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SU(3) IMPLICATIONS OF THE OBSERVATION OF THE A_1 AND C MESONS

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ABSTRACT

A new determination of the $Q_A - Q_B$ mixing angle and of the anti-symmetric coupling for the vector-pseudoscalar decay of the axial vector mesons is presented. This uses information from the decay rates of the A_1 and C-mesons found in the study of baryon exchange processes in K^-p interactions at 4.2 GeV/c combined with the decay rate $B \rightarrow \omega\pi$. The consistency between the results obtained from backward produced A_1 and C and diffractively produced Q_1 and Q_2 is discussed.

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1. INTRODUCTION

In a recent search for backward production of axial vector mesons in K^-p interactions at 4.2 GeV/c, evidence [1,2,3] has been found not only for the well established $J^{PC} = 1^{+-}$ B-meson, but also for the more controversial $A_1 \Rightarrow 3\pi$ and $C(Q_1) \Rightarrow K\pi\pi$ mesons. Backward scattering is, in principle, more favourable for the study of these states than diffractive processes where Deck backgrounds are known to be important and therefore the resonant contributions are difficult to disentangle.

The A_1 parameters found at 4.2 GeV/c were: mass = (1040 ± 13) MeV and width = (230 ± 50) MeV. These values are compatible with those determined in several other ways: in backward production from incident π^- scattering [4], from the partial wave analysis of the diffractive three-pion systems produced in π^- interactions on nuclei [5] and from the three-pion mass spectrum of τ decay [6]. However, the results of the analysis of the diffractive three-pion system produced in π^-p scattering are still not conclusive [7,8] as to whether a resonant contribution really exists above the Deck background.

The situation for the $K\pi\pi$ system in the mass region between threshold and 1.450 GeV, is even more complicated. The analysis of the diffractive $K\pi\pi$ system shows in fact evidence for two 1^+ resonances [9]: $Q_1(1290)$ mainly coupled to ρK , with a mass $M = [1289 \pm 3 \pm (25)]$ MeV, width $\Gamma = [150 \pm 9 \pm (70)]$ MeV and $Q_2(1400)$ mainly coupled to $K^*\pi$, $M = [1404 \pm 3 \pm (\pm 10)]$ MeV and $\Gamma = [142 \pm 4 (\pm 15)]$ MeV^(*).

In contrast, in the forward $K\pi\pi$ systems produced by charge exchange only evidence for $Q_2(1400)$ coupled to $K^*\pi$ is observed [11], while in those produced by incident π^- [12], backward by incident K^- [3] or in $\bar{p}p$ annihilations [13] only a single relatively narrow signal ($\Gamma \lesssim 100$ MeV) in the mass range 1.235 - 1.300 GeV is seen mainly coupled to ρK . Historically, this enhancement was first observed in $\bar{p}p$ annihilation at rest and was called the C-meson. (In what follows although we will identify Q_1 and C as the same physical state we will keep the double notation (Q_1/C) to indicate whether it is produced diffractively or not).

(*) This result has been recently confirmed by a unitary, analytic, coupled-channel re-analysis of the same data by Basdevant and Berger [10].

At present no convincing overall explanation exists for the above differences in production, but it seems quite feasible, with different production mechanisms for the two Q's, to suppress the production of one of them and enhance the other in a simple way [14,15]. It is striking, nevertheless, that the general features of the decays of the two states appear to be independent of the way they are produced. Thus, Q_1/C couple mainly to ρK and Q_2 to $K^* \pi$. It is then natural to relate these decay properties to those of the other axial vector mesons in both the $J^{PC} = 1^{++}$ and 1^{+-} multiplets using SU(3). The simplest interpretation of the experimental results is in terms of an SU(3) scheme which allows the mixing of the strange members of these two multiplets [15]. A previous attempt at such an interpretation has been made by Carnegie et al. [16] using SLAC information on diffractively produced Q_1 and Q_2 .

Our aim in this paper is to supplement this analysis with the ACNO results on backward produced A_1 and C and check independently the consistency of the data with such a mixing scheme. This study will highlight the many ambiguities which occur in such an analysis and allow a detailed comparison with the result of the SLAC paper [16] to be made. This we discuss in sect. 2 and 3. We show that an overall consistent picture is possible. However, at the present stage of our knowledge of the axial vector mesons, this picture is far from unique.

In sect. 4 we shall discuss the question of whether the E is a member of the $J^{PC} = 1^{++}$ multiplet. Within the simple framework considered there, we conclude that this is improbable. The conclusions are given in sect. 5.

2. PARTIAL DECAY RATES AND REDUCED COUPLINGS

2.1 Definitions

The aim of this section is to discuss how experimental information on decays determines the partial decay widths and hence the reduced couplings which we assume to be related by SU(3).

In principle, experiment determines the total width of the resonance and the number of events in each channel. If all the decay channels have thresholds well below the resonance mass then the situation is straight-forward

$$\Gamma_{\text{tot}} = \sum_i \Gamma_i \quad (1)$$

$$\Gamma_i = \frac{N_i}{N_{\text{tot}}} \Gamma_{\text{tot}}, \quad (2)$$

where N_i , N_{tot} are the number of events in a particular channel and in total, respectively.

Then the reduced coupling constants γ_i for an S-wave decay of a resonance of mass M is given by

$$\Gamma_i = \frac{\langle q_i \rangle}{M^2} \gamma_i^2 \quad (3)$$

$\langle q_i \rangle$ being a suitably defined average momentum available in the decay. The choice of an analogous kinematic factor has been well tested in the case of baryon decays [17] where the reduced couplings are found to obey exact SU(3) and the symmetry breaking effects apparent in the widths arise solely in the physical (SU(3) broken) masses used in eq. (3).

In the case of C decay we study here, two factors can produce complications to these simple definitions: eqs (2,3). The first arises specifically when the threshold for the decay occurs within the width of the parent resonance, e.g. $C \rightarrow \omega K$, distorting its line shape and so considerably affecting the determination of the average $\langle q \rangle$. One way to determine the partial width to such a channel is to continue to use eq. (2). However, another possibility is that chosen by the SLAC group who compensate for this distortion in the line shape of $Q_1 \rightarrow \omega K$ and define

$$\Gamma_i = \frac{N_i}{N} \Gamma_{\text{tot}} \frac{\langle q_i(M = M_{\text{res}}) \rangle}{\int dM \langle q_i(M) \rangle BW_A(M) / \int dM BW_A(M)}, \quad (4)$$

where $BW_A(M)$ indicates the usual relativistic Breit-Wigner function for the decay of the axial meson into channels with thresholds below the resonance mass and N is the appropriate normalization to ensure eq. (1). For a resonance mass M far above the threshold for channel "i" this is almost the same as eq. (2) when $N \rightarrow N_{\text{tot}}$.

This ambiguity in definition, eqs (2,4), changes the value of the ratio $\Gamma(Q_1 \rightarrow \omega K)/\Gamma(Q_1 \rightarrow \rho K)$ and consequently affects the separation of the partial widths via eq. (1). However, in practice, this difference turns out to be less crucial than other uncertainties, as we shall comment on later.

A second arbitrariness arises in how the reduced coupling constants γ_i , which are assumed to be related by SU(3), are defined from these partial widths. Though eq. (3) is the defining relation, there is an arbitrariness in determining $\langle q_i \rangle$ when one of the decay products is a resonance. Below we present two possible definitions. Let the parent particle have a well defined mass M , shape $BW_A(M)$ and decay to a resonance of mass m and shape $BW_V(m)$ and some other particle, here a pseudoscalar.

Then the SLAC group chooses

$$\langle q_i(M) \rangle = \frac{\int dm q_i(M,m) BW_V(m)}{\int dm BW_V(m)}, \quad (5)$$

where the integral in the numerator is over all values of m which allow physical momenta i.e. $q_i^2(M,m) \geq 0$, while the integral in the denominator is over the undistorted B.W. shape of the daughter resonance. We shall call this the "undistorted" phase space factor. However, this choice is not unique.

Physically a more natural definition of this average momentum available in this decay is for the integral in the denominator also to be only over values of m physically allowed in this process, just as in the numerator. We shall call this "physical" phase space.

This latter definition naturally arises if we require the daughter resonance (here ω or ρ) to be the product of a decay of the parent (Q_1).

For parent resonances far above the decay channel threshold, these alternative definitions are identical. However, for $Q_1 \rightarrow \rho K$ or $Q_1 \rightarrow \omega K$ they can easily differ by a factor of two. Since this alters the determination, via eq. (3), of the reduced couplings, the definition of $\langle q \rangle$ has an important effect in relating these couplings by SU(3). This is illustrated in the following analysis where both these two phase space factors are alternatively used.

Yet another ambiguity is that $\langle q_i \rangle$ in eq. (3) can be chosen to be either

$$\langle q_i \rangle = \langle q_i (M = M_{\text{res}}) \rangle \quad (6)$$

as used by SLAC, or the mean value of q averaged over the parent resonance, i.e.

$$\langle q_i \rangle = \frac{\int dM \langle q_i(M) \rangle BW_A(M)}{\int dM BW_A(M)}, \quad (7)$$

which we also use. However, this difference turns out to be negligible.

2.2 From experimental data to couplings (ACNO-SLAC comparison)^(*)

Using eqs (1,2) we find the results given in table 1 for the C , A_1 and their decays.

In the analysis of the C meson the channel $K\bar{C}$ and $K\pi$ are taken to be non-resonant as has been done in ref. [10] and as suggested for $\bar{C}\pi$ by ref. [19] in the treatment of the A_1 . The total width has been determined using the same Breit-Wigner parametrization as the SLAC group in ref. [9]. However, in their SU(3) analysis they use $\Gamma_{\text{tot}} = 150 \pm 9$ MeV, clearly not in agreement with our result. The sharing of this width, eq. (1), between the various channels is also different because they explicitly include the

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(*) For consistency only Q_1 , Q_2 parameters and related SU(3) implications obtained by the simple analysis of SLAC [9] will be taken into account in this comparison, the analysis by Bowler [18] being somewhat different from our treatment.

$K\pi$ and Ek as decay modes. Their results are shown in table 1 too. Comparing C with Q_1 we see that the two experiments give different results. It should further be noticed that, unlike the ACNO result, the ωK channel is not determined in the SLAC experiment, but is an upper limit obtained from the data of ref. [20]. This we shall comment on in sect. 3.4.

The reduced couplings defined by eq. (3), obtained using the two different $\langle q \rangle$ definitions previously discussed, are set out in table 2 for both SLAC and ACNO data. In the next section we shall try to relate these couplings by SU(3) bearing in mind the ambiguity in the choice of phase space already discussed.

3. Q_A AND Q_B MIXING

3.1 The mixing scheme and decay parameters

If the Q_1/C were a pure SU(3) state in the 1^+ nonets, its couplings to $K^*\pi$ and ρK would be equal and consequently, because of phase space, its width to $K^*\pi$ somewhat larger than to ρK . As shown in table 1, it is a feature of the Q_1 and C that this is not the case. This fact can be simply explained if it is assumed that the physical state is a mixture of pure SU(3) states Q_A and Q_B belonging to the 1^{++} and 1^{+-} nonets.

This scheme requires the existence of an orthogonal state Q_2 coupling to the same decay channels with correlated parameters. Since such a state Q_2 is suggested by diffractive and charge exchange data it is then natural to interpret the ACNO/SLAC results within such a scheme. Writing

$$\begin{aligned} |Q_1\rangle &= \cos\theta_Q |Q_A\rangle + \sin\theta_Q |Q_B\rangle \\ |Q_2\rangle &= -\sin\theta_Q |Q_A\rangle + \cos\theta_Q |Q_B\rangle \end{aligned} \tag{8}$$

the reduced couplings, γ_i , for the decays of $Q_{1,2}$ to $K^* \pi$, ρK and ωK are given in table 2 in terms of the five parameters:

- θ_Q the Q's mixing angle;
- θ_v the vector nonet mixing angle;
- g_1 the symmetric singlet coupling;
- g_A, g_B which describe the anti-symmetric and symmetric octet couplings respectively, for axial vector to vector + pseudoscalar decay.

The last four parameters can, in principle, all be determined independently of the Q's as follows:

- (a) θ_v is known from the decays of the vector nonet into pions. It is found to be [17]

$$\theta_v = -31^\circ \pm 3^\circ. \quad (9)$$

- (b) g_A is fixed by the S-wave decay $A_1 \rightarrow \rho \pi$ and using our result of ref. [2] is

$$g_A = (1.15 \pm 0.12) \text{ GeV}. \quad (10)$$

- (c) As seen from table 2 the S-wave decays $B \rightarrow \omega \pi$, $B \rightarrow \phi \pi$ determine together g_B, g_1 . If the OZI rule were exact, the decay $B \rightarrow \phi \pi$ would be forbidden and hence

$$g_1 = -\frac{g_B}{\sqrt{5}} \cot \theta_v \quad (11)$$

in which case

$$g_B = (-0.82 \pm 0.03) \text{ GeV},$$

using the known S-wave decay width of the $B \rightarrow \omega \pi$ [8]. Experimentally, the decay rate $B \rightarrow \phi \pi / B \rightarrow \omega \pi$ may be as large as 4%, in which case the ratio of the corresponding reduced couplings may be as large as 31%. While the results we shall quote are for the limit of exact OZI rule, eq. (11), those taking into account OZI breaking will not be significantly different.

The remaining parameter θ_Q is determined by the S-wave decays of the Q_1 , C into $K^* \pi$, ρK and ωK .

3.2 Decoupling conditions

As already noted, the Q_1 , C almost decouple from $K^*\pi$ and the Q_2 , seen by SLAC, appears to decouple from ρK . In the situation of exact decoupling, (table 2), θ_Q , g_A and g_B are determined to be

$$\theta_Q = 45^\circ; \quad \frac{g_A}{g_B} = -\frac{3}{\sqrt{5}} \quad (12)$$

which, with the value of g_B given previously, requires

$$g_A = (1.10 \pm 0.04)\text{GeV}$$

in excellent agreement with the ACNO determination using the coupling of the A_1 eq. (10).

The decoupling relations also fix all the other couplings of Q_1 and Q_2 , in particular

$$\gamma(Q_1 \rightarrow \rho K) = (0.78 \pm 0.03)\text{GeV}, \quad \gamma(Q_2 \rightarrow K^*\pi) = (0.78 \pm 0.03)\text{GeV}$$

$$\gamma(Q_1 \rightarrow \omega K) = (-0.54 \pm 0.1)\text{GeV}, \quad \gamma(Q_2 \rightarrow \omega K) = (0.13 \pm 0.10)\text{GeV}$$

which give, depending on the phase space factors used, the following decay widths

	$\Gamma(Q_1 \rightarrow \rho K)$ (MeV)	$\Gamma(Q_1 \rightarrow \omega K)$ (MeV)	$\Gamma(Q_2 \rightarrow K^*\pi)$ (MeV)	$\Gamma(Q_2 \rightarrow \omega K)$ (MeV)
"physical" phase space	90 ± 7	37 ± 15	} 121 ± 10	$3 \pm \frac{5}{3}$
"undistorted" phase space	53 ± 4	22 ± 9		

where the $Q_1 \rightarrow \rho K$ and $Q_2 \rightarrow K^*\pi$ widths are roughly in agreement with experiment. We shall comment on $Q_1 \rightarrow \omega K$ in sect. 3.4.

3.3 SU(3) fits

In this section we give the results of fitting the "experimental" couplings to the SU(3) expressions listed in table 2. Each of these couplings

imposes a constraint on g_A , g_B and θ_Q , which is plotted in figs 1 and 2 (the error on g_B is so small compared to the errors on the other two parameters that we can consider g_B to be fixed at the value - 0.82 GeV).

The best values of the couplings g_A and g_B and of θ_Q are given by the results of a χ^2 -fit listed in tables 3 and 4 (θ_V and g_1 are fixed as in eqs (9,11). When not all the decays of the A_1 , B, C, Q_1 , Q_2 are used as input, the partial widths not fitted are, as a result, predicted and these are also given in tables 3 and 4. The nomenclature is such that, as previously remarked, the C, A_1 are from ref. [2,3] (ACNO) and Q_1 , Q_2 from ref. [16] (SLAC), B is from ref. [8]. We discuss the results for the different possible kinematics factors separately.

3.3.1 "Undistorted" phase space

The figs 1(a), 1(b) show the conditions given by the ACNO and SLAC data respectively and illustrate the fits a and b of table 3. The independent fits are not dissimilar and the predicted Q_2 , A_1 parameters are each in agreement with the experimental result not used in the fit. This indicates a satisfactory common interpretation of both the ACNO and SLAC data in terms of the SU(3) mixing scheme. The mixing angle in the fit to the ACNO data is $(27^\circ \pm 8^\circ)$. This is less than the 45° of sect. 3.2 because of our small $C \rightarrow \omega K$ coupling.

In each of the four fits the values of g_A found are roughly in agreement with the value $g_A = (1.10 \pm 0.04)\text{GeV}$ given in sect. 3.2. In fits (b, c and d) where the SLAC information on the Q_2 is included, together with its important properties of decoupling from ρK , the mixing angle tends towards 45° as we would expect from eq. (12). This is not surprising since we have already seen that the decoupling of C from $K^*\pi$ together with the ACNO value for the A_1 width already implies the decoupling of Q_2 from ρK as seen by SLAC.

3.3.2 "Physical" phase space

We now repeat these fits using the other kinematic factor we consider, in order to check the reliability of the above picture. The results are shown in table 4. The values of g_A and g_B turn out to be slightly smaller than before. As seen in fig. 2(b), the value of θ_Q in the fits using

SLAC data does not change. However, there is a four standard-deviation discrepancy with the value determined by the ACNO data. This is because the ACNO couplings for $C \rightarrow \rho K$, ωK now only overlap with the A_1 coupling for small θ_Q . In particular, $C \rightarrow \omega K$ in fig. 2(a) is seen to be inconsistent with the decoupling of Q_2 from ρK shown in fig. 2(b). This shows up in fit a of table 4 in the prediction of 29% for the branching ratio $Q_2 \rightarrow \rho K / Q_2 \rightarrow K^* \pi$. Because of this it is clearly meaningless to perform a fit combining the ACNO C , A_1 with SLAC Q_2 , which we did for the undistorted phase space, giving the result in table 3, fit d.

Comparing figs 1(b), 2(b) it is seen that the SLAC data are in excellent agreement not only with the mixing scheme independently of the phase space factor chosen, but also with the parameter g_A determined from our observed A_1 . This fortunate situation only arises for the values of the partial widths of the Q 's determined from the SLAC analysis of ref. [9]. The more sophisticated treatment by Bowler [18] having larger partial widths overestimates the coupling g_A compared to our value of 1.15 GeV of eq. (10) for example; the fit to Bowler's couplings given in ref. [16] has $g_A = (1.95 \pm 0.04) \text{ GeV}$. In the case of the ACNO data consistency with the SLAC Q_2 is only obtained using the "undistorted" phase-space factors. The disagreement in the case of what we call "physical" phase-space is largely attributable to our small $C \rightarrow \omega K$ coupling. This we now comment on.

3.4 The coupling and branching ratio to ωK of the C and Q_1

As already mentioned, the evaluation of the branching ratio to ωK for the C and Q_1 and its interpretation in terms of a reduced coupling is far from unique.

We find the cross section ratio

$$\frac{\sigma(C \rightarrow \omega K)}{\sigma(C \rightarrow \rho K)} = 0.05 \pm 0.05, \quad (13)$$

when all the events of the ωK channel in the C region are ascribed to the resonance [3]. A more restrictive upper limit of 5% is given if the background in this channel is assumed to be pure phase space [3]. This experimental result is in good agreement with the only other determination of this ratio [20] which gives

$$\frac{\sigma(Q_1 \rightarrow \omega K)}{\sigma(Q_1 \rightarrow \rho K)} = 0.09 \pm 0.03 \quad (14)$$

However, the comparison of these results eqs (13,14) with the SLAC finding on $Q_2 \rightarrow \rho K$ depends sensitively on the phase space factor used in deducing the reduced couplings. This is particularly apparent in figs 2(a), 2(b).

That the SLAC group is able to find compatibility regardless of phase space factor between the $Q_1 \rightarrow \omega K$ and their Q_2 data is largely due to the combining of data from different experiments [9,20]. A more precise determination of the $Q_1, Q_2 \rightarrow \omega K$ partial widths is thus needed in order to judge conclusively the consistency of the data with the mixing scheme. Agreement with the ACNO data would suggest only the presence of the Q_2 in the ωK spectrum, while the SLAC analysis would prefer just the Q_1 to be seen.

4. IS THE E MESON A MEMBER OF THE A_1 NONET TOGETHER WITH Q_A AND D?

Having discussed the implications of SU(3) for the decay rates, we now consider its constraints on the masses. This is clearly only possible if we know all the members of the nonet. Assuming the mixing scheme of eq. (8) and the SLAC/ACNO data on C/Q_1 , the pure SU(3) states Q_A, Q_B are determined^(*). This means that eight of the nine members of the $J^{PC} = 1^{++}$ multiplet can be considered well-established, viz. A_1, Q_A and $D^{(**)}$. The only known candidate for the second isoscalar member is the E at 1.42 GeV, for which the spin-parity has not yet been determined.

We can then use the Gell-Mann-Okubo mass formula to test whether the E really can be a member of this multiplet. Assuming, the usual mixing between the isoscalars, D and E, with mixing angle θ_A , we have

$$3 \cos^2 \theta_A (E^2 - D^2) = 4 Q_A^2 - 3D^2 - A_1^2 \quad (15)$$

$$\text{where } Q_A^2 = \frac{1}{2} (Q_1^2 + Q_2^2 + (Q_1^2 - Q_2^2) \cos 2\theta_Q). \quad (16)$$

The value of $\cos^2 \theta_A$ is directly related to the partial width of the E into $(K^* \bar{K} + \bar{K}^* K)$ by

(*) The Q_A and Q_B masses are ~ 1.34 GeV for $\theta_Q \sim 45^\circ$.

(**) The isoscalar D did not enter the analysis of sect. 3 because all its decays into $1^+ 0^-$ are kinematically suppressed.

$$\Gamma_{K^* \bar{K} + \bar{K}^* K} = \langle q_{K^*} \rangle \frac{g_A^2}{m_E^2} \cos^2 \theta_A. \quad (17)$$

Substituting for the A_1 and C the masses from table 1, for the D and E those from ref. [8] and combining eqs (15, 16, 17) we obtain the following inequality

$$\Gamma_{K^* \bar{K} + \bar{K}^* K} \geq (56 \pm 12) \text{ MeV} \quad (18)$$

independently of the mass of the Q_2 and of the mixing angle θ_Q , where g_A is taken from the ACNO A_1 width. This is an absolute lower limit for the total width of the E . However, this total width has recently been found [21] to be $(26 \pm 8) \text{ MeV}$, of which probably less than 40% [8] is in the $(K^* \bar{K} + \bar{K}^* K)$ channel. This is quite inconsistent with eq. (18). To make the above limit lower we must increase the mass of the A_1 , however, 1.1 GeV seems the maximum allowed from the physical region fits [8]; with this value the limit of eq. (18) is only reduced to 41 MeV.

Thus, the experimentally observed E appears not to be a member of the same multiplet as the A_1 , Q_1 and D in agreement with the result of the analysis of ref. [22]. However, we have assumed that the masses, experimentally determined from Breit-Wigner fits used in evaluating eq. (15), are not far from the pole positions on the second sheet. This is not necessarily so for broad resonances like the A_1 and Q 's particularly if they couple to many channels [20]. This freedom, which we do not explore here, may still allow the E to belong to this nonet.

5. CONCLUSIONS

The backward production of the A_1 , B and C mesons in the same $K^- p$ experiment at 4.2 GeV/c [1,2,3] makes it natural to test whether the decays of these resonances, each into a vector meson plus a pseudoscalar, are compatible with SU(3). In this, our analysis is similar in spirit to that of the SLAC group [16], who have observed the Q_1 and Q_2

diffractively produced. Because of the particular kinematics of the decays we study, the deduction of which couplings are SU(3) related is far from unique. We have therefore discussed these ambiguities (which, of course, arise in all analyses of such decays) at length, in order to highlight what further information is required to provide a stringent test of the mixing scheme of the 1^{++} and 1^{+-} multiplets and the SU(3) relationship between the couplings this implies.

Our analysis shows that both the SLAC and ACNO experimental results are consistent with the Q_A, Q_B mixing scheme, provided what we call the "undistorted" phase space factor is used in defining the SU(3) related couplings. However, if a different ("physical") phase space factor is used, the ACNO data [3] on the branching ratio for $C \rightarrow \omega K$ is too small to be compatible with the SLAC observation [9] of the almost complete decoupling of the Q_2 from the ρK channel. In contrast, the calculation of the $Q_1 \rightarrow \omega K$ coupling by the SLAC group [16] is consistent with the Q_A, Q_B mixing scheme using either of the phase space factors we consider. The reasons for this were discussed. We conclude that a crucial test of the mixing scheme and of which phase space factor is correct will therefore only be possible when the ωK decay channel of both the Q_1 and Q_2 are well determined. For this we await new data.

Lastly, we have considered the mass splitting of the 1^{++} multiplet assuming naïvely that the true masses of these states are given by simple Breit-Wigner fits. With this assumption we have shown that the E is unlikely to be a member of the same nonet as the A_1, Q_A and D.

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- [22] A. Irving and H. Sepangi, Nucl. Phys. B139 (1978) 327.

TABLE CAPTIONS

- [1] Data on the C , Q_1 and A_1 used in the $SU(3)$ analysis.
- [2] $SU(3)$ expressions and experimental values for the couplings $\gamma(1^+ \rightarrow 1^-0^-)$.
- [3] The results of the fits using the "undistorted" phase space factor described in sect. 3.
- [4] The results of the fits using the "physical" phase space factor described in sect. 3.

TABLE 1

Resonance	Experiment	Mass MeV	Γ_{tot} MeV	$\Gamma_{\rho K}$ MeV	$\Gamma_{K^*\pi}$ MeV	$\Gamma_{\omega K}$ MeV	$\Gamma_{K\bar{K}+\pi\pi}$ MeV
C	ACNO	1.275 ± 10	75 ± 15	57 ± 14	14 ± 11	4 ± 4	=
Q ₁	SLAC	$1.289 \pm 3 \pm (25)$	$150 \pm 9 \pm (70)$	75 ± 6	2 ± 2	24 ± 3	48 ± 7
A ₁	ACNO	$1.040 \pm 25^{(a)}$	230 ± 50	$\Gamma_{\rho\pi} = \Gamma_{\text{tot}}$			

(a) Error of ref. [2] has been doubled to take account of systematic uncertainties in B.W. parametrization.

TABLE 2

Couplings	SU(3) expressions	ACNO data Undistorted Ph.Sp. (GeV)	SLAC data Undistorted Ph.Sp. (GeV)	ACNO data Physical Ph.Sp. (GeV)	SLAC data Physical Ph.Sp. (GeV)
$\gamma(A_1 \Rightarrow \rho\pi)$	$\frac{\sqrt{6}}{3} g_A$	0.94 ± 0.11	=	0.94 ± 0.11	=
$\gamma(Q_1 \Rightarrow \rho K)$	$\frac{1}{2} g_A \cos\theta_Q - \frac{3}{\sqrt{20}} g_B \sin\theta_Q$	0.88 ± 0.11	1.02 ± 0.04	0.62 ± 0.08	0.72 ± 0.04
$\gamma(Q_1 \Rightarrow K^* \pi)$	$\frac{1}{2} g_A \cos\theta_Q + \frac{3}{\sqrt{20}} g_B \sin\theta_Q$	0.27 ± 0.11	0.11 ± 0.05	0.27 ± 0.11	0.11 ± 0.05
$\gamma(Q_1 \Rightarrow \omega K)$	$\frac{1}{2} g_A \cos\theta_Q \sin\theta_V +$ $\left[\frac{1}{\sqrt{20}} g_B \sin\theta_V + g_1 \cos\theta_V \right] \sin\theta_Q$	-0.27 ± 0.18	-0.47 ± 0.08	-0.18 ± 0.09	-0.34 ± 0.08
$\gamma(B \Rightarrow \phi\pi)$	$\frac{g_B}{\sqrt{5}} \cos\theta_V + g_1 \sin\theta_V$	0.	0.	0.	0.
$\gamma(B \Rightarrow \omega\pi)$	$\frac{g_B}{\sqrt{5}} \sin\theta_V - g_1 \cos\theta_V$	0.72 ± 0.03	0.72 ± 0.03	0.72 ± 0.03	0.72 ± 0.03
$\gamma(Q_2 \Rightarrow \rho K)$	$\frac{1}{2} g_A \sin\theta_Q + \frac{3}{\sqrt{20}} g_B \cos\theta_Q$	=	0.13 ± 0.03	=	0.13 ± 0.03
$\gamma(Q_2 \Rightarrow K^* \pi)$	$\frac{1}{2} g_A \sin\theta_Q - \frac{3}{\sqrt{20}} g_B \cos\theta_Q$	=	0.78 ± 0.03	=	0.78 ± 0.03
$\gamma(Q_2 \Rightarrow \omega K)$	$\frac{1}{2} g_A \sin\theta_Q \sin\theta_V -$ $\left[\frac{1}{\sqrt{20}} g_B \sin\theta_V + g_1 \cos\theta_V \right] \cos\theta_Q$	=	$\sim 0.$	=	$\sim 0.$
$\gamma(E \Rightarrow K^* \bar{K}^* K)$	$g_A \cos\theta_A$				

$\theta_Q = Q_A - Q_B$ mixing angle.

$\theta_V =$ Vector meson mixing angle.

$\theta_A = D - E$ mixing angle.

TABLE 3
Undistorted phase space

	Input				Fit			Predictions (output)				
	C	Q ₁	Q ₂	A ₁ B	g_A (GeV)	g_B (GeV)	θ_Q	χ^2/NDF	Γ_{A_1} (GeV)	$\frac{\Gamma(Q_2 \Rightarrow \rho K)}{\Gamma(Q_2 \Rightarrow K^* \pi)}$	$\frac{\Gamma(Q_2 \Rightarrow \omega K)}{\Gamma(Q_2 \Rightarrow K^* \pi)}$	
a	X	-	-	X X	1.2 ± 0.1	-0.83±0.04	27° ± 8°	2.2/2	=	0.134	.07	.08
b	-	X	X	- X	1.4 ± 0.06	-0.80±0.03	45° ± 2°	25/3	0.330 ^(a)	=	=	.0
c	-	X	X	X X	1.36 ± 0.05	-0.81±0.03	45° ± 2°	28/4	=	=	=	.0
d	X	-	X	X X	1.23 ± 0.05	-0.78±0.03	48° ± 2°	13/4	=	=	=	.0

(a) A₁ Mass from ACNO Collaboration

X = Present.

- = Absent.

TABLE 4
"Physical" phase space

	Input		Fit					Predictions (output)				
			g_A (GeV)	g_B (GeV)	θ_Q	χ^2/NDF	ΓA_1 (GeV)	ΓQ_2 (GeV)	$\frac{\Gamma(Q_2 \Rightarrow \rho K)}{\Gamma(Q_2 \Rightarrow K^* \pi)}$	$\frac{\Gamma(Q_2 \Rightarrow \omega K)}{\Gamma(Q_2 \Rightarrow K^* \pi)}$		
a	X	-	X	X	1.04 ± 0.10	-0.82 ± 0.03	$16^\circ \pm 8^\circ$	2.6/2	=	0.135	0.29	0.21
	-	X	X	-	X	1.21 ± 0.05	-0.82 ± 0.03	48 ± 2	17/3	0.250	=	.0
c	-	X	X	X	X	1.2 ± 0.05	-0.76 ± 0.03	48 ± 2	17/4	=	=	.0

X = Present.
- = Absent.

FIGURE CAPTIONS

Fig. 1 g_A vs θ_Q plots using "undistorted" phase space for vector-pseudoscalar decays of:

(a) ACNO C and A_1 .

(b) SLAC Q_1 and Q_2 .

The bands correspond to plus minus one standard deviation error on each coupling.

Fig. 2 g_A vs θ_Q plots using "physical" phase space for vector-pseudoscalar decay of:

(a) ACNO C and A_1 .

(b) SLAC Q_2 and Q_2 .

with the bands as described for fig. 1.

fig. 1

Fig. 2