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BACKWARD AXIAL VECTOR MESON PRODUCTION AT INTERMEDIATE ENERGY

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ABSTRACT

We analyse the recent data on backward axial vector meson production which come predominantly from a large K p bubble chamber experiment at 4.2 GeV/c. In an attempt to understand the production mechanisms, we study the isospin and SU(3) structure of A_1 , B, D(1285) and C(1280) production and compare this with the corresponding production of pseudoscalar, vector and tensor mesons in the backward direction. The isospin and SU(3) study shows that octet exchange is dominant but there are indications that other exchanges, lower-lying than the nucleon (N_α) trajectory, must also be important. We show that a consistent description of backward resonance production is possible, but further experiments are required to confirm this.

1. INTRODUCTION

Backward scattering of meson systems provides an important source of spectroscopic information. Simple natural parity states such as the ρ^0 , f or K^* , which can be produced by π -exchange, are profitably studied in the forward direction. However, states such as the A_1 or Q , which have three-body decays, may best be studied in baryon exchange configurations where Deck mechanism backgrounds are less debilitating. Indeed, the axial vector mesons ($J^P = 1^+$) A_1 [1,2], $D(1285)$ [3], B [4] and $C(1280)$ [5] have all been observed in this way.

Since baryon exchange is less well understood than forward meson Regge exchange, it is not possible to correlate backward production processes to the same degree as for example π -exchange production. However, factorization of the production mechanism is an important property which can be used to identify bona fide resonant states. Fortunately, one can compare these backward resonance production reactions, not only with each other, but also with relatively abundant data for backward pseudoscalar meson production. This comparison forms the basis of the ensuing analysis.

In sect. 2 we outline the exchange structure of backward scattering. The constraints which follow from isospin and from $SU(3)$ symmetry are discussed in sects 3 and 4 respectively. Born term estimates of the relative strengths of pseudoscalar and axial-vector production are made in sect. 5 and this is followed by an analogous study of vector meson production (sect. 6). Finally, in sect. 7, some conclusions are drawn.

2. EXCHANGE STRUCTURE

If we use the notation N , Δ to represent u -channel $I = 1/2$ and $3/2$ exchange respectively (likewise Λ , Σ for $I = 0, 1$ strange baryons), the quantum number exchange structure of the simpler backward scattering processes is as shown in table 1. As regards $SU(3)$, N , Λ , Σ represent octet exchange while Δ and Σ^* represent decuplet exchange. Further discussion of the $SU(3)$ structure is reserved for sect. 4.

In table 1, the final state meson is taken to be pseudoscalar but, of course, an identical structure is obtained if, for example, $\pi(J^{PC} = 0^{-+})$ is replaced by $\rho(1^{--})$, $A_1(1^{++})$ or $B(1^{+-})$. These relations allow one to compare processes at the level of SU(2) (sect. 3) or SU(3) (sect. 4) and, for a given SU(2), SU(3) configuration, to compare production strengths of different quark model multiplets ($J^{PC} = 0^{-+}, 1^{--}, 1^{++}, 1^{+-}, 2^{++} \dots$) by means of their Born term structure. This is done in sect. 5.

3. ISOSPIN CONSTRAINTS

Measurement of more than one charge configuration enables one to determine the exchanged isospin. For example, various authors [6,7] have used the $\pi N \rightarrow N\pi$ data to isolate the $I = 1/2$ and $3/2$ exchange cross sections. In the notation of ref. [6]

$$\begin{aligned}\sigma_N &= 3/2 [\sigma_+ + \sigma_0 - \sigma_-/3] = 9\mu^2 |N|^2 \\ \sigma_\Delta &= \sigma_- = 9 |\Delta|^2 \\ \sigma_{N\Delta} &= 3/4 [\sigma_+ - 2\sigma_0 + \sigma_-/3] = 9\mu \text{Re}(N\Delta^*)\end{aligned}\tag{1}$$

(the subscript denotes the charge of the final pion). For the $\Sigma\pi$ reactions, although the neutral ($\Sigma^0\pi^0$) final state is not measured, one can nonetheless obtain bounds on the N exchange amplitude i.e.

$$\begin{aligned}[\sqrt{9\sigma(\Sigma^-\pi^+)/\sigma(\Sigma^+\pi^-)} - 1]^2 &\leq |N|^2/|\Delta|^2 \leq [\sqrt{9\sigma(\Sigma^-\pi^+)/\sigma(\Sigma^+\pi^-)} + 1]^2, \\ |\Delta|^2 &= 1/9\sigma(\Sigma^+\pi^-),\end{aligned}\tag{2}$$

with similar relations for ΣA_1 , ..., etc. Likewise for the strange baryon exchange processes, one obtains

$$\begin{aligned}[\sqrt{4\sigma(\Xi^-K^+)/\sigma(\Xi^0K^0)} - 1]^2 &\leq |\Lambda|^2/|\Sigma+\Sigma^*|^2 \leq [\sqrt{4\sigma(\Xi^-K^+)/\sigma(\Xi^0K^0)} + 1]^2, \\ |\Sigma+\Sigma^*|^2 &= 1/4\sigma(\Xi^0K^0).\end{aligned}\tag{3}$$

The observed cross sections for axial vector mesons produced backward in K^-p collisions at 4.2 GeV/c are summarized in table 2 [1,3,4,5,8,9,10]. While a clear signal for the A_1 is observed in $\Sigma^-(3\pi)^+$ [9], only shoulders are to be seen in the A_1 region of $\Sigma^+(3\pi)^-$ and $\Lambda(3\pi)^0$. To obtain an estimate of A_1 production in the latter two processes we adopt the following procedure. From the partial wave studies of ref. [10] we observe that the dominant contribution near each shoulder in the mass spectrum indeed has $J^P = 1^+$. Assuming the same Breit-Wigner parameters as those measured in the $\Sigma^-(3\pi)^+$ process, we fit the 3π mass spectra in the $\Sigma^+(3\pi)^-$ and $\Lambda(3\pi)^0$ channels to determine the production cross sections. The large errors shown in table 2 reflect the considerable uncertainties in this procedure^(*). We then deduce that for $\Sigma^-A_1^+$ production $I = 3/2$ exchange is relatively unimportant since:

$$0.03 \leq |\Delta|^2/|N|^2 \leq 0.44 \quad (A_1). \quad (4)$$

Similarly, for Σ^-B^+ production one finds

$$|\Delta|^2/|N|^2 \leq 0.06 \quad (B). \quad (5)$$

We conclude that both A_1 and B mesons are produced predominantly by $I = 1/2$ exchange. One obvious candidate for such an exchange is the nucleon, or N_α , trajectory and this is discussed further in sects 4 and 5. For $C(1280)$ production eq. 3 implies

$$|\Sigma + \Sigma^*|^2/|\Lambda|^2 \leq 0.05 \quad (C). \quad (6)$$

Thus, the lower of the possible isospins ($I = 0$ exchange in this case) is again strongly favoured [9].

The corresponding quantities for π and K backward production can be deduced from the data summary in table 3 [8,11,12] i.e.

(*) Further discussion of the extraction of cross sections for backward axial vector meson production will appear elsewhere [10].

$$0.09 \leq |\Delta|^2/|N|^2 \leq 0.75 \quad (\pi) \quad (7)$$

and

$$0.05 \leq |\Sigma + \Sigma^*|^2/|\Lambda|^2 \leq 0.28 \quad (K) \quad (8)$$

It appears that the suppression of the higher isospin exchange is less marked for backward π and K scattering than it is for analogous axial vector meson production processes at the same energy. We shall comment on this later in sect. 7.

4. SU(3) COMPARISON

Following the above isospin analysis, one might reasonably conjecture that A_1 and B are mainly produced by nucleon (N_α) exchange in the backward direction. Before drawing any conclusion about the SU(3) relationships for axial vector meson production, we must first review the status of this symmetry in $0^- 1/2^+ \rightarrow 1/2^+ 0^-$ scattering where more detailed analyses are possible. Fig. 1 shows the typical exchange diagrams being considered. Clearly, this mechanism implies that the observed Λ/Σ ratio be independent of the produced meson system, provided that a single factorizable exchange is involved.

Theoretically^(*), there are several candidates for non-strange baryon exchange N_α , N_β , N_γ and Δ_δ . In duality schemes [14], these trajectories are exchange degenerate in pairs, (N_α, N_γ) and (Δ_δ, N_β) , but because the exchange degeneracy appears so badly broken it is common to keep only the higher-lying trajectories N_α (nucleon) and Δ_δ ($\Delta(1236)$) for which

$$\begin{aligned} \alpha_N &= -.37 + .9 u \\ \alpha_\Delta &= 0 + .9 u. \end{aligned} \quad (9)$$

In the case of the $I = 1/2$ exchanges, some encouragement in this direction is provided by the observation of a dip in σ_N at $u \simeq -.15$ (near $\alpha_N = -1/2$, the NWSZ' position) as shown in fig. 2(a). Were the opposite signature trajectory N_γ also important, this dip would be filled in since the N_γ amplitude has no zeroes in this neighbourhood. Of course, this may not

(*) A recent review of the phenomenology of backward scattering may be found in [13].

be so for axial vector meson production. In fact, for backward photo-production, and possibly vector meson production also, this " N_α " dip is apparently filled in and in models [15] this may be achieved by including important N_γ contributions.

For simplicity, we shall as far as possible deal only with the α (nucleon octet) and δ (decuplet) trajectories. For the nucleon octet coupling to pseudoscalars, the on-shell ($u = M^2$) SU(3) mixing parameter F/D is found^(*) to be [16]

$$F/D = .56 \pm .03 \quad (10)$$

as compared to the SU(6) value 2/3. This parameter can, of course, be u -dependent and is best determined phenomenologically in the configuration of relevance. In this case, we shall need to know its value in the negative u region of the processes shown in fig. 1. Barger et al. [6] have compared $\sigma_N(N\pi)$ (fig. 2(a)) [6,7] with $d\sigma/dt(K^-p \rightarrow \Lambda\pi^0)$ (fig. 2(b)) [12,17] and so evaluated F/D (table 1 and eq. (1)). As they pointed out, however, this is an insensitive measure. Much more sensitive, and more relevant to present purposes, is the Σ/Λ ratio

$$\sigma_N(\Sigma\pi)/\sigma(\Lambda\pi^0) = 12 \left(\frac{1-F/D}{1+3F/D} \right)^2 \quad (11)$$

with $\sigma_N(\Sigma\pi) = |N|^2$. This ratio is plotted in fig. 3. The range of F/D implied by this ratio measured^(**) for $-u < 1 \text{ GeV}^2$ is

$$0.33 \lesssim F/D \lesssim 0.42 \quad (12)$$

(*) Actually, one must use the pseudovector coupling constant definition which differs from the usual pseudoscalar one (sect. 5) by SU(3) mass-breaking factors.

(**) The $|N|^2$ bounds (fig. 3(c)) were deduced from the $\Sigma^\pm \pi^\mp$ data using eq. 2 as a function of u , and the Σ/Λ ratio then determined by comparing these with the data of fig. 2(b) at all u , taking into account the appropriate errors.

All values allowed by the ratio $\sigma_N(N\pi)/\sigma(\Lambda\pi^0)$ are acceptable but the on-shell value, eq. (10), is clearly excluded.

Comparison of figs 2(a) and 2(b) shows that the u -dependence of $|N|^2$, including the dip near $u = -.15$, is similar in $\pi N \rightarrow N\pi$ and in $K^- p \rightarrow \Lambda\pi$. Furthermore, this is compatible with the u -dependence implied by the $\Sigma\pi$ bounds (fig. 2(c)) [11]. These facts encourage our belief that

- (a) N_α dominates $I = 1/2$ exchange.
- (b) $SU(3)$ symmetry for exchange amplitudes is reasonable for $0^- 1/2^+ \rightarrow 1/2^+ 0^-$ scattering.

The continuous curve in fig. 2 is an interpolation (by eye) of all three estimates (a, b, c) and corresponds to

$$F/D = 0.41 . \quad (13)$$

Note that care must be taken to compare at fixed u (rather than u'). From the continuous curve of fig. 2, we may estimate how much of a particular integrated cross section is "lost" due to a large value of $-u_{\min}$. Fig. 4 shows the percentage observable cross section relative to $u_{\min} = 0.10 \text{ GeV}^2$ (e.g. $K^- p \rightarrow \Lambda\pi^0$ at 4.2 GeV/c).

4.1 A_1 and B production

It has already been noted [18,11] that $SU(3)$ is successful in relating Δ exchange in $K^- p \rightarrow \Sigma^+ \pi^-$ and $\pi^- p \rightarrow p\pi^-$ (table 1). Likewise, we may compare the cross section for $\pi^- p \rightarrow pA_1^-$ measured at 9 and 12 GeV/c [2] with that for $K^- p \rightarrow \Sigma^+ A_1^-$ at 4.2 GeV/c by scaling the former according to $p_{\text{LAB}}^{2\alpha\Delta-2}$ ($\sim p_{\text{LAB}}^{-2.4}$ by eq. (9)). These give $3.5 \pm 1.4 \mu\text{b}$ (9 GeV/c) and 5.2 ± 2.4 (12 GeV/c) which agree rather well with the $\Sigma^+ A_1^-$ cross section of $5 \pm 3 \mu\text{b}$.

As we have seen in the last section, Δ exchange is relatively unimportant in B^+ and A_1^+ production (for $K^- p \rightarrow \Lambda\Delta$ it is obviously excluded).

Henceforth, we assume $I = 1/2$ (N) exchange only and attempt to achieve a consistent description with just a single^(*) trajectory (N_α).

The Σ^-/Λ ratio for A_1^+ production is $2 \pm .6$ which is not incompatible with the value for π production. This comparison tests the dominance of a single Regge exchange (e.g. the nucleon), which naturally implies equality of these ratios. The ratio for A_1 production corresponds to

$$F/D = 0.27 \pm 0.04 \quad (14)$$

Observation of the characteristic dip at $u = -.15$ in $d\sigma/du(\Sigma^- A_1^+)$ would inspire confidence that one is really discussing pure N_α exchange. However, present statistics do not permit a sufficiently good u -resolution for this. At 4.2 GeV/c, $u_{\min}$ is not far from the dip position and one therefore expects a rather flat u -dependence for $0 \lesssim |u'| \lesssim 1 \text{ GeV}^2$ (fig. 2 for $-u \gtrsim 0.1 \text{ GeV}^2$). Indeed, the mean slope parameter b is found to be of the order of 2 GeV^{-2} (table 2). The same discussion applies to the u -dependence of B production. The Σ/Λ ratio for B production is not measurable in this bubble chamber experiment because of the two neutrals in B^0 decay.

4.2 D(1285) production

The pseudoscalar analogue of the process $K^- p \rightarrow \Lambda D$ is $K^- p \rightarrow \Lambda(\eta \text{ or } \eta')$. Using the 4.2 GeV/c data, Marzano et al. [12] have performed an SU(3) analysis of the latter process together with $K^- p \rightarrow \Lambda \pi^0$. Taking into account η, η' mixing, they find a solution^(**) compatible with the on-shell value $F/D = 0.56$ (eq. (10)) i.e. larger than that deduced from the Σ/Λ ratio. This gives some idea of the uncertainties involved in such comparisons. For D production, there are further uncertainties: (a) it is by no means certain that the D is related by SU(3) to the A_1 [19]; (b) the mixing

(*) We assume that any parity doublet partner present for $u \lesssim 0$ has the same SU(3) properties.

(**) They also find a solution with $F/D \simeq 0.8$.

angle between possible singlet (D_1) and octet (D_8) components is not well-known and (c) the D_1/D_8 coupling ratio to nucleons is not established. For (a) and (b) we use the mixing parameters of [19] ($\theta = -16^\circ$) and for (c) we use the naïve quark model result $\langle D_1 | \bar{p}p \rangle / \langle D_8 | \bar{p}p \rangle = \sqrt{2}$ (i.e. the strange quarks decouple). With these assumptions, and taking F/D to lie between 0.41 and $2/3$ we predict

$$\sigma(\Lambda D) / \sigma(\Sigma^- A_1^+) = .01 \text{ to } 1 \quad (15)$$

compared with the experimental ratio of 0.6 ± 0.3 (table 2). The latter ratio would correspond to $F/D = 0.63 \pm 0.04$. Clearly, this is a very sensitive quantity.

The observation of backward $D(1285)$ production in K^-p scattering is a very important one. According to the OZI rule, one should not see this if, like the ϕ (sect. 6), the D is ideally mixed ($s\bar{s}$ quarks only). The fact that it is produced (just as the η and η' are) implies that it is not a pure $s\bar{s}$ state.

4.3 C(1280) production

The C or Q mesons are thought to be mixtures of the strange members of the A_1 and B nonets (Q_A and Q_B). How much of the C(1280), for example, is related to the A_1 and how much to the B is a complex question which is dealt with elsewhere (e.g. [20,21,22]). Here we shall only predict the cross sections for production of the SU(3) eigenstates Q_A and Q_B .

Barger [23] and Eisner et al. [24] have assumed $\Lambda_\alpha, \Lambda_\gamma$ exchange only to describe $K^+p \rightarrow pK^+$ [23] and $K^-p \rightarrow \bar{E}K^+$ [24]. However, from eq.(8) we have seen that $I = 1$ exchange is not negligible in EK production (pure $I = 0$ exchange would imply $\sigma(E^0K^0)/\sigma(\bar{E}K^+) = 0$ rather than 0.5 as observed). In fact, according to table 1, $K^-p \rightarrow \bar{E}^0K^0$ and $K^-p \rightarrow \Sigma^-\pi^+$ have the same SU(3) structure up to mass-breaking effects, i.e.

$$\begin{aligned}
 \Sigma/N &= 1/2 \xi \\
 \Sigma^*/\Delta &= 1/2 \xi^* \\
 \Lambda/\Sigma &= 2(\lambda^2/\mu\nu) \xi',
 \end{aligned}
 \tag{16}$$

where the various ξ parameters would be 1.0 in an unbroken SU(3) world ($m_N = m_{\Sigma} = m_{\Lambda}$, $\alpha_N = \alpha_{\Sigma} = \alpha_{\Lambda}$, etc.). In practice, it seems reasonable to assume $\xi^* \approx \xi$ and $\xi' = 1$. Hence,

$$\frac{d\sigma}{du} (\Xi^0 K^0) / \frac{d\sigma}{du} (\Sigma^- \pi^+) \approx \xi^2,
 \tag{17}$$

where ξ is certainly energy dependent and possibly also u -dependent. This comparison (eq. (17)) is made in fig. 5 [11,25] and suggests

$$\xi^2 = 0.9 \pm 0.3
 \tag{18}$$

at this energy.

Turning to the axial vector production analogues, we predict (assuming Λ_α exchange only)

$$\sigma(\Xi^- Q_A^+) / \sigma(\Sigma^- A_1^+) = \sigma(\Xi^- Q_B^+) / \sigma(\Sigma^- B^+) = \xi^2 \left[\frac{1}{6} \cdot \frac{9(F/D)^2 - 1}{(F/D)^2 - 1} \right]^2 \equiv R_c. \tag{19}$$

For $F/D = 0.41(2/3)$, this ratio^(*) is 0.1 (.7). Since the C(1280) is presumed to be a mixture of Q_A and Q_B , one should really add the latter production amplitudes coherently before comparing with the C production data. Thus, R_c provides a conservative upper bound on the total C production strength (including its SU(3) mixing partner's contribution). This is $(\sqrt{\sigma(\Sigma A_1)} + \sqrt{\sigma(\Sigma B)})^2 R_c = 0.24$ and 17 μb corresponding to F/D ratios of 0.41 and 2/3 respectively. These may be compared to an observed signal of 7.9 μb from C alone decaying into $K^* \pi$ and $K\rho$. To satisfy this

(*) This ratio involves precisely the same sensitive function of F/D as does the $\Lambda D_8 / \Sigma A_1$ ratio.

very conservative limit, one must therefore choose a value F/D rather larger than suggested by the pseudoscalar production data (eq. (12)), but which is however not too unreasonable (0.6).

5. BORN TERM ESTIMATES

The nucleon exchange Born term cross section for $K^- p \rightarrow \Lambda \pi^0$ is

$$\frac{d\sigma}{du} = \frac{389.3}{64\pi q^2 s} \cdot \frac{g_{Kp\Lambda}^2 g_{\pi^0 pp}^2}{(u - M^2)^2} s(M^2 - u) \text{ (}\mu\text{b GeV}^{-2}\text{)}, \quad (20)$$

where M is the nucleon mass and $g_{\pi^0 pp}^2/4\pi = g_{\pi NN}^2/4\pi = 14.4$ [6]. For ΛA_1 production we find^(*)

$$\frac{\frac{d\sigma}{du} (K^- p \rightarrow \Lambda A_1^0)}{\frac{d\sigma}{du} (K^- p \rightarrow \Lambda \pi^0)} = \frac{M^2 + 2m_A^2 - u}{m_A^2} (g_{A_1 pp}^2 / g_{\pi pp}^2). \quad (21)$$

It is convenient to study the ratio of cross sections so that many of the ambiguities in Reggeisation and pole-extrapolation (from $\sqrt{u} = -M$ to $u < 0$) cancel out. The extent of these uncertainties can be gauged by evaluating the ratio of Born terms both at u and M^2 and at $u = 0$. Using $g_{A_1 pp}^2/4\pi = 0.77$ (from axial vector meson dominance of the weak form factor [26]), we find

$$\sigma(\Lambda A_1^0)/\sigma(\Lambda \pi^0) = \left. \begin{matrix} .11 \\ .15 \end{matrix} \right\} \begin{matrix} u = M^2 \\ u = 0 \end{matrix} \quad (22)$$

This is compatible with the experimental ratio of 0.41 ± 0.24 at 4.2 GeV/c. However, by SU(3) or factorization (sect. 4) this estimate implies an even smaller $\Sigma^- A_1^+$ cross section, $\sigma(\Sigma^- A_1^+)/\sigma(\Lambda \pi^0) = 0.1$ to 0.2 which is well below the observed value $0.85 \pm .2$ (tables 2,3). In fact, one should probably reduce the above predicted ratios by a further 55% to account for $u_{\min}$ biases (fig. 4).

(*) The πpp and $A_1 pp$ vertices are respectively $\bar{g}u\gamma_5 u$ and $\bar{g}u\gamma_\mu \gamma_5 u$.

For B production^(*), we find that the nucleon exchange contribution^(**) is,

$$\frac{\frac{d\sigma}{du} (K^- p \rightarrow \Sigma^- B^+)}{\frac{d\sigma}{du} (K^- p \rightarrow \Sigma^- \pi^+)} = (M^2 - u + m_B^2/2) (g_{Bpp}^2 / g_{\pi pp}^2) \quad (23)$$

$$= \begin{matrix} 0.19 \\ 0.41 \end{matrix} \left\{ \begin{matrix} u = M^2 \\ u = 0 \end{matrix} \right.$$

where we have used exchange degeneracy of π and B exchange in pp scattering to estimate

$$g_{Bpp}^2 / 4\pi = \alpha' / 4 \quad g_{\pi pp}^2 / 4\pi . \quad (24)$$

The prediction in eq.(23), when corrected by a factor of 0.50 for $u_{\min}$ biases, is rather smaller than, but of the same order of magnitude as, the observed ratio of around 0.6 (tables 2,3). Although there are considerable uncertainties involved, one may conclude that the ΣA_1 and ΣB production signals are larger than expected using the simplest possible theoretical estimates.

6. VECTOR AND TENSOR MESON PRODUCTION

A good test of nucleon exchange models for resonance production is provided by ρ, ω and ϕ production. It has already been observed [28] that the process $K^- p \rightarrow \Lambda \phi$ is strongly suppressed in the backward direction. This is to be expected if non-strange baryon exchange dominates, but not if direct channel (resonance) effects are important. There also

(*) The B_{pp} vertex is $g u \gamma_5 \sigma^{\mu\nu} p_\nu u$.

(**) The Born term calculations in sects 5 and 6 have been cross-checked using the algebraic reduction program REDUCE [27].

exist measurements of ρ^0 and ω production in backward π^+n [29] and K^-p [28] scattering near 4 GeV/c. In fig. 6 we show the $d\sigma/du$ data for $K^-p \rightarrow \Lambda\omega$ together with an interpolation of $K^-p \rightarrow \Lambda\pi^0$ data (scaled by 6.0), the $K^-p \rightarrow \Lambda\rho^0$ data (scaled by 1.33) and the $\pi^+n \rightarrow p\omega^0$ data (scaled by 1.30). Because of a lack of statistics it is not possible to assess how well the $d\sigma/du$ shapes agree with each other and with simple nucleon exchange. There is, however, some hint of a dip in the relevant u region.

The $\Lambda\omega/p\omega$ comparison suggests an F/D value in the range 0.1 to 0.3 i.e. inconsistent with the precise $\Sigma\pi/\Lambda\pi$ determination but consistent with $N\pi/\Lambda\pi$ and $\Sigma A_1/\Lambda A_1$ (fig. 3). As in sect. 5, one can use Born term diagrams to estimate the $\Lambda\omega/\Lambda\pi$ production strength ratio in terms of $g_{\pi^0 pp}^2$ and $(G_{V,T}^\omega)^{2(*)}$ [16]. For example, identifying at $u = M^2$, we obtain

$$\frac{\frac{d\sigma}{du} (K^-p \rightarrow \Lambda\omega)}{\frac{d\sigma}{du} (K^-p \rightarrow \Lambda\pi^0)} \approx \frac{2 G_V^2 + 2 G_T^2 + 9/2 G_V G_T}{g_{\pi^0 pp}^2} \quad (25)$$

$$= 1.2$$

(or 2.1 if we use the $u = 0$ expression) which is considerably smaller than the observed value of ~ 6 (fig. 6). However, for ρ production, one finds

$$\frac{d\sigma}{du} (K^-p \rightarrow \Lambda\rho^0) / \frac{d\sigma}{du} (K^-p \rightarrow \Lambda\pi^0) = 3.9 \text{ (7 at } u = 0), \quad (26)$$

which compares reasonably well with the value (~ 5) observed experimentally (**).

The prediction for the ρ/ω production ratio ($= 3.3$) is on a firmer footing than the previous Born term estimates since the ρ and ω are rather similar in mass and quantum numbers and since their couplings are well-known.

(*) We use the pole position values in table 11.2 of ref. [16], (but with the normalization given in table 2.2).

(**) No $u_{\min}$ corrections are necessary since we compare at fixed u .

The ratio: $G_V^\omega/G_V^0 = 4$ is close to the SU(6) and vector meson universality values of 3 [16]. Similarly, vector meson dominance applied to the isoscalar and isovector anomalous magnetic moments of the nucleon [30] suggests $G_T^\omega \sim 0$ but G_T^0/G_V^0 large (~ 5). These same systematics are also found when the ρ and ω are virtual (reggeons) [16]. Thus, one should probably regard the discrepancy between the nucleon exchange model (3.3) and experiment (0.75 ± 0.25) as significant.

In common with the axial-vector mesons, the tensor mesons are $L = 1$ excitations in the quark model, and have similar masses. For this reason it is interesting to consult the tensor production data as well.

These are summarized in table 4 [8,10,25]. As for the pseudoscalar and axial vector production, we note that $I = 1/2$ exchange (N) dominates $I = 3/2$ exchange in $K^- p \rightarrow \Sigma^- A_2^+$ ($.05 \leq |\Delta|^2/|N|^2 \leq .14$).

Assuming $I = 1/2$ exchange above, these data imply the following Σ^0/Λ production ratios for tensor mesons

$$\begin{aligned} \sigma(\Sigma^0 A_2^0)/\sigma(\Lambda A_2^0) &= 0.41 \pm 0.10 \\ \sigma(\Sigma^0 f)/\sigma(\Lambda f) &= 0.24 \pm 0.16 \end{aligned} \tag{27}$$

to be compared with the analogous quantities for 0^- and 1^+ backward production

$$\begin{aligned} \sigma(\Sigma^0 A_1^0)/\sigma(\Lambda A_1^0) &= 0.50 \pm 0.15 \\ \sigma(\Sigma^0 \pi^0)/\sigma(\Lambda \pi^0) &= 0.28 \pm 0.08. \end{aligned} \tag{28}$$

We see that, within the large errors, the Σ/Λ ratios for f , A_2 , A_1 and π production are compatible with each other. These Σ/Λ ratios correspond to an average $F/D = 0.30 \pm 0.03$ (fig. 3).

7. DISCUSSION AND CONCLUSIONS

The foregoing description of backward resonance production is far from straightforward. One might reasonably question if 4.2 GeV/c is a high enough momentum at which to discuss backward processes realistically in terms of baryon exchange. There are at least two very good reasons for believing that it is:

- (a) The success of SU(3) in relating $\pi^- p \rightarrow p \pi^-$ to $K^- p \rightarrow \Sigma^+ \pi^-$ (sect. 4) would be destroyed if there were important direct channel effects. These would imitate non- Δ exchange quantum numbers [13].
- (b) As discussed, in sect. 6, the suppression of $K^- p \rightarrow \Lambda \phi$ can only be satisfactorily explained if non-strange baryon exchange is dominant.

We have seen that backward A_1 and B production in $K^- p$ interactions at 4.2 GeV/c occurs dominantly via $I = 1/2$ exchange. The C(1280) is largely produced by $I = 0$ exchange. This much is clear. To determine whether the $I = 1/2$ component is a single factorizing exchange, for example the nucleon, we have made various factorization, SU(3) and Born term comparisons with pseudoscalar, vector and tensor meson production. Some degree of inconsistency between these is to be expected if more than one exchange is important for backward resonance production. For backward photoproduction and related vector meson processes this has already been recognised (eq. (18)). In our case, additional $I = 1/2$ exchanges (N_β, N_Y) would result in different effective F/D ratios in different processes and poor agreement with nucleon Born term calculations.

A priori, little is known about the relative coupling strengths of the various baryon exchanges to different produced mesons. One rather crude indication is given by Finite Mass Sum Rule (FMSR) duality arguments which predict the production cross section for a state of mass m by exchange of trajectory α_r to be [31]

$$\sigma_r(m) \sim (m^2)^{-2\alpha_r} , \quad (29)$$

at least for meson exchange. Even for baryon exchange, there are indications [29,32] that eq. (29) is also of some relevance in that the higher mass resonances do seem to be more prominent for baryon exchange ($\alpha_r \lesssim 0$) than for meson exchange ($\alpha_r > 0$). Conversely, for a given cross section, the more massive the produced resonance, the more important are the lower lying exchange contributions likely to be.

Classified according to their intercept values, the non-strange exchanges are

$$\Delta_\delta(0), N_\beta(-.29), N_\alpha(-.37), N_\gamma(-.8).$$

Thus, for 0^- production ($\langle m^2 \rangle \sim 0.25 \text{ GeV}^2$) both Δ_δ and N_α are important, but for 1^{++} and 1^{+-} production ($\langle m^2 \rangle \sim 1.5 \text{ GeV}^2$) one might expect Δ_δ to be less important^(*) and some lower lying contribution such as N_γ ^(**) to become significant. Similar arguments apply to vector and tensor production ($\langle m^2 \rangle \sim .8$ and 2 GeV^2 respectively). These rather qualitative statements are in agreement with what is observed, but a complete quantitative description would require a considerable improvement in the backward resonance production data.

Backward scattering has proved to be an excellent place to observe traditionally shy resonances such as the A_1 - compare the simplicity of the $K^- p \rightarrow \Sigma^- A_1^+$ analysis with the years of fruitless searching in $\pi^\pm p \rightarrow (3\pi)^\pm p$. If one treats existing A_1 and Q backward production experiments as successful feasibility studies, then there is obviously a very good case for mounting high statistics counter experiments aimed specifically at these channels. There is much to be learned. One would like, in particular:

- (a) A high statistics search for $K^- p \rightarrow \Lambda A_1^0$. A full Partial Wave Analysis (PWA) of the 3π system is essential.
- (b) A similar study of $K^- p \rightarrow \Sigma^- A_1^+$. Here, one already knows there is an excellent signal to be analysed. What one requires is a large improvement in the statistics so that one may observe the phase behaviour of the PWA amplitudes and a higher beam momentum to exclude the possibility of a kinematic enhancement [34].

(*) An application of this idea can be found in [33].

(**) Since the N_β is high-lying and unimportant for 0^- production we can neglect its contribution to high mass production.

- (c) A detailed analysis of the $C(1280)$ decay into $K^*\pi$, $K\rho$ and $K\omega$ together with a more detailed search for a corresponding Q_2 -like state near 1400 MeV. Most models for mixing of the Q_A and Q_B SU(3) eigenstates predict two Q enhancements usually at 1300 and 1400 MeV [22], although the second state could be very weak and unobservable [21].
- (d) Sufficiently detailed u -dependent data to settle the question of N_α dominance of resonance production data. This would be useful for ρ and ω production as well.

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TABLE 1

Process	Exchange amplitudes	SU(3) coefficients
$K^- p \rightarrow \Sigma^- \pi^+$	$N+\Delta$	$\lambda = \frac{1}{2\sqrt{3}} \frac{3F/D+1}{1-F/D}$
$K^- p \rightarrow \Sigma^+ \pi^-$	3Δ	
$K^- p \rightarrow \Lambda \pi^0$	λN	
$K^- p \rightarrow \Lambda \eta_8$	$-\lambda N(\lambda/\sqrt{3}\mu\nu)$	
$\pi^+ p \rightarrow p \pi^+$	$-(2\mu N+\Delta)$	$\mu = \frac{1}{2} \frac{F/D+1}{F/D-1}$
$\pi^- p \rightarrow n \pi^0$	$-\sqrt{2}(\mu N-\Delta)$	
$\pi^- p \rightarrow p \pi^-$	-3Δ	
$K^- p \rightarrow \Xi^- K^+$	$\Sigma+\Sigma^*+\Lambda$	$\nu = \frac{3F/D+1}{3F/D-1}$
$K^- p \rightarrow \Xi^0 K^0$	$-2(\Sigma+\Sigma^*)$	
$K^+ p \rightarrow p K^+$	$-(2\mu\Sigma+\Sigma^*+\nu\Lambda)$	

TABLE 2

Process	$\langle u_{\min} \rangle$	$\sigma \text{ } \mu\text{b}$	$b \text{ GeV}^{-2}$	ref.
$K^- p \rightarrow \Sigma^- A_1^+$	-.08	7.2 ± 1	$2.2 \pm .4$	[1]
$K^- p \rightarrow \Sigma^+ A_1^-$		$5 \pm 3^{(*)}$	-	[8,10]
$K^- p \rightarrow \Lambda A_1^0$	-.06	$3.5 \pm 2^{(*)}$	-	[8,9,10]
$K^- p \rightarrow \Xi^- C^+$		$6.2 \pm .6 (K\rho)$ $1.7 \pm .5 (K^* \pi)$	$1.6 \pm .3$	[5]
$K^- p \rightarrow \Xi^0 C^0$	-.2	$< .5$	-	[5]
$K^- p \rightarrow \Lambda D^0$	-.17	4.5 ± 2	$\lesssim 2$	[3]
$K^- p \rightarrow \Sigma^- B^+$		3.2 ± 0.5	$2 \pm .2$	[4]
$K^- p \rightarrow \Sigma^+ B^-$	-.17	$< .5$	-	[4]

(*) No clear resonant signal is observed (sect. 3 of the text)

TABLE 3

Process	$\langle u_{\min} \rangle$	$\sigma \text{ } \mu\text{b}$	ref.
$\bar{K}^- p \rightarrow \Sigma^- \pi^+$	.11	$9.0 \pm .6$	[11]
$\bar{K}^- p \rightarrow \Sigma^+ \pi^-$		16.0 ± 1.0	[11]
$\bar{K}^- p \rightarrow \Lambda \pi^0$	.10	$8.5 \pm .7$	[12]
$\bar{K}^- p \rightarrow \Xi^- K^+$		13.7 ± 0.9	[8]
$\bar{K}^- p \rightarrow \Xi^0 K^0$	.10	5.5 ± 1.0	[8]
$\bar{K}^- p \rightarrow \Lambda \eta$	.06	1.9	[12]
$\bar{K}^- p \rightarrow \Lambda \eta'$	-.02	$2.9 \pm .8$	[12]

TABLE 4

Process	$\langle u_{\min} \rangle$	$\sigma \text{ } \mu\text{b}$	ref.
$\bar{K}^- p \rightarrow \Lambda f^0$	-.16	41 ± 7	[25]
$\bar{K}^- p \rightarrow \Sigma^0 f^0$	-.20	10 ± 5	[25]
$\bar{K}^- p \rightarrow \Lambda A_2^0$	-.18	9 ± 3	[8,10]
$\bar{K}^- p \rightarrow \Sigma^- A_2^+$	-.22	15 ± 4	[8,10]
$\bar{K}^- p \rightarrow \Sigma^+ A_2^-$	-.22	10 ± 3	8,10

FIGURE CAPTIONS

- Fig. 1 Typical baryon exchange diagrams for backward K^-p scattering.
- Fig. 2 Isospin 1/2 exchange cross sections at 4.2 GeV/c for: (a) $\pi N \rightarrow N\pi$, (b) $K^-p \rightarrow \Lambda\pi^0$ and (c) $K^-p \rightarrow \Sigma\pi$. The σ_N values (eq. (1)) are from ([6] (O)) and ([7] (●)) scaled in momentum according to eq.(9). The $\Lambda\pi^0$ data (b) are from ([12] (O)) and ([17] (●)) (scaled from 5 GeV/c). The $\Sigma\pi$ bounds are deduced from the data of [1] using eq.(2) (the hatched area is an estimate of the error corridor). The continuous interpolation shown in (a), (b) and (c) is described in the text.
- Fig. 3 Cross section ratios plotted as a function of the SU(3) F/D parameter. The symbols N/Λ and Σ/Λ denote $\sigma_N(N\pi)/\sigma(\Lambda\pi^0) = (3\mu/\lambda)^2$ and $\sigma_N(\Sigma\pi)/\sigma(\Lambda\pi^0) = 1/\lambda^2$ respectively (table 1). The hatched areas are the ranges allowed by experiment as determined from fig. 2.
- Fig. 4 The observable fraction F of an $I = 1/2$ exchange cross section (fig. 2) as a function $u_{\min}$, where $F = \int_{-1}^{u_{\min}} \frac{d\sigma}{du} du / \int_{-1}^{+0.1} \frac{d\sigma}{du} du$.
- Fig. 5 The differential cross section for $K^-p \rightarrow \Xi^0 K^0$ [25] compared with that for $K^-p \rightarrow \Sigma^- \pi^+$ (scaled by .90) at 4.2 GeV/c [11].
- Fig. 6 The differential cross section for $K^-p \rightarrow \Lambda\omega$ (O) at 4.2 GeV/c [28] compared with $\frac{d\sigma}{du}(K^-p \rightarrow \Lambda p)$ (●), scaled by 1.33 [28], and with $\frac{d\sigma}{du}(\pi^+ n \rightarrow p\omega^0)$ (▲) at 4 GeV/c, scaled by 1.30 [29]. Also shown is the error corridor deduced from the $K^-p \rightarrow \Lambda\pi^0$ data of fig. 2(b), (scaled by 6.0).

TABLE CAPTIONS

- Table 1 The exchange structure in backward scattering. The exchange amplitudes are further related by broken SU(3) (eq.(16)).
- Table 2 A summary of the backward axial vector meson production data at 4.2 GeV/c in K^-p . The cross sections are integrated over the backward hemisphere and are corrected for unseen decays (the D branching ratio into $\eta\pi^+\pi^-$ was estimated to be 1/4 [3]). The slope parameter b is defined by $d\sigma/du = Ae^{bu}$. The C(1280) is defined as the relatively narrow enhancement at threshold in the $K\rho$ channel [5].
- Table 3 A summary of the cross section data for pseudoscalar production in the backward hemisphere of K^-p scattering at 4.2 GeV/c.
- Table 4 A summary of the backward tensor meson production data at 4.2 GeV/c in K^-p . The cross sections are integrated over the backward hemisphere and corrected for unseen decays.

FIG.1

FIG. 2

FIG.3

FIG. 4

FIG.5

FIG.6