle the decades-long discussion about the nature of the $\Lambda(1405)$—true 3-quark state or mere $\overline{K}N$ threshold effect?—unambiguously in favor of the first interpretation (which is not to say that the proximity of the $\overline{K}N$ threshold has no effect on the $\Lambda(1405)$). In fact, models of baryon-resonance spectroscopy should now *start* with the narrow charmed baryons, and work back to those broad old resonances.

Footnotes:

[*] There is evidence for two more baryons with one c quark—a $\Lambda_c(2765)^+$ and a $\Lambda_c(2880)^+$—and for a baryon with *two* c quarks—a Ξ_{cc}^+ at 3519 MeV. However, they have not yet been promoted to the Summary Table. 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 that decays strongly has its mass as part of its name; otherwise it doesn't. Thus $\Sigma(1385)$ and $\Sigma_c(2455)$ but Ω^- and Ξ_c'.