84. Charmed Baryons

Revised August 2019 by C.G. Wohl (LBNL).

Figure 84.1(a) shows the spectrum of the charmed baryons—there are now 24 of them. The $\Lambda_c(2860)$ and the top five Ω_c^0's are new with this 2018 edition. Figure 84.1(b) shows the spectrum of the eleven known bottom baryons. Since the latter set differs only by the replacement of a charm quark with a bottom quark, the spectra ought to be very similar—and they are. We discuss the charmed baryons here; nearly all we say would apply to the bottom baryons with the replacement of a c with a b.

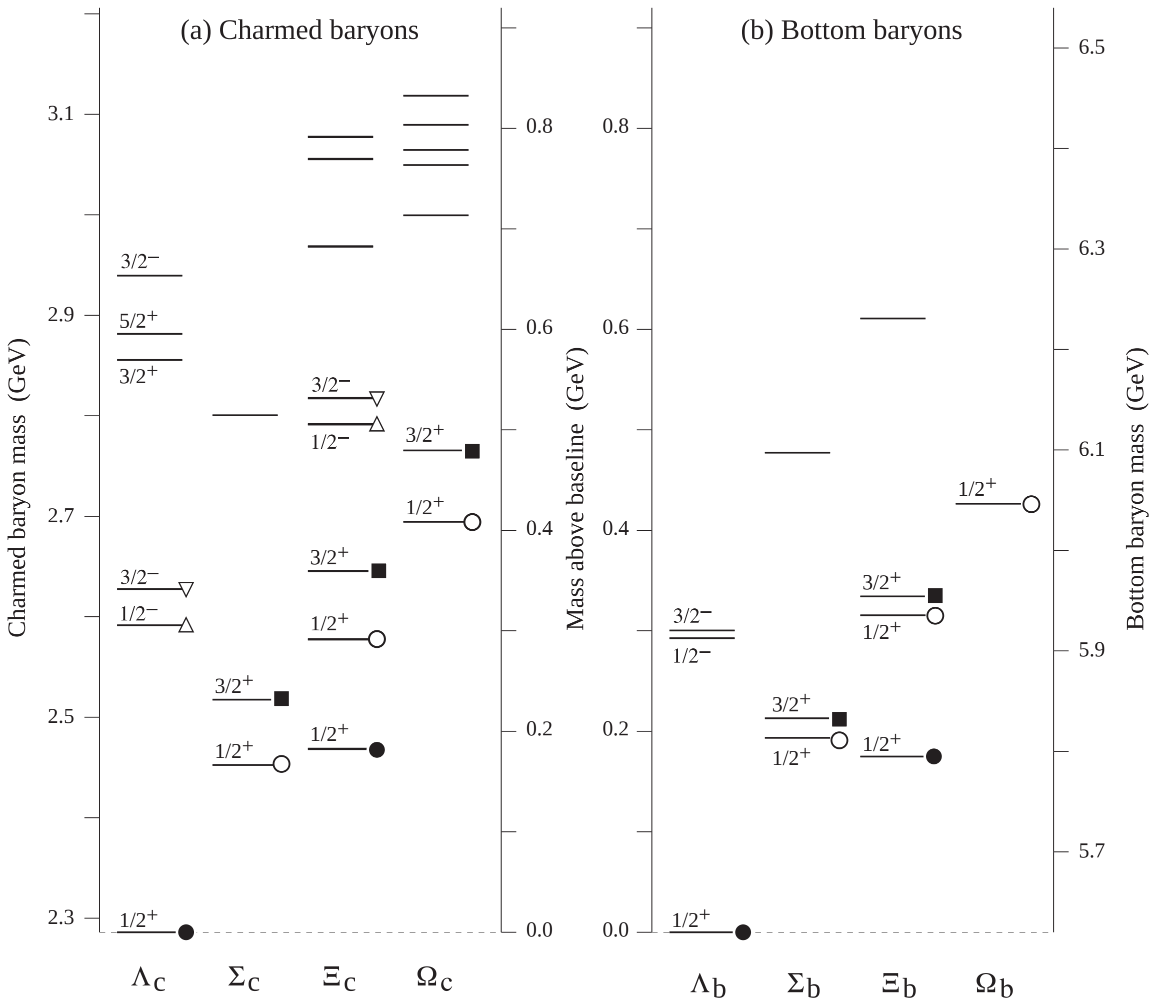

Figure 84.1: (a) The 24 known charmed baryons, and (b) the eleven know bottom baryons. We discuss the charmed baryons; similar remarks would apply to the bottom baryons. The five $J^P = 1/2^+$ states, all tabbed with a circle, belong to the *udsc*-SU(4) multiplet that includes the nucleon. States with a circle with the same *fill* belong to the same SU(3) multiplet within that SU(4) multiplet (see below). The three $J^P = 3/2^+$ states tabbed with a square belong to the SU(4) multiplet that includes the $\Delta(1232)$. The $J^P = 1/2^-$ and $3/2^-$ states tabbed with triangles complete two SU(4) $\bar{4}$ multiplets.

We review briefly the theory of SU(4) multiplets, which tells what charmed baryons to expect.

84.1. 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 84.2(a) shows the 20-plet whose bottom level is an SU(3) decuplet, such as the decuplet that includes the $\Delta(1232)$; each of its three sloping faces are also decuplets. Figure 84.2(b) shows the $20'$-plet whose bottom level is an SU(3) octet, such as the octet that includes the nucleon; each of its three sloping faces are also octets. Figure 84.2(c) shows the $\bar{4}$ multiplet, an inverted tetrahedron; each of its sloping faces are also triangles. The tetrahedral symmetry of the diagrams is of course what the SU(4) symmetry is about. As the masses in a multiplet are widely different, the symmetry is badly broken, but that does not spoil it as a classification scheme.

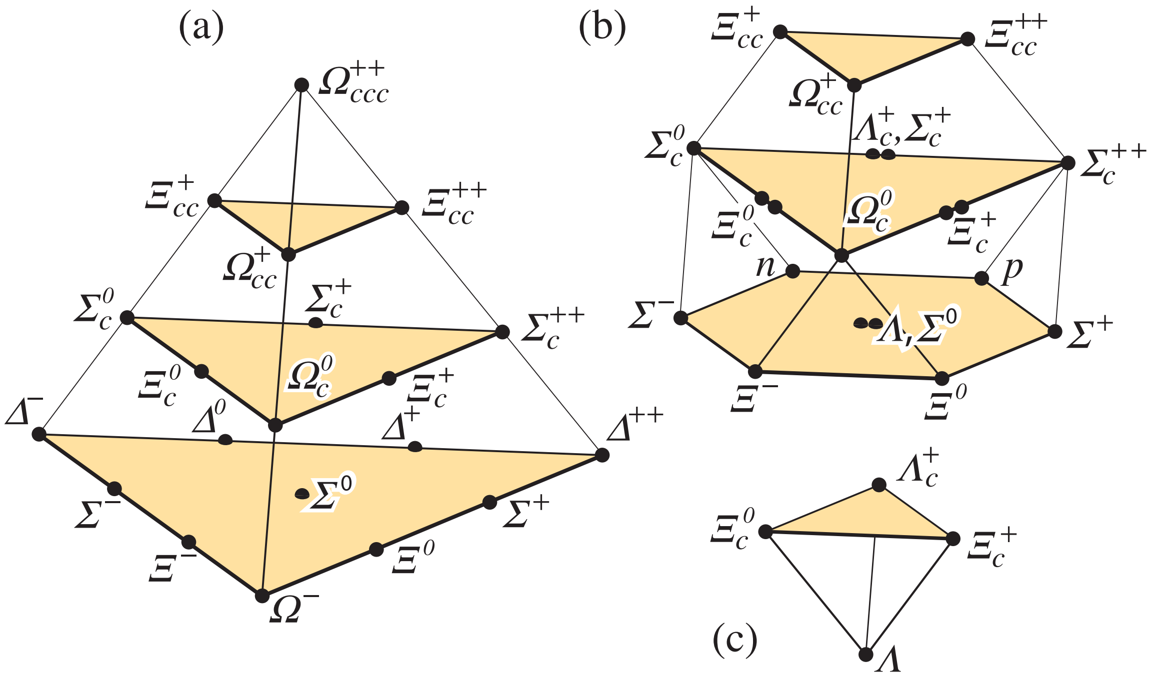

Figure 84.2: SU(4) multiplets of baryons made of u, d, s, and c quarks. (a) The 20-plet with an SU(3) decuplet on the lowest level. (b) The $20'$-plet with an SU(3) octet on the lowest level. (c) The $\bar{4}$-plet. Note that here and in Fig. 84.3, but not in Fig. 84.1, each charge state is shown separately.

The baryons with one c quark are one level up from the bottom of each multiplet. The baryons in a given multiplet all 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. We expect to find (and do!) 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 84.3 shows in more detail the middle level of the $20'$-plet of Fig. 84.2, which 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 $\bar{3}$.

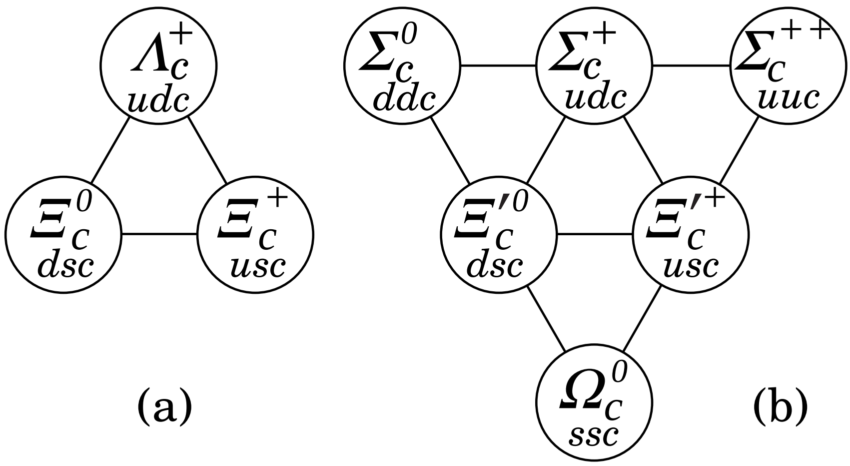

Figure 84.3: The SU(3) multiplets on the second level of the SU(4) multiplet of Fig. 84.2(b). The Λ_c and Ξ_c tabbed with closed circles in Fig. 84.1(a) complete a $J^P = 1/2^+$ SU(3) $\bar{3}$-plet, as in (a) here. The Σ_c, Ξ_c, and Ω_c tabbed with open circles in Fig. 84.1(a) complete a $J^P = 1/2^+$ 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. 84.2(b).

The spacing in mass of the particles with open circles in Figs. 84.1(a) and (b) and with squares in Fig. 84.1(a) brings to mind an old, approximate U-spin rule for the mass differences, one to the next, between the $\Delta(1232)^-$, $\Sigma(1385)^-$, $\Xi(1530)^-$, and Ω^-, which lie along the bottom left edge of the multiplet in Fig. 84.2(a): the differences should be and are about equal.* The same rule also predicts that the mass differences along the left edges of the 6-plets on the second level of Fig. 84.2(a) and in Figure 84.3(b) should

* Reminder: the mass is part of a particle's name if it decays strongly.

be the same. It does not work well here:

	Particle 1	Particle 2	Mass difference (MeV)
$J = 3/2$:	$\Xi_c(2645)^0$	$\Sigma_c(2520)^0$	127.90 ± 0.29
	$\Omega_c(2770)^0$	$\Xi_c(2645)^0$	119.5 ± 2.0
$J = 1/2$:	$\Xi_c'^0$	$\Sigma_c(2455)^0$	125.5 ± 0.5
	Ω_c^0	$\Xi_c'^0$	116.4 ± 1.8
$J = 1/2$:	$\Xi_b'(5935)^-$	Σ_b^-	119.38 ± 0.27
	Ω_b^-	$\Xi_b'(5935)^-$	111.1 ± 1.7

For what it is worth, the rule *fails* by the same amount in the three cases: 8.4 ± 2.0, 9.5 ± 1.9, and 8.3 ± 1.7 MeV. This is not the place for further explorations of the mass spectra.