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Rather than presenting a complete survey of baryon resonances, we shall confine our attention to two topics:
(a) A discussion experimental results completed since the Berkeley Conference in September 1966,
(b) Assignment of resonances to multiplets through use of mass formulae, and a critique of these assignments by means of a detailed comparison of various decay rates.

I. Recent Experimental Results

Since the 1966 survey of strange baryon resonances by Ferro-Luzzi[1] there have been two notable advances, both of which were reported in preliminary form at that time. Davies et al.[2] have done a precise total cross-section experiment on K^-p and K^-d covering a momentum range of 600 to 1400 MeV/c. Figure 1 shows their results for the $I = 1$ and $I = 0$ cross sections after the important smearing effect of deuterium internal momentum has been removed. The dominant bump in $I = 1$ is the well-known $Y_1^*(1765)$, and the very small satellites on either side are $Y_1^*(1660)$ and $Y_1^*(1910)$, the former being seen for the first time in the elastic channel and the latter being a confirmation of the effect reported by Cool et al.[3] Since the unfolding of internal momentum is not a completely unambiguous process, especially near the ends of the momentum region covered, these small bumps are rather close to the limit of accuracy of this technique. The $I = 0$ cross section displays the highly elastic $Y_0^*(1820)$ as well as a new discovery in this experiment--the very nice bump at 800 MeV/c. This experiment makes a clear statement calling for a $Y_0^*(1698)$ with a width $\Gamma = 40$ MeV. It does not yield the spin-parity, but from the height of the bump one obtains an elasticity x given by $(J + \frac{1}{2})x = 0.49$.

The second experiment concerns the spin-parity assignment of this resonance. The CERN-Heidelberg-Saclay (CHS) Collaboration[4] has made a study of the reactions $K^-p \rightarrow \Sigma^{\pm}\pi^{\mp}$ covering the range 600 to 1200 MeV/c. Figures 2 and 3 show the angular distribution coefficients from a Legendre polynomial expansion. The striking effects are the very large bumps in A_0 and A_2 in the $\Sigma^-\pi^+$ reaction at about 730 MeV/c without correspondingly large bumps in $\Sigma^+\pi^-$. This can come about only by interference of two states of the same spin-parity, one in $I = 0$ and the other in $I = 1$. The dashed lines are the best-fit solution to a χ^2 minimization of all the angular distribution data using resonances in D and F waves and nonresonant S- and P-wave amplitudes varying linearly with momentum. It was found that a good solution compatible with the known J^P of $Y_1^*(1765)$ and $Y_0^*(1820)$ could be obtained only if $Y_0^*(1698)$ and $Y_1^*(1660)$ both had $J^P = 3/2^-$. (The mass and width of $Y_0^*(1698)$ come out in this fit to be 1682 MeV and 55 MeV.) This spin-parity assignment for $Y_1^*(1660)$ is now the most favored possibility from other experiments.[1] Figure 4 shows the polynomial expansion

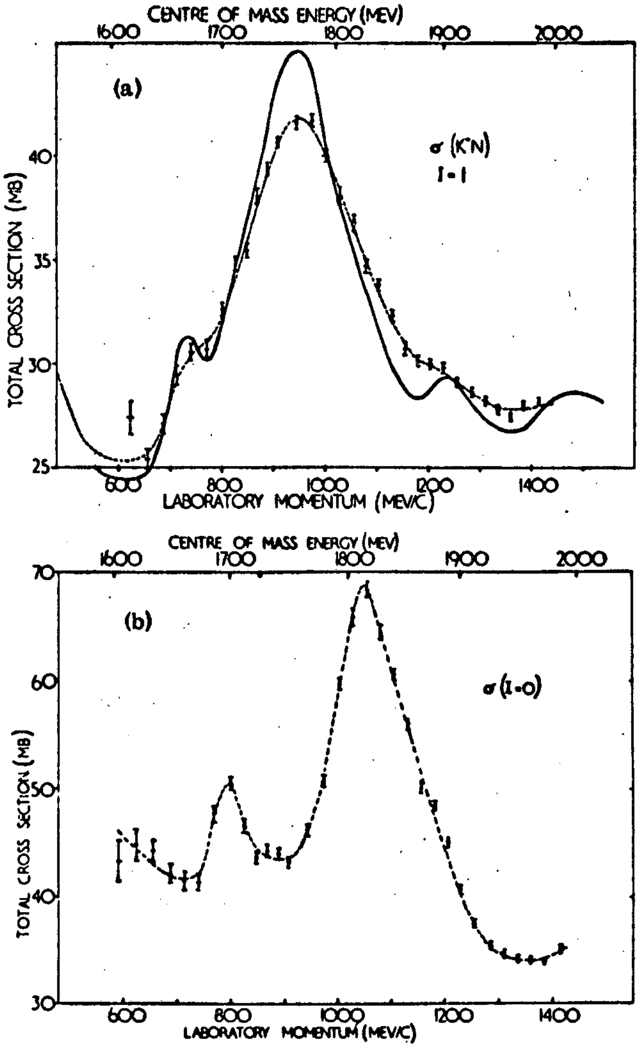

Fig. 1. The I = 1 and I = 0 K^-N total cross sections from 600 to 1400 MeV/c as measured by Davies et al. (Ref. 2).

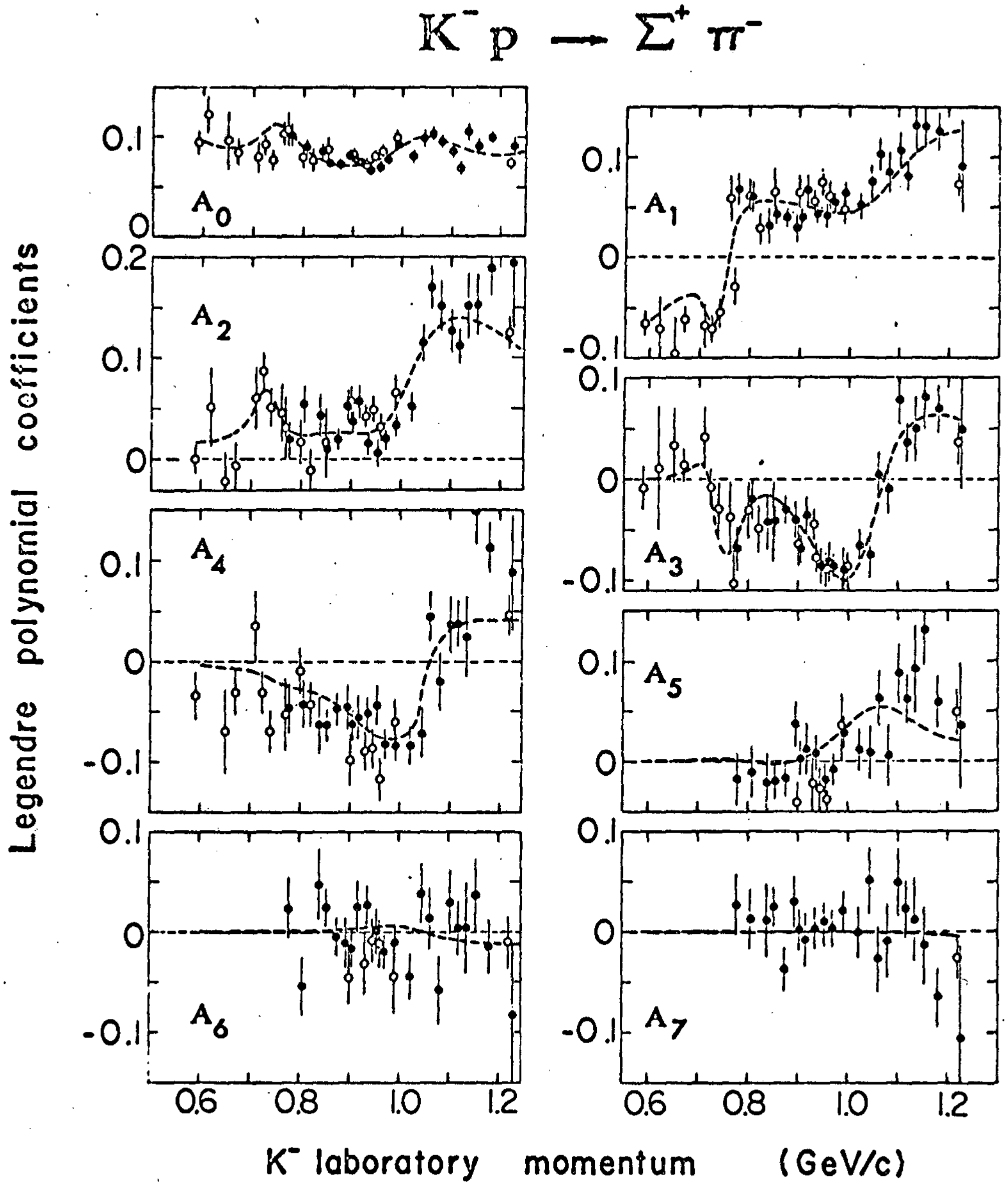

Fig. 2. The Legendre polynomial coefficients for the angular distribution of the reaction $K^-p \rightarrow \Sigma^+\pi^-$ covering the range 600 to 1200 MeV/c. The solid circles are measurements from the CERN-Heidelberg-Saclay collaboration (Ref. 4); the open circles at lower momenta are other experimental results from D. Rahm et al., presented at the Berkeley Conference (Ref. 1). The dashed line is a simultaneous fit to all $\Sigma^\pm\pi$ coefficients as described in the text.

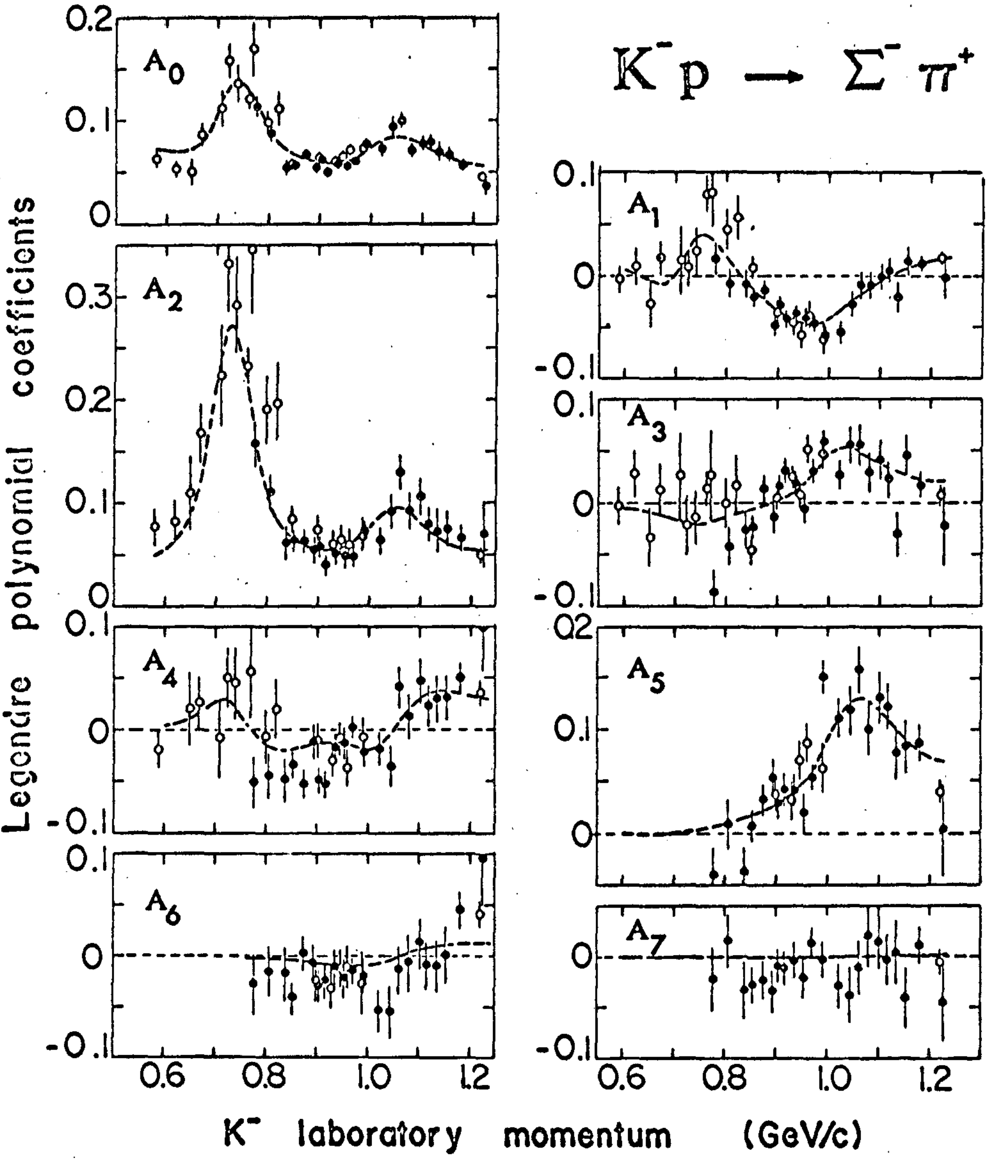

Fig. 3. As in Fig. 2 but for the reaction $K^-p \rightarrow \Sigma^-\pi^+$.

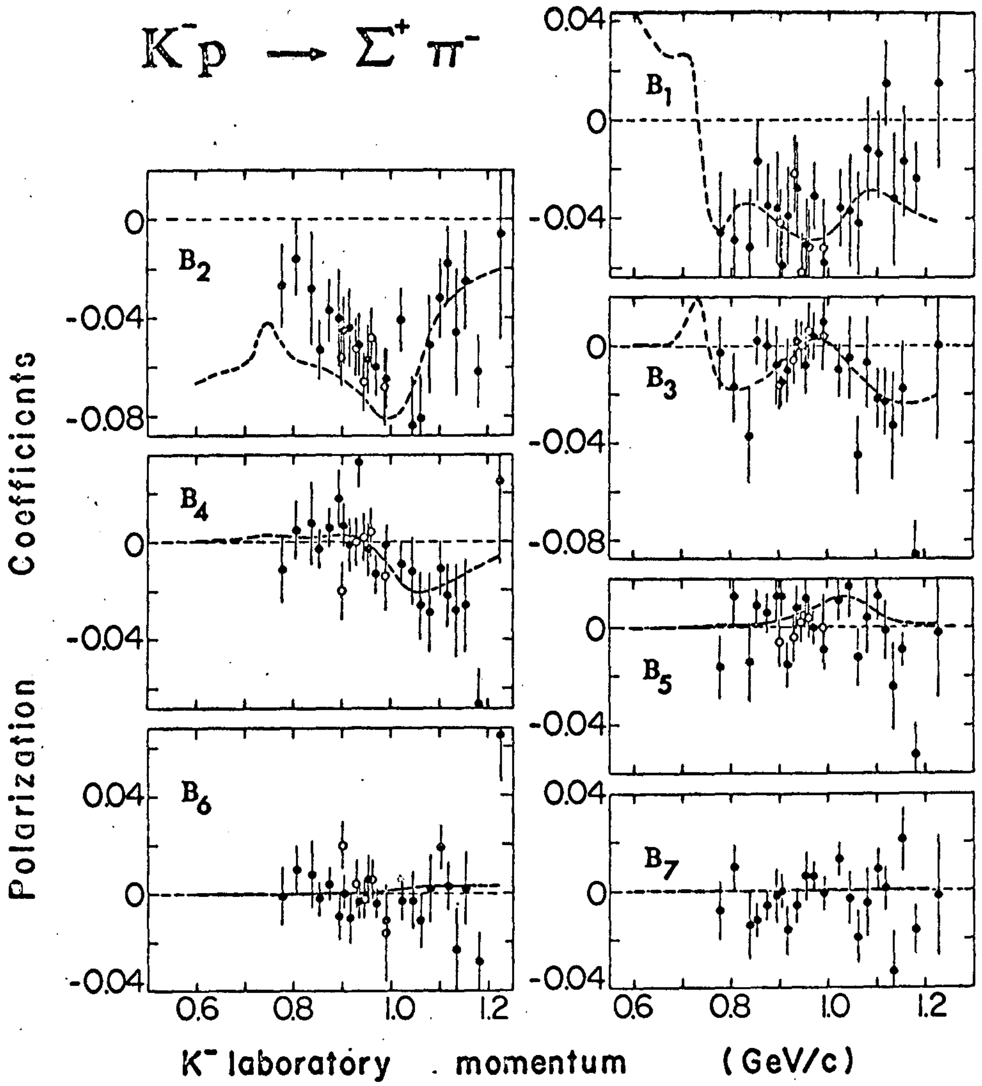

Fig. 4. Coefficients of the polarization expansion for the reaction $K^-p \rightarrow \Sigma^+\pi^-$. The curves have been calculated from the angular distribution data of Figs. 2 and 3, and represent a prediction for the polarization.

coefficients for the Σ^+ polarization, along with the predicted polarization from the fit to the angular distributions. The agreement seems generally very good, and lends some confidence in the uniqueness of the fit. Further evidence for this resonance comes from an analysis[1] of the angular distributions for elastic and charge-exchange scattering also by the CHS collaboration, which also suggests the presence of a resonant $3/2^-$ $I = 0$ amplitude in this region.

Another result emerging from the analysis of $\Sigma^\pm\pi^\mp$ is the necessity of a large $5/2^-$ $I = 0$ amplitude essentially degenerate in mass and width with the $5/2^+$ $Y_0^*(1820)$. Taking this new amplitude to be resonant improves the fit over that which can be obtained with a nonresonant amplitude. Although an unequivocal statement cannot be made that a new resonance exists there, the presumption is quite reasonable that a part of the $I = 0$ bump in Fig. 1 is to be associated with a new $Y_0^*(1827)$. This will be assumed in later discussions, where the $\Sigma\pi$ decay rates obtained by the CHS analysis will be used.

II. Decuplets, Unitary Singlets, and Their Recurrences

The $3/2^+$ decuplet consisting of $\Delta(1236)$, $\Sigma(1385)$, $\Xi(1530)$, and $\Omega(1674)$ is now known to satisfy moderately well the relative decay-rate relationships of SU(3) when suitably corrected for mass differences. The old discrepancy arising from the apparent absence of the decay mode $\Sigma(1385) \to \Sigma\pi$ has been resolved by a better measurement,[5] in good agreement with SU(3).

To compare the various partial widths we use the expression

$$\Gamma = C^2 g^2 B_\ell (M_N/M_R)\, p, \qquad (1)$$

where C is the appropriate SU(3) coefficient, g^2 is the coupling constant, and B_ℓ is the centrifugal barrier penetration factor for an angular momentum ℓ as given approximately for a nonrelativistic square-well potential by Blatt and Weisskopf.[6] We do not use the Glashow-Rosenfeld[7] prescription here because significant numerical factors are left out in their expression. M_R is the mass of the resonance; M_N, the mass of the nucleon, is introduced only to make g^2 dimensionless and of order unity; p is the c.m. momentum for the decay products.

Figure 5 shows g^2 calculated from Eq. 1 for the various decay modes of the $3/2^+$ decuplet and for those decay modes of the presumed $7/2^+$ recurrence of the $3/2^+$ decuplet for which decay rates are known. The major discrepancy in the $3/2^+$ decuplet lies in the relative decay rate of $\Xi(1530)$ compared with $\Delta(1236)$. This difference of slightly more than a factor of two, if acceptable, can be looked upon as setting the scale for discrepancies in decay rates that might be tolerated among more questionable multiplets. The $7/2^+$ rates are seen to be in satisfactory agreement and to yield a g^2, using this centrifugal barrier expression, of nearly the same size as for the $3/2^+$ decuplet.

Figure 6 is a plot of g^2 for all currently available decay rates of two presumed unitary singlets $\Lambda(1520)$ of $J^P = 3/2^-$ and $\Lambda(2100)$ of $J^P = 7/2^-$. Within the rather larger experimental uncertainties, the agreement appears satisfactory, again giving g^2 comparable to the $3/2^+$ and $7/2^+$ decuplets.

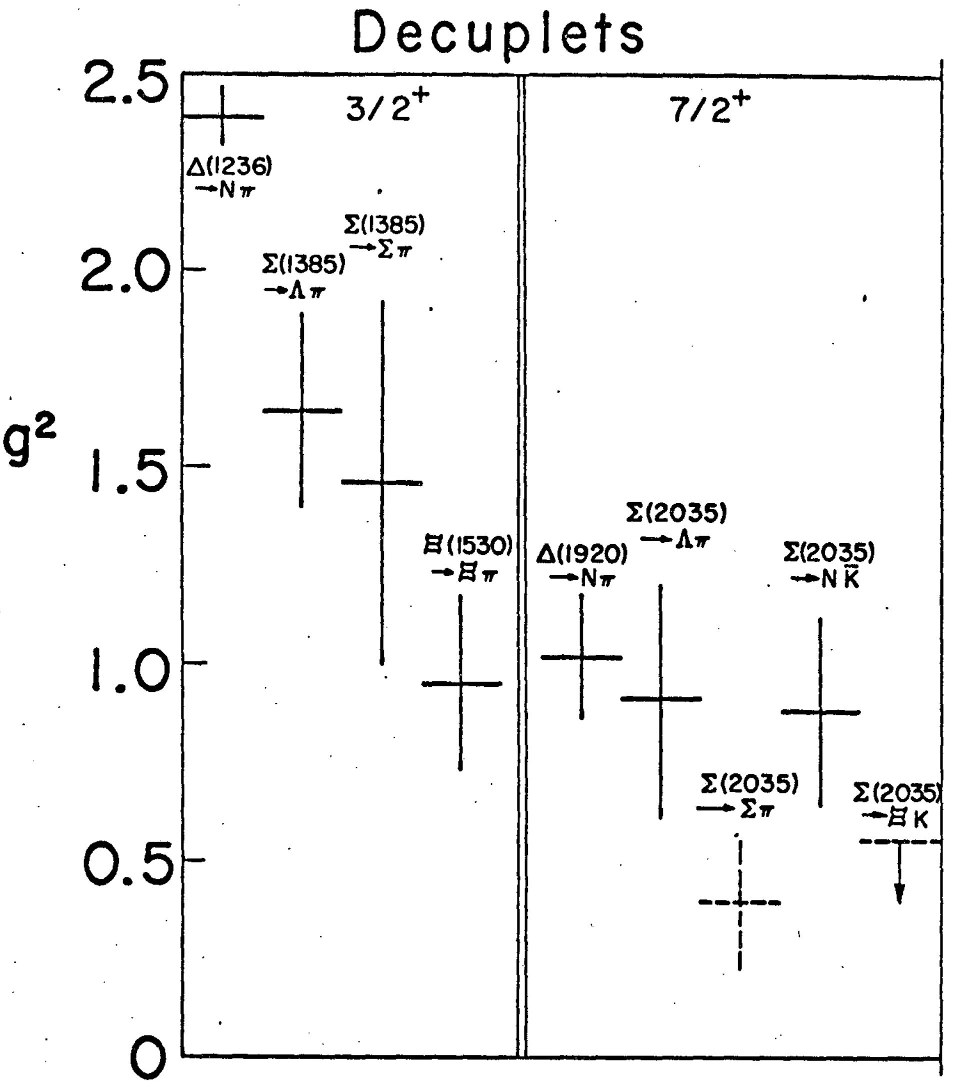

Fig. 5. Relative coupling constants for various decay modes of the $3/2^+$ decuplet and its recurrence. The decay rate $\Sigma(2035) \rightarrow \Sigma\pi$ is a preliminary value from A. Barbaro-Galtieri (private communication). The rate for $\Sigma(2035) \rightarrow \Xi K$ is an upper limit.

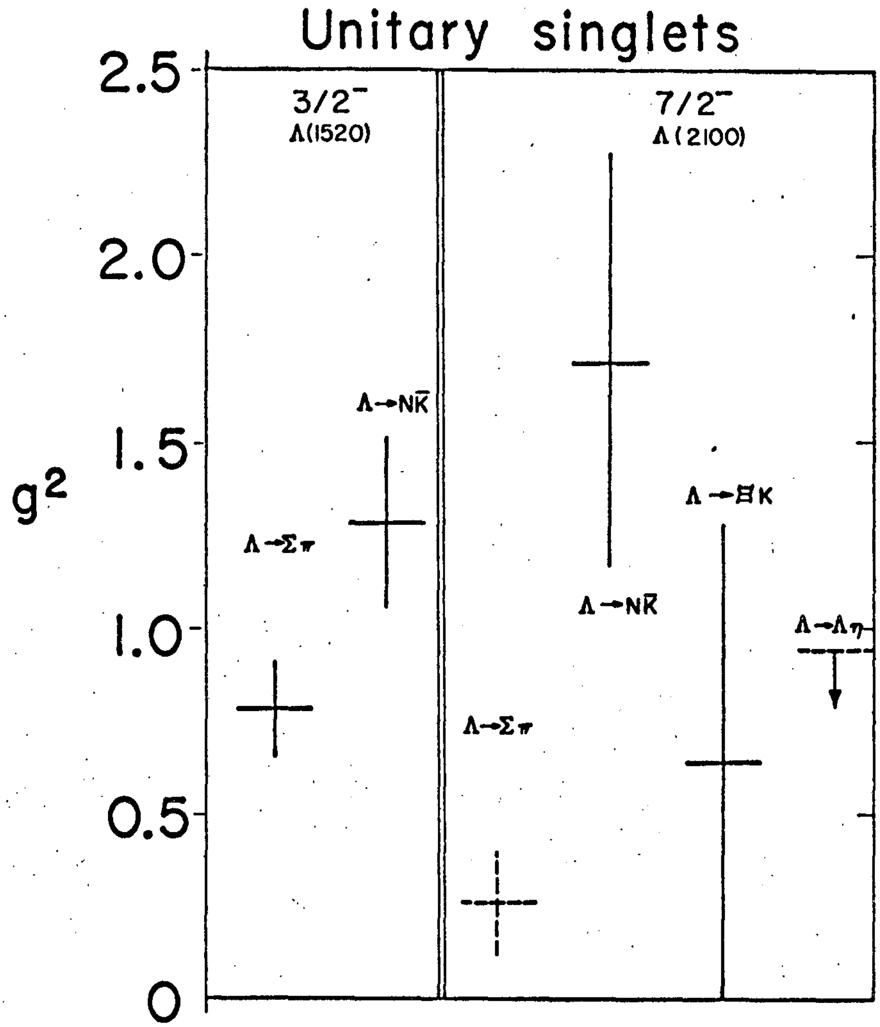

Fig. 6. Relative coupling constants for various decay modes of the presumed unitary singlets $\Lambda(1520)$ and $\Lambda(2100)$. The rates for $\Lambda(2100) \to \Sigma\pi$ and $\Lambda\eta$ are from A. Barbaro-Galtieri and C. Wohl respectively (private communication).

III. Octets

There have been a number of suggested baryon octets. The $3/2^-$ octet originally considered[7] now seems untenable. Proposals more in keeping with current data have often been mentioned in the literature. Recently Goldberg et al.[8] have discussed the possible $3/2^-$ and $5/2^+$ octets decay rates. Figure 7 is a mass plot of four of the more respectable possibilities, along with the Dalitz version[9] of how the quark model accounts for the three negative-parity octets shown and the two unitary singlets $\Lambda(1405)$ and $\Lambda(1520)$ of $J^P = 1/2^-$ and $3/2^-$ respectively. Dashed horizontal lines in the quark scheme indicate multiplet levels for which there is currently insufficient evidence.

The $1/2^-$ states consist of a nonet: $\Lambda(1405)$ and a presumed octet of eta-baryon resonances. Only for two of these four octet states has there, so far, been any convincing experimental evidence. For $\Sigma(1770)$ there has been some meager indication,[1] but there has been no report of a $J^P = 1/2^-$ Ξ predicted to be at 1820 MeV from the Gell-Mann-Okubo mass formula [assuming no mixing with $\Lambda(1405)$]. This should lie considerably below $\Xi\eta$ threshold, which is indicated by a horizontal line.

The $3/2^-$ nonet states are composed of $\Lambda(1520)$ and the octet, which is perhaps completed now by the discovery of $\Lambda(1690)$ mentioned in Section I. (We shall use here a compromise of the masses found in the two experiments.) The unmixed mass of the Λ member of the octet should lie at 1677 MeV, but a mixing angle of a few degrees with the unitary singlet could displace it upward. For all members except $\Xi(1815)$ the spin-parity can now be considered to be firmly known; for $\Xi(1815)$ it is rather likely to be $3/2^-$.

With the appearance of a strong $5/2^-$ amplitude in $I = 0$ at 1827 MeV, as noted in Section I, a possible $5/2^-$ octet can now be constructed. This is indicated in Fig. 7. $N(1688)$ and $\Sigma(1765)$ both have $J^P = 5/2^-$, while nothing yet is known concerning the spin-parity of $\Xi(1933)$. We include it here only because it falls at the correct mass to complete the octet.

Members of a $5/2^+$ octet occur at approximately the correct masses to correspond to recurrences of the $1/2^+$ baryon octet. $N(1688)$ and $\Lambda(1815)$ are known to have $J^P = 5/2^+$, whereas for $\Sigma(1910)$ there is only weak evidence[10] for this J^P assignment. The Ξ predicted by means of the mass formula to lie at 1990 MeV has not, as yet, been seen.

At this point the agreement with SU(3) and, in particular, the quark model appears rather satisfactory. All states have not yet been seen, but there is no reason to suppose that even in the lower mass region our knowledge of the baryon resonances is complete. We shall now proceed to make as complete a comparison of decay rates among members of each octet as is possible with our present experimental knowledge. For each octet we shall find that there is at least one decay rate which is in serious disagreement with the assignments proposed in Fig. 7.

Since both symmetrical and antisymmetrical octets can be formed from the baryon and meson octets, we must consider the octets of baryon resonances to be linear combinations of these two symmetries. Generally this combination is denoted by a mixing parameter α, but in order to construct a state whose normalization is independent of the mixing we shall instead use a mixing angle θ such that[11]

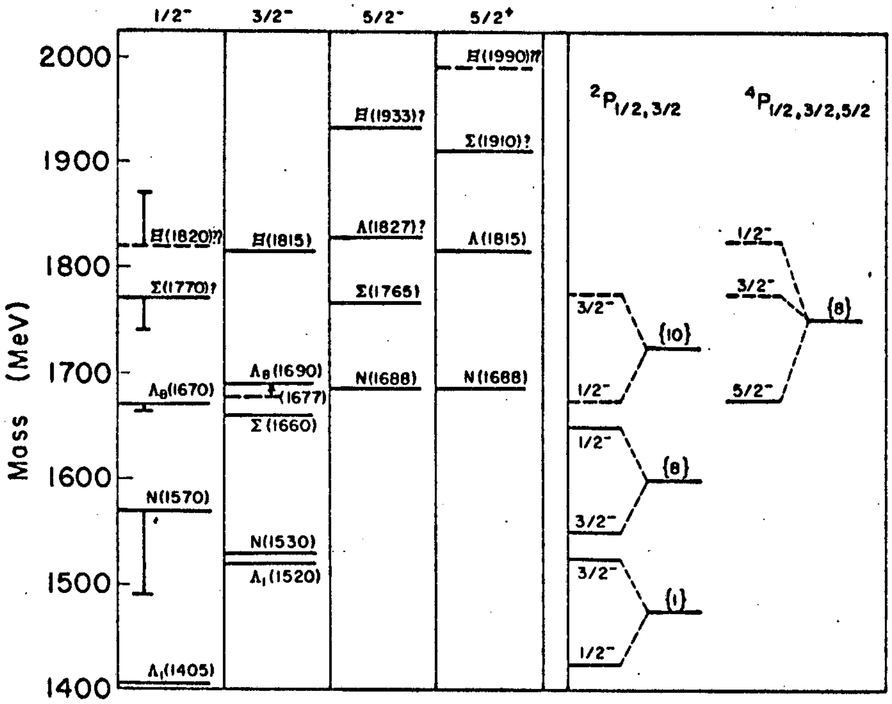

Fig. 7. A mass plot for four proposed octets. The short horizontal lines in the $\frac{1}{2}^-$ octet correspond to the baryon-eta threshold mass. The diagram on the right shows the Dalitz version (Ref. 9) of the quark-model scheme for the negative-parity octets.

$$\psi = \cos\theta\,\psi_8 + \sin\theta\,\psi_{8'}, \qquad (2)$$

where ψ_8 and $\psi_{8'}$ are the symmetric and antisymmetric states. In this way g^2 and θ form an independent set of parameters to describe the decay rates. The mixing angle θ is related to α (defined in Gell-Mann's convention) by

$$\alpha^{-1} = 1\ (\sqrt{5}/3)\tan\theta. \qquad (3)$$

The partial widths are now functions of g^2 and θ,

$$\Gamma = f^2(\theta)\, g^2\, B_\ell\, (M_N/M_R)p, \qquad (4)$$

where $f(\theta)$ is the combination of $\cos\theta$ and $\sin\theta$ appropriate for each decay mode. For each measured decay rate we may then plot g^2 as a function of θ. Since $f(\theta)$ always has at least one zero it is more convenient to plot g^{-2} vs θ. Satisfactory agreement among members of a multiplet will be indicated by a common value of g and θ for all decay rates within that multiplet. We now proceed to investigate each multiplet in turn.

Four decay rates of N(1570) and Λ(1670) of the $1/2^-$ octet are plotted in Fig. 8. In order to extract a decay rate from the known excitation cross sections for the reactions, it has been assumed that each resonance decays predominantly into the indicated two channels. A satisfactory crossover of the four curves is found in the regions of $g^2 = 2$, $\theta = -30$ deg ($\alpha = 1.75$). Considering the uncertainty in the experimental data, the agreement is quite adequate. If one now introduces the presumed $\Sigma(1770) \to \Sigma\eta$ and $N\bar{K}$, it is found that the $\Sigma\eta$ decay mode fits well with the other four, while the partial width into $N\bar{K}$ is predicted to be much larger than would be expected on the basis of present experimental information. However, since so little is known about this state, it may well be more elastic and contain other decay modes. Even if we restrict consideration to N(1570) and Λ(1670), though, a serious disagreement results if we proceed with the above value of g^2 and θ to predict the partial width of the only remaining open channel, namely $\Lambda(1670) \to \Sigma\pi$. This gives 820 MeV, whereas the total width of the resonance is only 18 MeV! The disagreement here is at least two orders of magnitude, so cannot be dismissed as a consequence of symmetry breaking.

Figure 9 shows the corresponding plot for the decay rates of the $3/2^-$ octet. Here a large number of decay rates are known, so to avoid confusion we plot them on two separate plots, one for the π decay modes and the other for the K decay modes. The separation is made this way under the supposition that departures from SU(3) will quite possible be associated with the large K/π mass ratio. In fact, no systematic shifts of this nature are noted in these or subsequent figures. An effort is made in these figures to impart a feeling for the precision of the experimental partial width by the thickness of each line. A heavy line is known to perhaps 20%; a very light line may have an uncertainty in its ordinate of a factor of 2 or more.

Figure 9 shows a rather good crossover of five pionic rates at $g^2 = 0.8$, $\theta = 60$ deg ($\alpha = 0.4$). For these parameters the decay modes $\Sigma \to N\bar{K}$ and $\Lambda \to N\bar{K}$ are a factor of five too large and too small respectively, but the major discrepancy (of at least a factor of 50) lies in

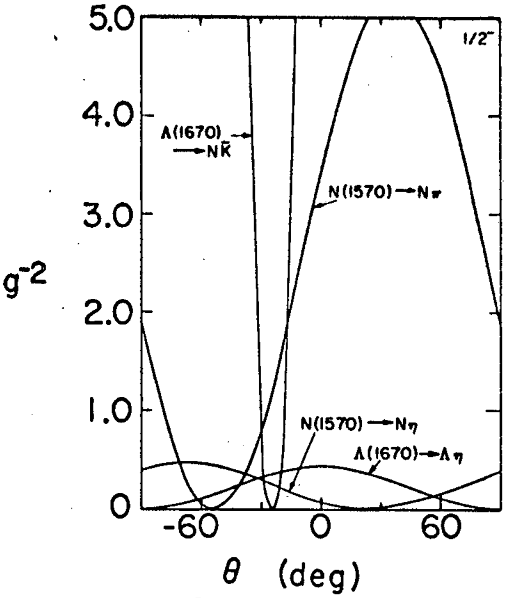

Fig. 8. Plot of g^{-2} vs mixing angle θ as given by Eq. 4 for the four reasonably well known partial widths in the $\frac{1}{2}^-$ octet. Satisfactory agreement is found for $g^2 = 2$, $\theta = -30$ deg.

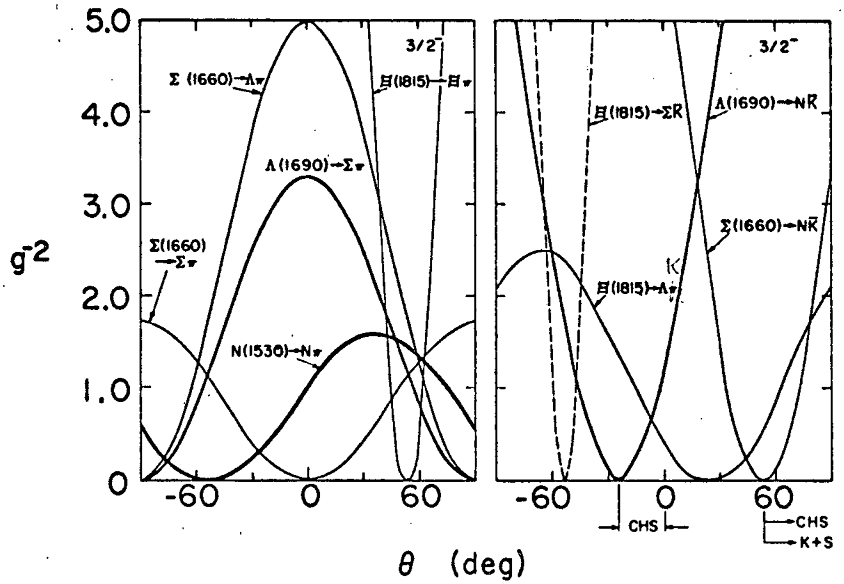

Fig. 9. Plot of g^{-2} vs mixing angle θ for nine partial widths of the $3/2^-$ octet. Heavy lines indicate well measured widths; light lines indicate that the width may be uncertain to a factor of 2. Dashed lines denote upper limits. Apart from $\Xi(1815) \to \Sigma\bar{K}$, satisfactory agreement is found for $g^2 = 0.8$, $\theta = 60$ deg.

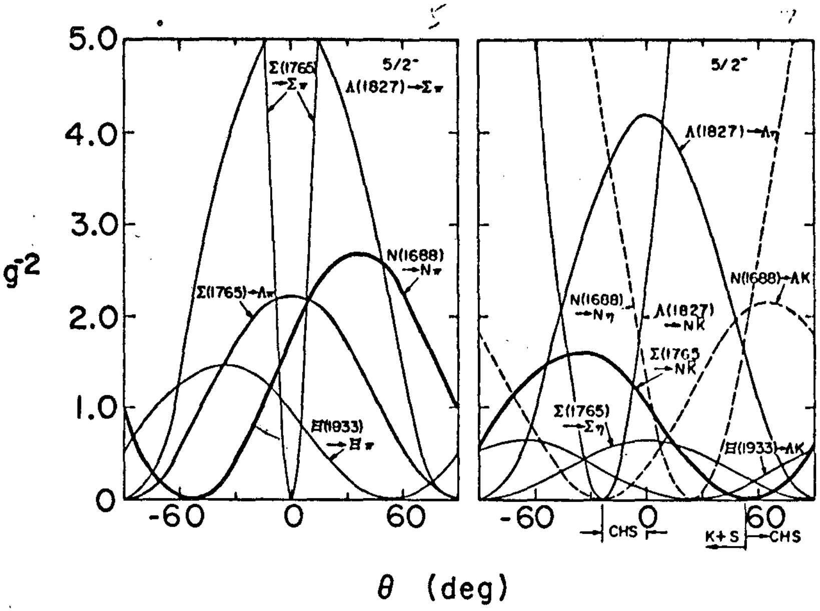

Fig. 10. As in Fig. 9 but for the $5/2^-$ octet. The upper limit on the rate $N(1688) \to \Lambda K$ is calculated from angular distribution coefficients supplied by J. Anderson and J. Doyle (private communication).

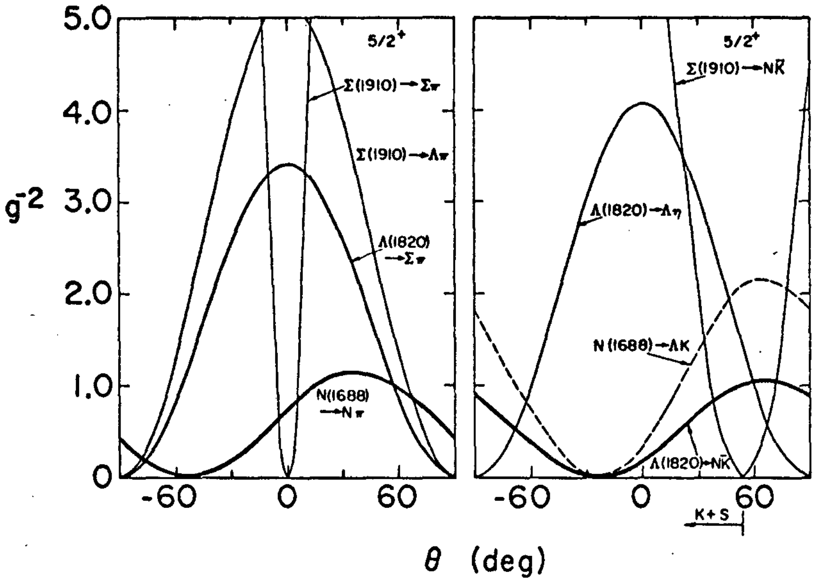

Fig. 11. As in Figs. 9 and 10 but for the $5/2^+$ octet.

the apparent complete absence of the $\Sigma\bar{K}$ decay mode. Within the framework of SU(3) this could have several explanations, none of which is particularly appealing:

(a) $\Xi(1815)$ could be a member of a 27, in which case the decay rates should be in the ratio $\Lambda\bar{K} : \Sigma\bar{K} : \Xi\pi = 9:1:1$. Experimental uncertainties could be stretched to satisfy these ratios. However, no clear example of a 27 has yet been seen.

(b) $\Xi(1815)$ could have some other spin-parity.

(c) Within the quark model it could be a member of the other predicted but unseen $3/2^-$ octet. Since $\Xi \rightarrow \Sigma\bar{K}$ has the same θ dependence as $N \rightarrow N\pi$ (they are both independent of α), the absence of $\Xi(1815) \rightarrow \Sigma\bar{K}$ would imply the existence of an N^* with virtually zero elasticity. Thus its nonappearance in detailed elastic scattering experiments would have a natural explanation. However, this same mixing angle would necessitate a highly elastic resonance $\Sigma \rightarrow N\bar{K}$. This should be easily found, but it has not yet revealed itself, so the puzzle remains.

Figure 10 shows the decay rates for the $5/2^-$ octet. A consistent picture can be had with $g^2 = 0.6$ and $\theta = 0$ deg ($\alpha = 1$) within the considerable uncertainty of some of the decay rates. Little is known about $\Xi(1933)$, but it also seems not to have a $\Sigma\bar{K}$ decay mode. Since its spin-parity has not been determined, there are many possibilities for it, but it would appear to be excluded from this $5/2^-$ octet on the lack of evidence for a $\Sigma\bar{K}$ decay mode.

The known decay rates into π, K, and η are collected for the $5/2^+$ octet in Fig. 11. Apart from $\Sigma(1910) \rightarrow \Sigma\pi$ there seems to be good agreement with $g^2 = 1$ and a mixing angle of about 60 deg. The measured[4] decay rate $\Sigma(1910) \rightarrow \Sigma\pi$ is only about 1/100 as large as expected, so again the proposed octet is untenable in this form. It is interesting to note that with a mixing angle of about 60 deg the elasticity of (1910) would be very low, so that it could well have gone undetected so far in scattering experiments. What is observed at 1910 MeV may be in another multiplet, not necessarily of this J^P, since the spin-parity assignment for this resonance is not firmly established.[10] If it is in another multiplet, then if $\Sigma(1910)$ of $J^P = 5/2^+$ is coupled strongly to K^*, it may show up only in production experiments at higher energy, where K^* exchange often seems to play an important role.

In conclusion, the experimental knowledge of baryon resonances acquired during the past several years has fitted rather well within the framework of SU(3). Despite the flexibility of the theory, the general agreement found among decay rates can no longer reasonably be regarded as fortuitous. However, there still remain a number of mysterious discrepancies far outside the range considered legitimate for departures from SU(3). Whether they are attributable to deficiencies in the theory or in our experimental knowledge remain to be seen.

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