CHARMED BARYONS

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There are now ten (!) known charmed baryons, each with one c quark. Figure 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 assignments given in Fig. 1(a) have not been measured but have been assigned in accord with expectations of the theory.

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) octet, such as the octet that includes the nucleon. Figure 2(b) shows the 20-plet whose bottom level is an SU(3) decuplet, such as the decuplet that includes the $\Delta(1232)$. One level up in each multiplet are the baryons with one c quark. The $\bar{4}$ multiplet (not shown), an inverted tetrahedron, contains a Λ, a Λ_c^+, a Ξ_c^+, and a Ξ_c^0 (states at the centers of the four faces of the $20'$-plet). 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(a), 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^-.

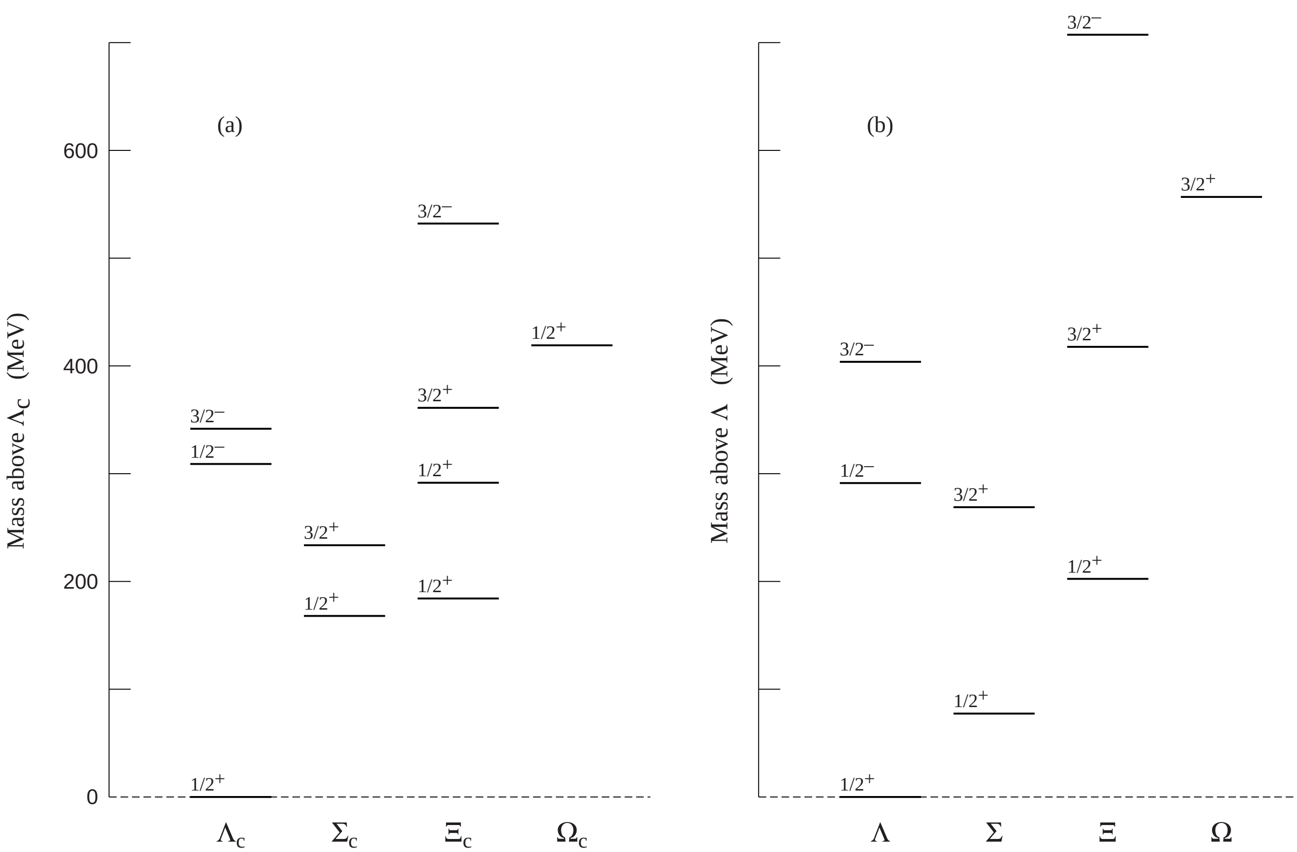

Figure 1. (a) The known charmed baryons, and (b) the lightest strange baryons. The baseline masses are $m(\Lambda_c) = 2284.9$ MeV and $m(\Lambda) = 1115.7$ MeV. Isospin splittings are not shown. Note that there are two $J^P = 1/2^+$ Ξ_c states, and that the Ω_c does not have $J = 3/2$. In fact, none 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.

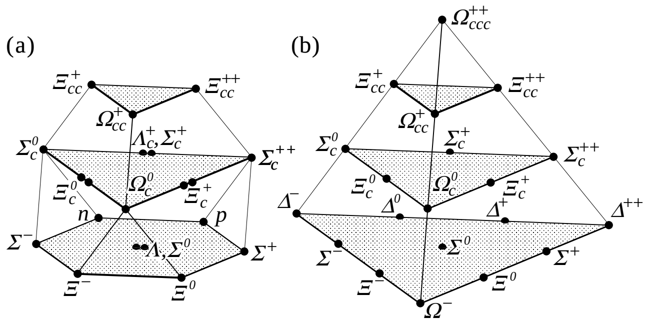

Figure 2: SU(4) multiplets of baryons made of u, d, s, and c quarks. (a) The 20-plet with an SU(3) octet on the lowest level. (b) The 20-plet with an SU(3) decuplet on the lowest level.

Figure 3 shows in more detail the middle level of the 20′-plet of Fig. 2(a); 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 $\bar{3}$.

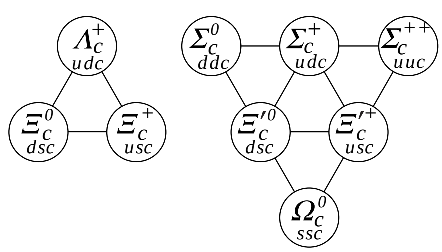

Figure 3: The SU(3) multiplets on the second level of the SU(4) multiplet of Fig. 2(a).

The observed spectra—(1) The parity of the lowest Λ_c is defined to be positive (as are the parities of the p, n, and Λ); and the limited evidence about its spin is consistent with $J = 1/2$. Otherwise, however, none of the J^P quantum numbers 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 $J^P = 3/2^+$ $\Delta(1232)^-$, $\Sigma(1385)^-$, $\Xi(1535)^-$, and Ω^-, those particles along the lower left edge of the 20-plet in Fig. 2(b), should be, according to SU(3), and nearly are equal; see the $J^P = 3/2^+$ states in Fig. 1(b). Similarly, 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 equal—assuming, of course, that they *do* all have the same J^P. And the observed differences are 126.6 ± 3.3 MeV and 125.2 ± 5.1 MeV—perfect, within errors. In fact, the mass difference between the presumed $J^P = 3/2^+$ $\Sigma_c(2520)^0$ and $\Xi_c(2645)^0$ is the same, 127.0 ± 2.3 MeV, which would put the $3/2^+$ Ω_c^0 at about 2772 MeV (= 487 MeV on Fig. 1(a)).

(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 $\Lambda_c(2593)$.

(4) The heavier c 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 $\Lambda(1405)$.

Footnotes:

† 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'.