Evidence for SU(3) octet mixing*

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The strong decays of the two strange axial-vector mesons $Q_1(1289)$ and $Q_2(1404)$ are examined within the context of SU(3). It is found that the decays can be successfully explained by treating the Q's as mixed states of two pure $C=+1$ and $C=-1$ SU(3) octets. The vector-axial-vector–pseudoscalar S-wave coupling constants are calculated to be approximately 2.8 GeV for the A_1 multiplet and 4.2 GeV for the B multiplet, and the mixing angle approximately 48°.

Evidence has recently been presented[1,2] supporting the existence[3] of strangeness-one axial-vector mesons in the region 1300–1400 MeV. These particles, called Q_1 and Q_2, are observed from partial-wave analysis[4] to have masses 1289 and 1404 MeV, respectively. It is tempting to assign these particles to two different SU(3) octets whose $I=1$ members are the $A_1(1100)$ and $B(1235)$. The charge-conjugation parity of the neutral and nonstrange members of the Q_1, A_1 multiplet would be even, while that of the Q_2, B multiplet would be odd. This assignment would be favored by the SU(6) $\otimes$O(3) quark model,[5] which predicts two axial-vector multiplets with even and odd C parity.

However, the decays of the Q's are not easily incorporated into a scheme with approximate SU(3) symmetry of the coupling constants. For example, the ratio $\Gamma(Q_1\to\rho K)/\Gamma(Q_1\to K^*\pi)$ should be about 1/3 according to SU(3) and phase-space considerations; however, it is observed[4] to be at least 10, even with the most liberal interpretation of errors. A possible way around this difficulty would be to construct a model with SU(3)-symmetry breaking. In a model of SU(3) breaking via a λ_8 spurion,[6] one finds that in order to suppress the $Q_1\to K^*\pi$ decay one needs large SU(3) breaking, that is, the SU(3)-breaking parameters are as large as the SU(3)-preserving ones. This is certainly not in accord with our previous experience[7] with SU(3).

The near degeneracy of the mean mass of the two axial-vector multiplets suggests the possibility of mixing between them. This idea was proposed some time ago by several authors[8] when the characteristics of the Q's were much less well defined. If, as has been suggested, the two multiplets considered here have different C parities, then invariance of the strong interactions under G parity would dictate that only the Q's, which are eigenstates of strangeness and therefore not of G parity, would mix. Thus, the axial-vector–vector–pseudoscalar (AVP henceforth) vertex involving the Q's will contain both f- and d-type coupling.

The Lorentz-covariant decay amplitude for $A_i\to V_jP_k$ is given by

$$T=g_S\epsilon_A\cdot\epsilon_V+g_D\epsilon_A\cdot p_V\,\epsilon_V\cdot p_A\,, \tag{1}$$

where the ϵ's and the p's are the polarizations and momenta of the vector and axial-vector mesons. We express the mixing of the strange members of the A_1 and B octets via the angle γ:

$$\begin{aligned} g_S(Q_1)&=if_{ijk}g_A^S\cos\gamma+d_{ijk}g_B^S\sin\gamma\,,\\ g_S(Q_2)&=-if_{ijk}g_A^S\sin\gamma+d_{ijk}g_B^S\cos\gamma\,, \end{aligned} \tag{2}$$

with similar expressions for g_D.

Helicity amplitudes proportional to those introduced by Colglazier and Rosner[8] are easily constructed from g_S and g_D:

$$\begin{aligned} H_0&=[g_D m_A q^2+(m_V{}^2+q^2)^{1/2}g_S]/m_V\,,\\ H_1&=g_S\,, \end{aligned} \tag{3}$$

where m_V and m_A are the masses of the vector and axial-vector mesons, and q is the center-of-mass momentum of the decay process. In terms of H_0 and H_1 the decay rates are given simply by

$$\Gamma(A\to VP)=\frac{q}{24\pi m_A{}^2}(H_0{}^2+2H_1{}^2)\,. \tag{4}$$

A compilation of $B\to\omega\pi$ data[9] yields $g_B^D/g_B^S=-2.90$ GeV^{-2}. While definitive data on the A_1 multiplet are lacking, one may estimate g_A^D/g_A^S via a quark-model sum rule[10] involving the H's:

$$2\left(\frac{H_1}{H_0}\right)_{A\to\rho\pi}=\left(\frac{H_0}{H_1}\right)_{B\to\omega\pi}-1\,. \tag{5}$$

We obtain $g_A^D/g_A^S=2.58$ GeV^{-2}.

The decay processes to which we apply these formulas are listed in Table I. The small values for $\Gamma(Q_1\to K^*\pi)$ and $\Gamma(Q_2\to\rho K)$ imply that $g_A\simeq g_B$ and $\gamma\simeq 45°$. (These would be equalities if the two rates vanished.) These conditions also imply that $\Gamma(Q_1\to\rho K)/\Gamma(Q_2\to K^*\pi)\simeq 0.4$, which is plausible if one includes the large systematic error in the $Q_1\to\rho K$ rate. The first five decay rates in the table are used for a minimum-χ^2 fit, while the remaining three are predictions. The errors chosen for the minimization in the decays of the Q's are the systematic ones. The Q_1 decay rates depend critically on the Q_1 mass, because of the small phase space available. Because there is a 25-MeV systematic uncertainty associated with the Q_1 mass, we have chosen a value of 1300 MeV for our calculations. Raising or lowering the mass by 10 MeV changes the ρK and ωK rates accordingly by about 20%. We show the solutions found for the fit with and without the D-wave contribution included. In the latter case, there are two solutions with roughly the same χ^2, so both are given. We note that it is a good first approximation to ignore the D-wave contribution. We have listed here only those solutions with positive coupling constants and mixing angle in the first quadrant. Other simple ambiguities exist due to choice of quadrant for γ and sign of g_A^S/g_B^S, but they yield the same results for the processes listed in Table I. As more data become available, one will hopefully be able to distinguish between these solutions.

Some $A \to SP$ decays of the Q's have also been observed. Simple calculation shows that these rates would be given by

$$\Gamma(Q_{1i} \to P_j S_k) = \frac{2}{3} \frac{q^3}{m_{Q_1}{}^2} \frac{(h_A d_{ijk} \cos\gamma + i h_B f_{ijk} \sin\gamma)^2}{4\pi} ,$$
$$\Gamma(Q_{2i} \to P_j S_k) = \frac{2}{3} \frac{q^3}{m_{Q_2}{}^2} \frac{(-h_A d_{ijk} \sin\gamma + i h_B f_{ijk} \cos\gamma)^2}{4\pi} , \quad (6)$$

where h_A and h_B are dimensionless coupling constants defined analogously to g_A and g_B. The fact that the $\kappa\pi$ channel is more strongly coupled to Q_1 than Q_2 also supports a nonzero value for the mixing angle, although a numerical analysis is not yet possible.

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TABLE I. Predicted and observed decay widths of the Q's. Solution I, which includes the D-wave contribution, has $g_A^S = 2.78$ GeV, $g_B^S = 4.20$ GeV, and $\gamma = 47.8°$. Solutions II and III, with no D wave, have $g_A = 3.26$ GeV, $g_B = 3.57$ GeV, $\gamma = 54.7°$ and $g_A = 2.85$ GeV, $g_B = 3.64$ GeV, $\gamma = 45.1°$. The first error in the observed-width column is statistical, while the second (in parenthesis) is systematic. The vector mixing angle is taken to be 37.3°. [D. H. Boal and R. Torgerson, Phys. Rev. D (to be published); R. Torgerson, Phys. Rev. D 10, 2951 (1974).]

Decay	Predicted width (MeV) I	II	III	Observed width (MeV)
$Q_1 \to \rho K$	62.7	59.3	54.2	145 ± 9 (± 70) [a]
$Q_1 \to K^*\pi$	6.9	6.3	1.9	5 ± 3 (± 5) [a]
$Q_2 \to \rho K$	4.5	1.7	1.4	2 ± 1 (± 2) [a]
$Q_2 \to K^*\pi$	139	144	136	140 ± 4 (± 15) [a]
$B \to \omega\pi$	123	123	128	125 ± 10 [b]
$Q_1 \to \omega K$	16.1	15.1	13.9	...
$Q_2 \to \omega K$	1.2	1.0	0.2	...
$A_1 \to \rho\pi$	158	184	140	≈300 [b]

[a] See Ref. 4.
[b] See Particle Data Group, Ref. 3.

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[7]See Ref. 5 for a review. For a recent discussion of the role of SU(3) breaking in radiative decays, see Ref. 6 and D. H. Boal, R. H. Graham, and J. W. Moffat, Phys. Rev. Lett. 36, 714 (1976).
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[10]See Colglazier and Rosner, Ref. 8.