PHYSICAL REVIEW D VOLUME 55, NUMBER 1 1 JANUARY 1997

Mixing of Ξ_c-Ξ_c' baryons

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(Received 14 June 1996)

The mixing angle between the Ξ_c and Ξ_c' baryons is shown to be small in quark model calculations, with a negligible shift in the Ξ_c masses. [S0556-2821(97)03501-7]

PACS number(s): 12.40.Yx, 14.20.−c, 14.40.−n

Some concern has been expressed [1,2] that mixing between the Ξ_c and Ξ_c' baryons could have a significant effect on their masses. However, we show here that this mixing is small in quark model calculations, and shifts the Ξ_c and Ξ_c' masses by a negligible amount [3].

The theory for mixing between ''flavor-degenerate'' baryons which, like the Ξ_c and Ξ_c', contain three different flavor quarks that differ only in their internal spin composition has been developed in Ref. [4]. The Ξ_c and Ξ_c' are each composed of three different flavored quarks, n, s, and c. (We use the quark symbol n to refer to either the u or d quark.) The n and s quarks are in a relative spin 0 state for the Ξ_c, and in a spin 1 state for the Ξ_c'. The physical Ξ_c and Ξ_c' states with masses M and M' can be written in terms of unmixed quark model states $|nsc\rangle$ and $|nsc'\rangle$ as

$$\Xi=+\cos\theta|nsc\rangle+\sin\theta|nsc'\rangle, \tag{1}$$

$$\Xi'=-\sin\theta|nsc\rangle+\cos\theta|nsc'\rangle. \tag{2}$$

There will be a shift in mass from the pure quark state masses M_0 and M_0' given by [5]

$$\delta M'=-\delta M=\Delta\sin^2\theta, \tag{3}$$

where $\Delta=M'-M$ is the mass difference between the two physical states.

If flavor symmetry breaking is dominated by two body interaction energies with a quark mass dependence $\sim 1/m_i m_j$, then it is shown in Ref. [4] that

$$\tan 2\theta=\frac{\sqrt{3}(m_2-m_1)}{2m_3-m_1-m_2}. \tag{4}$$

For Ξ_c and Ξ_c' mixing, we use quark masses

$$m_1=m_n=330 \text{ MeV}, \quad m_2=m_s=510 \text{ MeV},$$

$$m_3=m_c=1.6 \text{ GeV}, \tag{5}$$

with the result

$$\theta_{\Xi_c\text{-}\Xi_c'}=3.8°, \quad \delta M'=0.4 \text{ MeV}. \tag{6}$$

This is our main result. The small value for $\delta M'$ depends on the small ratio $(m_s-m_n)/m_c=0.11$, which is about the same for all quark models.

Although the assumption that the symmetry-breaking quark$_i$-quark$_j$ interaction has a $\sim 1/m_i m_j$ dependence is part of most baryon mass calculations, the Ξ_c-Ξ_c' mixing can be estimated more generally assuming only the dominance of two body symmetry breaking. In fact for Σ-Λ mixing in the light baryon sector, this is necessary because the magnetic interaction between quarks has additional flavor independence. For this case, the Σ-Λ mixing angle can be written in terms of light baryon masses as [5]

$$\sin 2\theta_{\Sigma-\Lambda}=\frac{(\Sigma^- - \Sigma^+)-(\Sigma^{*-}-\Sigma^{*+})}{\sqrt{3}(\Sigma^0-\Lambda)}, \tag{7}$$

where the baryon symbol stands for its mass. For Σ-Λ mixing this leads to [6]

$$\theta_{\Sigma-\Lambda}=0.8°\pm 0.2°, \quad \delta M'=0.015 \text{ MeV}. \tag{8}$$

Although the mass shift is negligible, the Σ-Λ mixing does lead to a significant shift in the Λ magnetic moment of -0.045 ± 0.002 nuclear magnetons which should be included in any quark model calculation of the Λ magnetic moment.

Equation (7) for Σ-Λ mixing can be extended to the charmed baryons by simply replacing the uds quarks of the Σ^0 and Λ in Eq. (7) by the nsc quarks of the Ξ_c and Ξ_c' That is, as in Ref. [7], we make the quark substitutions

$$u\to u, \quad d\to s, \quad s\to c \tag{9}$$

everywhere in Eq. (7). This results in

$$\sin 2\theta_{\Xi_c\text{-}\Xi_c'}=\frac{(\Omega_c^0-\Sigma_c^{++})-(\Omega_c^{*0}-\Sigma_c^{*++})}{\sqrt{3}(\Xi_c'^{+}-\Xi_c^{+})}. \tag{10}$$

The Ω_c^* baryon has not been observed yet, so we use the sum rule [8]

$$\Omega_c^{*0}-\Omega_c^0=2(\Xi_c^{*+}-\Xi_c'^{+}+\delta M')-(\Sigma_c^{*++}-\Sigma_c^{++}) \tag{11}$$

to replace Eq. (10) with

$$\sin 2\theta_{\Xi_c\text{-}\Xi_c'}=\frac{2[(\Sigma_c^{*++}-\Sigma_c^{++})-(\Xi_c^{*+}-\Xi_c'^{+})]}{(\Xi_c'^{+}-\Xi_c^{+})(\sqrt{3}+\tan\theta_{\Xi_c\text{-}\Xi_c'})}. \tag{12}$$

A similar equation holds for the Ξ_c^0 and $\Xi_c'^0$ baryons if the quark substitution $u\to d$ is made in Eq. (12). The $\tan\theta_{\Xi_c\text{-}\Xi_c'}$ term in Eq. (12) is a small correction that permits the use of only physical baryon masses in the equation.

We use the masses[1] (in MeV)

$$\Xi_c^{*+}=2644.6\pm 2.3,\quad \Xi_c'^{+}=2563\pm 15,$$

$$\Xi_c^{+}=2465.1\pm 1.6, \tag{13}$$

$$\Sigma_c^{*++}=2530\pm 7,\quad \Sigma_c^{++}=2453 \tag{14}$$

to get the results

[1]Equation (13) masses obtained from Refs. [9–11], respectively. Equation (14) masses obtained from Refs. [12,11], respectively.

$$\theta_{\Xi_c\text{-}\Xi_c'}=-2°\pm 6°,\quad \delta M'<2\ \ \text{MeV}. \tag{15}$$

This is consistent with Eq. (6), but better experimental accuracy would be required to make a significant comparison. We have used the 1σ experimental error to get the 2 MeV limit on $\delta M'$. This is already negligible for most applications, and would be expected to decrease as the experimental accuracy improves.

Our conclusion is that Ξ_c-Ξ_c' mixing can be consistently neglected in quark model calculations. A similar conclusion holds for b quark baryons where the quark substitution $c\rightarrow b$ would lead to even smaller Ξ_b-Ξ_b' mixing.

[1] Richard F. Lebed, Phys. Rev. D **54**, 4463 (1996).

[2] T. Ito and Y. Matsui, Nagoya University Report No. DPNU-96-26, HEP-PH/9605289 (unpublished).

[3] R. E. Cutkosky and P. Geiger, Phys. Rev. D **48**, 1315 (1993), have reached a similar conclusion in a specific model calculation.

[4] J. Franklin, D. B. Lichtenberg, W. Namgung, and D. Carydas, Phys. Rev. D **24**, 2910 (1981).

[5] Reference [4] used small angle approximations, but the trigonometry is treated exactly here. Also note that Ref. [4] used a different convention for designating the primed state.

[6] The Σ-Λ mixing parameters given here come from using Eqs. (48)–(51) of Ref. [4]. We use newer experimental masses so that the numbers given here are different than those in Ref. [4].

[7] J. Franklin, Phys. Rev. D **12**, 2077 (1975).

[8] J. Franklin, this issue, Phys. Rev. D **55**, 423 (1997). Six sum rules such as Eq. (11), derived in this reference and Ref. [7], have been compared with experiment. They all agree with experiment to within 20 MeV, which is about the experimental error of the numerator in Eq. (12).

[9] CLEO Collaboration, L. Gibbons *et al.*, Phys. Rev. Lett. **77**, 810 (1996).

[10] WA89 Collaboration, E. Chudakov *et al.*, presented at Heavy Quarks ’94, Charlottesville, Virginia, 1994 (unpublished).

[11] Particle Data Group, L. Montanet *et al.*, Phys. Rev. D **50**, 1173 (1994).

[12] V. V. Ammosov *et al.*, JETP Lett. **58**, 247 (1993).