Update of heavy baryon mass predictions

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Predictions of unknown heavy baryon masses based on an expansion in $1/m_Q$, $1/N_c$, and SU(3) breaking are updated to take into account a recent measurement of the Σ_c^* mass. Values are given for the two remaining unknown charm baryon masses Ξ_c' and Ω_c^* and the seven unknown bottom baryon masses Ξ_b, Σ_b, Ξ_b', Ω_b, Σ_b^*, Ξ_b^*, and Ω_b^*. [S0556-2821(97)50201-3]

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The spectrum of baryons containing a single charm or bottom quark recently has been analyzed in an expansion in $1/m_Q$, $1/N_c$, and SU(3) flavor breaking [1]. The analysis of Ref. [1] yields a hierarchy of mass relations among heavy quark baryons, as well as additional relations between heavy baryon mass splittings and mass splittings of the octet and decuplet baryons. From this analysis, it is possible to predict the unknown charm and bottom baryon masses to varying accuracies, where the errors on the predicted values reflect both experimental errors of measured baryon masses and the expected theoretical accuracies of the mass relations.

Recently, a very precise measurement of the Σ_c^* mass has been reported by CLEO [3]. The most precise flavor-27 mass relations [2,1] of the charm baryons determine Ξ_c' and $(\Sigma_c^*+\Omega_c^*)$, but not Σ_c^* and Ω_c^* separately. Given the Σ_c^* mass, it is possible to pin down the Ω_c^* mass. With the entire charm baryon spectrum determined rather precisely, prediction of the bottom baryon spectrum from the charm baryon spectrum is improved. The mass predictions of Ref. [1] are updated in this note. Mass predictions for individual bottom baryon masses are given.

The presently measured charm baryon masses are

$$\begin{aligned}
\Lambda_c &= 2285.0 \pm 0.6 \ \text{MeV} \ [4],\\
\Xi_c &= 2467.7 \pm 1.2 \ \text{MeV} \ [4],\\
\Sigma_c &= 2452.9 \pm 0.6 \ \text{MeV} \ [4\text{–}6],\\
\Omega_c^0 &= 2699.9 \pm 2.9 \ \text{MeV} \ [7],\\
\Sigma_c^* &= 2518.6 \pm 2.2 \ \text{MeV} \ [3],\\
\Xi_c^* &= 2644.0 \pm 1.6 \ \text{MeV} \ [8].
\end{aligned} \tag{1}$$

An observation of the $\Xi_c' \sim 2560$ MeV with an error bar of order 15 MeV has been reported by the WA89 Collaboration [11]. The Ω_c^* has never been observed. At present, only the bottom baryon mass

$$\Lambda_b = 5623 \pm 5 \pm 4 \ \text{MeV} \ [9] \tag{2}$$

is accurately measured. Reported measurements of $\Sigma_b^{(*)}$ by DELPHI [10] are not used.

There are two very accurate mass relations among the charm baryon masses given in Ref. [1]:

$$\tfrac{1}{4}[(\Sigma_Q^*-\Sigma_Q)-2(\Xi_Q^*-\Xi_Q')+(\Omega_Q^*-\Omega_Q)]=0 \tag{3}$$

with an estimated theoretical error of 0.23 MeV for $Q=c$ and 0.07 MeV for $Q=b$, and

$$\begin{aligned}
&\tfrac{1}{6}[(\Sigma_Q+2\Sigma_Q^*)-2(\Xi_Q'+2\Xi_Q^*)+(\Omega_Q+2\Omega_Q^*)]\\
&\quad=\tfrac{1}{3}[\tfrac{1}{4}(2N-\Sigma-3\Lambda+2\Xi)+\tfrac{1}{7}(4\Delta-5\Sigma^*-2\Xi^*+3\Omega)]
\end{aligned} \tag{4}$$

with an estimated theoretical accuracy of 1.5 MeV for $Q=c,b$. The linear combination of octet and decuplet masses on the right-hand side of Eq. (4) equals -4.43 MeV with negligible error. Using Eqs. (3) and (4), it is possible to predict the two unknown charm baryon masses Ξ_c' and Ω_c^* in terms of the other measured charm baryon masses:

$$\begin{aligned}
\Xi_c' &= \tfrac{1}{2}(\Sigma_c+\Omega_c)+(4.43\pm 1.5) \ \text{MeV},\\
\Omega_c^* &= (2\Xi_c^*-\Sigma_c^*)+(-8.86\pm 3.0) \ \text{MeV},
\end{aligned} \tag{5}$$

which yields

$$\begin{aligned}
\Xi_c' &= 2580.8 \pm 2.1 \ \text{MeV},\\
\Omega_c^* &= 2760.5 \pm 4.9 \ \text{MeV}.
\end{aligned} \tag{6}$$

With the predicted Ξ_c' and Ω_c^* masses (6) and the measured charm baryon masses, it is possible to evaluate any charm baryon mass combination. The chromomagnetic mass splittings are evaluated to be

$$\begin{aligned}
(\Sigma_c^*-\Sigma_c) &= 65.7 \pm 2.3 \ \text{MeV},\\
(\Xi_c^*-\Xi_c') &= 63.2 \pm 2.6 \ \text{MeV},\\
(\Omega_c^*-\Omega_c) &= 60.6 \pm 5.7 \ \text{MeV}.
\end{aligned} \tag{7}$$

The spin-averaged sextet masses are

$$\begin{aligned}
\tfrac{1}{3}(\Sigma_c+2\Sigma_c^*) &= 2496.7 \pm 1.5 \ \text{MeV},\\
\tfrac{1}{3}(\Xi_c'+2\Xi_c^*) &= 2622.9 \pm 1.3 \ \text{MeV},\\
\tfrac{1}{3}(\Omega_c+2\Omega_c^*) &= 2740.3 \pm 3.4 \ \text{MeV},
\end{aligned} \tag{8}$$

while the sextet mass differences are

$$\tfrac{1}{3}(\Xi_c'+2\Xi_c^*)-\tfrac{1}{3}(\Sigma_c+2\Sigma_c^*)=126.2\pm2.0\ \mathrm{MeV},$$

$$\tfrac{1}{3}(\Omega_c+2\Omega_c^*)-\tfrac{1}{3}(\Xi_c'+2\Xi_c^*)=117.4\pm3.6\ \mathrm{MeV}. \quad (9)$$

The J_{ℓ}^2 hyperfine splittings in each strangeness sector are

$$\tfrac{1}{3}(\Sigma_c+2\Sigma_c^*)-\Lambda_c=211.7\pm1.6\ \mathrm{MeV},$$

$$\tfrac{1}{3}(\Xi_c'+2\Xi_c^*)-\Xi_c=155.2\pm1.8\ \mathrm{MeV}, \quad (10)$$

so the difference of these splittings is large,

$$[\tfrac{1}{3}(\Sigma_c+2\Sigma_c^*)-\Lambda_c]-[\tfrac{1}{3}(\Xi_c'+2\Xi_c^*)-\Xi_c] =56.5\pm2.4\ \mathrm{MeV}. \quad (11)$$

The bottom baryon masses can be predicted in terms of the charm baryon masses and the measured Λ_b mass.

The chromomagnetic hyperfine splittings of the heavy quark baryons are proportional to $1/m_Q$, so the bottom baryon chromomagnetic splittings can be obtained from the charm baryon splittings by rescaling by a factor of $\sim m_c/m_b$. Including renormalization group running, the scale factor is $(Z_b/Z_c)(m_c/m_b)\sim0.24\pm0.05$. Using this scale factor, the chromomagnetic mass splittings of the bottom baryons are predicted to be

$$(\Sigma_b^*-\Sigma_b)=15.8\pm3.3\ \mathrm{MeV},$$

$$(\Xi_b^*-\Xi_b')=15.2\pm3.2\ \mathrm{MeV}, \quad (12)$$

$$(\Omega_b^*-\Omega_b)=14.5\pm3.3\ \mathrm{MeV},$$

where the errors on the splittings are dominated by the uncertainty of the scale factor. Note that Eq. (3) is essentially an exact relation for the chromomagnetic splittings. In addition, by scaling from the charm system, one concludes that the mass combination

$$\tfrac{1}{6}[3(\Sigma_b^*-\Sigma_b)-(\Xi_b^*-\Xi_b')-2(\Omega_b^*-\Omega_b)] \quad (13)$$

is quite small, and can be at most a few MeV.

The spin-averaged sextet masses of the bottom baryons and the Ξ_b are determined by four mass relations. There are two very accurate relations: namely, Eq. (4),

$$\tfrac{1}{6}[(\Sigma_b+2\Sigma_b^*)-2(\Xi_b'+2\Xi_b^*)+(\Omega_b+2\Omega_b^*)] =-4.43\pm1.5\ \mathrm{MeV}, \quad (14)$$

and

$$\{-\tfrac{5}{8}(\Lambda_b-\Xi_b)+\tfrac{1}{24}[3(\Sigma_b+2\Sigma_b^*)-(\Xi_b'+2\Xi_b^*) -2(\Omega_b+2\Omega_b^*)]\}$$
$$=\{-\tfrac{5}{8}(\Lambda_c-\Xi_c)+\tfrac{1}{24}[3(\Sigma_c+2\Sigma_c^*)-(\Xi_c'+2\Xi_c^*) -2(\Omega_c+2\Omega_c^*)]\}\pm1.0\ \mathrm{MeV}, \quad (15)$$

where the errors are the estimated theoretical accuracies of the two relations. The charm mass combination on the right-hand side of Eq. (15) equals 37.5 ± 1.3 MeV, so Eq. (15) becomes

$$\{-\tfrac{5}{8}(\Lambda_b-\Xi_b)+\tfrac{1}{24}[3(\Sigma_b+2\Sigma_b^*)-(\Xi_b'+2\Xi_b^*) -2(\Omega_b+2\Omega_b^*)]\} =37.5\pm1.6\ \mathrm{MeV}. \quad (16)$$

There are two additional mass relations which are less accurate:

$$(\Lambda_b-\Xi_b)=(\Lambda_c-\Xi_c)\pm4.8\ \mathrm{MeV}, \quad (17)$$

and

$$-\tfrac{1}{3}(\Lambda_b+2\Xi_b)+\tfrac{1}{18}[3(\Sigma_b+2\Sigma_b^*)+2(\Xi_b'+2\Xi_b^*) +(\Omega_b+2\Omega_b^*)]$$
$$=-\tfrac{1}{3}(\Lambda_c+2\Xi_c)+\tfrac{1}{18}[3(\Sigma_c+2\Sigma_c^*)+2(\Xi_c'+2\Xi_c^*) +(\Omega_c+2\Omega_c^*)]\pm5.1\ \mathrm{MeV}. \quad (18)$$

Since $(\Lambda_c-\Xi_c)=-182.7\pm1.3$ MeV experimentally, the first equation becomes

$$(\Lambda_b-\Xi_b)=-182.7\pm5.0\ \mathrm{MeV}. \quad (19)$$

The charm baryon mass combination in the second equation is evaluated to be 172.6 ± 1.3 MeV, so

$$-\tfrac{1}{3}(\Lambda_b+2\Xi_b)+\tfrac{1}{18}[3(\Sigma_b+2\Sigma_b^*)+2(\Xi_b'+2\Xi_b^*) +(\Omega_b+2\Omega_b^*)] =172.6\pm5.3\ \mathrm{MeV}. \quad (20)$$

Combined with the measured Λ_b mass, $\Lambda_b=5623.0\pm6.4$ MeV, Eq. (19) implies

$$\Xi_b=5805.7\pm8.1\ \mathrm{MeV}. \quad (21)$$

The spin-averaged mass of the bottom antitriplet is evaluated to be

$$\tfrac{1}{3}(\Lambda_b+2\Xi_b)=5744.8\pm5.8\ \mathrm{MeV}. \quad (22)$$

Eliminating the Λ_b and Ξ_b masses from the remaining relations yields three mass relations involving the three spin-averaged sextet masses of the bottom baryons:

$$\tfrac{1}{6}[(\Sigma_b+2\Sigma_b^*)-2(\Xi_b'+2\Xi_b^*)+(\Omega_b+2\Omega_b^*)] =-4.43\pm1.5\ \mathrm{MeV},$$

$$\tfrac{1}{24}[3(\Sigma_b+2\Sigma_b^*)-(\Xi_b'+2\Xi_b^*)-2(\Omega_b+2\Omega_b^*)] =-76.7\pm3.5\ \mathrm{MeV}, \quad (23)$$

$$\tfrac{1}{18}[3(\Sigma_b+2\Sigma_b^*)+2(\Xi_b'+2\Xi_b^*)+(\Omega_b+2\Omega_b^*)] =5917.4\pm7.9\ \mathrm{MeV}.$$

The extracted spin-averaged mass combinations are

$$\tfrac{1}{3}(\Sigma_b+2\Sigma_b^*)=5834.7\pm 8.7 \text{ MeV},$$

$$\tfrac{1}{3}(\Xi_b'+2\Xi_b)=5961.0\pm 8.2 \text{ MeV}, \tag{24}$$

$$\tfrac{1}{3}(\Omega_b+2\Omega_b^*)=6078.4\pm 10.9 \text{ MeV}.$$

The precision of the above extraction of Ξ_b and the spin-averaged sextet masses presently is limited by the theoretical accuracies of the two least accurate mass relations and by the experimental error of the Λ_b mass measurement. Improved accuracy of the Λ_b value or accurate measurement of other bottom baryon masses will lead to more precise predictions. Note that there are correlations amongst the spin-averaged mass values so that certain linear combinations involving the spin-averaged mass combinations are known much more accurately than the spin-averaged masses themselves. For example, any linear combination of the two most accurate mass relations Eqs. (14) and (15) is predicted very accurately. One such linear combination is

$$[\tfrac{1}{3}(\Sigma_b+2\Sigma_b^*)-\Lambda_b]-[\tfrac{1}{3}(\Xi_b'+2\Xi_b^*)-\Xi_b] =56.5\pm 2.8 \text{ MeV}. \tag{25}$$

Finally, values for the individual bottom baryon masses masses can be obtained by combining the extracted chromomagnetic and spin-averaged masses:

$$\Xi_b=5805.7\pm 8.1 \text{ MeV},$$

$$\Sigma_b=5824.2\pm 9.0 \text{ MeV},$$

$$\Sigma_b^*=5840.0\pm 8.8 \text{ MeV},$$

$$\Xi_b'=5950.9\pm 8.5 \text{ MeV}, \tag{26}$$

$$\Xi_b^*=5966.1\pm 8.3 \text{ MeV},$$

$$\Omega_b=6068.7\pm 11.1 \text{ MeV},$$

$$\Omega_b^*=6083.2\pm 11.0 \text{ MeV}.$$

Again, the values of the individual bottom baryon masses are correlated so that many linear combinations are known much more accurately than the individual masses themselves. The uncertainty in the spin-averaged sextet masses is significantly larger than the uncertainty in the chromomagnetic sextet splittings, for example. Improved accuracy of the Λ_b measurement and accurate measurement of other bottom baryon masses in the future will lead to more precise determinations of the remaining unknown masses.

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[1] E. Jenkins, Phys. Rev. D **54,** 4515 (1996).
[2] M.J. Savage, Phys. Lett. B **359,** 189 (1995).
[3] CLEO Collaboration, G. Brandenburg *et al.*, CLEO CONF 96-13 (unpublished).
[4] Particle Data Group, R. Barnett *et al.*, Phys. Rev. D **54,** 1 (1996).
[5] E687 Collaboration, P.L. Frabetti *et al.*, Phys. Lett. B **365,** 461 (1996).
[6] CLEO Collaboration, G. Crawford *et al.*, Phys. Rev. Lett. **71,** 3259 (1993).
[7] E687 Collaboration, P.L. Frabetti *et al.*, Phys. Lett. B **338,** 106 (1994).
[8] CLEO Collaboration, P. Avery *et al.*, Phys. Rev. Lett. **75,** 4364 (1995); L. Gibbons *et al.*, Phys. Rev. Lett. **77,** 810 (1996).
[9] CDF Collaboration, J. Kroll (private communication).
[10] DELPHI Collaboration, DELPHI Report No. 95-107 (unpublished).
[11] WA89 Collaboration, Roland Werding, in *Proceedings of the 27th International Conference on High Energy Physics*, Glasgow, Scotland, 1994, edited by P. J. Bussey and I. G. Knowles (IOP, London, 1995).