104. Charmed Baryons

Revised March 2018 by C.G. Wohl (LBNL).

Figure 104.1(a) shows the spectrum of the charmed baryons—there are now 24 of them. The $\Lambda_c(2860)$ and the top five $\Omega_c^0$’s are new with this 2018 edition. Figure 104.1(b) shows the spectrum of the nine 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 $b$.

![Charmed and Bottom Baryon Spectra](image)

**Figure 104.1:** (a) The 24 known charmed baryons, and (b) the nine known 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.
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We review briefly the theory of SU(4) multiplets, which tells what charmed baryons to expect.

104.1. 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 \(4 \times 4 \times 4 = 20 + 20_1 + 20_2 + 4\). Figure 104.2(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 104.2(b) shows the 20\(^\prime\)-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 104.2(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 104.2](image)

**Figure 104.2:** 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\(^\prime\)-plet with an SU(3) octet on the lowest level. (c) The \(\bar{4}\)-plet. Note that here and in Fig. 104.3, but not in Fig. 104.1, 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 \(\Delta\) or SU(3)-singlet-\(\Lambda\) resonance calls for another 20\(^\prime\)- 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 $\Lambda_c$, a $\Sigma_c$, two $\Xi_c$'s, and an $\Omega_c$. Note that this $\Omega_c$ has $J^P = 1/2^+$ and is not in the same SU(4) multiplet as the famous $J^P = 3/2^+$ $\Omega^-$.

Figure 104.3 shows in more detail the middle level of the $20'$-plet of Fig. 104.2, which splits apart into two SU(3) multiplets, a 3 and a 6. The states of the 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 $\Xi_c$ in the 6 from the one in the 3.

Figure 104.3: The SU(3) multiplets on the second level of the SU(4) multiplet of Fig. 104.2(b). The $\Lambda_c$ and $\Xi_c$ tabbed with closed circles in Fig. 104.1(a) complete a $J^P = 1/2^+$ SU(3) 3-plet, as in (a) here. The $\Sigma_c$, $\Xi_c$, and $\Omega_c$ tabbed with open circles in Fig. 104.1(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. 104.2(b).

The spacing in mass of the particles with open circles in Figs. 104.1(a) and (b) and with squares in Fig. 104.1(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 $\Omega^-$, which lie along the bottom left edge of the multiplet in Fig. 104.2(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. 104.2(a) and in Figure 104.3(b) should be

* Reminder: the mass is part of a particle’s name if it decays strongly.
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the same. It does not work well here:

<table>
<thead>
<tr>
<th>Mass difference (MeV)</th>
<th>Particle 1</th>
<th>Particle 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>127.84 ± 0.37</td>
<td>$\Xi_c(2645)^0$</td>
<td>$\Sigma_c(2520)^0$</td>
</tr>
<tr>
<td>119.6 ± 2.0</td>
<td>$\Omega_c(2770)^0$</td>
<td>$\Xi_c(2645)^0$</td>
</tr>
<tr>
<td>125.1 ± 0.5</td>
<td>$\Xi^0_c$</td>
<td>$\Sigma^0_c$</td>
</tr>
<tr>
<td>116.4 ± 1.8</td>
<td>$\Omega^0_c$</td>
<td>$\Xi^0_c$</td>
</tr>
<tr>
<td>119.5 ± 1.8</td>
<td>$\Xi^0_b$</td>
<td>$\Sigma^0_b$</td>
</tr>
<tr>
<td>111.1 ± 1.7</td>
<td>$\Omega^0_b$</td>
<td>$\Xi^0_b$</td>
</tr>
</tbody>
</table>

For what it is worth, the rule *fails* by the same amount in the three cases: $8.2 \pm 2.0$, $8.7 \pm 1.9$, and $8.4 \pm 2.5$ MeV. This is not the place for further explorations of the mass spectra.