KN AND $\bar{K}N$ INTERACTIONS*

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INTRODUCTION

The general topic under discussion is the strange particles and some of the resonances and interactions of strange particles that are particularly interesting. As is well-known, experimental developments are coming very fast in this field nowadays so there is some advantage in being located near an experimental centre, such as CERN, or near one of the United States experimental centres. However, those from more isolated places who are in this field should not be too discouraged. For one thing, having either been to the CERN conference or talked to many people who have, they are certainly not behind on experimental developments now. Also it is true that several of the very significant theoretical developments in this field have been suggested by experiments over a year old, so that it is not really necessary to be "on top of the new experimental data".

TABLE I

ESTABLISHED RESONANCE WITH S $\neq$ 0

B	S	I	Name	M	Γ	J
0	1	½	K^*	888	~50	?
1	-1	0	Y_0^*	1405	50?	?
1	-1	0	Y_0^{**}	1520	16	3/2
1	-1	0	Y_0^{***}	1815	-	?
1	-1	1	Y_1^*	1385	~50	3/2
1	-2	½	Ξ^*	~ 1535	(7 ~ 30)	?

Table I is a list I made of the well-established resonances of strangeness unequal to zero, and this paper will include all these resonances and will be divided into four parts:

* Text based on notes by E. Ferreira and G. Wolters.

(1) The spin and parities of the strange particles;
(2) The P-wave meson-baryon resonances and their significance;
(3) The S-wave meson-baryon interactions and their possible significance;
(4) The 1815 MeV resonance.

The fourth part is very short and is necessary because this resonance does not fit into what will be said in the first three points.

1. SPINS AND PARITIES OF THE STRANGE PARTICLES

The parity of the cascade particle is not yet known, but quite a bit happened last year about the parities of the Λ and Σ hyperons.

The usual convention a year ago (and even now) was to assign arbitrarily positive parity to the Λ particle, as to the nucleon, and then have the parities of K and Σ taken from the experiments. This was a natural convention when it was not known whether the neutral and charged K mesons were members of an isotopic spin doublet, having the same parities. It is now reasonably clear that isotopic spin is a good quantum number, that the K is a doublet, the Σ a triplet and so on. So, we adopt here the convention of calling K pseudoscalar and then determining the parities of the Λ and Σ particles from the experiments.

1.1. The Λ parity

Something new happened last year on the experimental side concerning the Λ parity, although the arguments involved are a couple of years old. When K^- is absorbed in helium, it can produce, among other things, the ${}_\Lambda He^4$ and ${}_\Lambda H^4$ hyperfragments:

$$K^- + He^4 \rightarrow {}_\Lambda He^4 + \pi^- \qquad (1)$$

$$\rightarrow {}_\Lambda H^4 + \pi^0 \qquad (2)$$

Since the spins of the K^-, He^4 and π are zero, if the spin J of the hyperfragment is also zero (we assume from charge symmetry that the spins of ${}_\Lambda H^4$ and ${}_\Lambda He^4$ are the same), the conservation of angular momentum implies conservation of orbital angular momentum. Hence if J=0 and parity is conserved, the very existence of the interaction implies that the Λ parity is even. This result is independent of the angular momentum ℓ of the state from which the capture takes place.

It is not known whether the ground state or an excited state of the hyperfragments is produced in reactions (1) or (2). If an excited state is produced, γ rays may be emitted before the decay of the hyperfragment takes place; however, the experimentalists have not yet looked carefully to see them. We can discuss our doubt about the spin of the states of the hyperfragments produced in the K^- capture by considering two possibilities, either of which would invalidate the argument for even Λ parity:

(a) The ground state is produced directly, and its spin is $J \neq 0$;

(b) The ground state may have spin J = 0, but what is actually produced is an excited state with J ≠ 0.

Most of the things that happened during the last year concern the spin of the ground state of the $_\Lambda He^4$ and $_\Lambda H^4$, and they show that most likely it is J = 0.

DALITZ and LIU [1], assuming that the mechanism of the pionic decay of $_\Lambda H^4$ is the same as that of the free Λ, computed the ratio:

$$R = [\,_\Lambda H^4 \to \pi^- + He^4]/[\,_\Lambda H^4 \to \text{all } \pi^- \text{ modes}]$$

(an example of one of the other modes is $_\Lambda H^4 \to \pi^- + p + H^3$). Calling J the spin of $_\Lambda H^4$, they found that

if J = 0, $R = 1.41|S|^2[1.84\,|S|^2 + 0.35|P|^2]^{-1}$

and

if J = 1, $R = 0.76|P|^2[0.43\,|S|^2 + 1.12|P|^2]^{-1}$,

where S and P are the magnitudes of the S and P-wave amplitudes for the $\Lambda \to \pi^- + p$ decay. The point then is to measure experimentally the ratio R and the ratio P/S and see which of these formulae fits better.

The ratio R has been measured by AMMAR et al. [2] in nuclear emulsions. They found R = 0.66 ± 0.06, a rather high value. Using the formulae above this implies that for J = 0 one should have $|P/S| \lesssim 1.5$, and for J = 1 there should be a large amount of P-waves, with $|P/S| \gtrsim 1.2$. A measurement of the polarization of the protons in the decay $\Lambda \to p + \pi^-$ may give information on the ratio P/S. The parameters that are usually referred to are

$$\alpha = \frac{2\,\mathrm{Re}\,(S^*p)}{|S|^2 + |P|^2}\,, \quad \beta = \frac{2\,\mathrm{Im}\,(S^*p)}{|S|^2 + |P|^2}\,, \quad \gamma = \frac{|S|^2 - |P|^2}{|S|^2 + |P|^2}\,.$$

By measuring the polarization of the emitted protons, BEALL et al. [3] have recently obtained

$$\alpha = -0.67 \pm 0.2\,, \quad \gamma = +0.74\,^{+0.13}_{-0.32}$$

By combining their results with those of Ammar et al. and taking as basis the calculations of Dalitz and Liu, they found that the assignment of J = 0 to the ground state of $_\Lambda H^4$ is strongly favoured.

Thus we can imagine that what happens is that the Λ decay goes essentially through S-waves and there is no need of spin flip in the $\Lambda \to p + \pi^-$ decay that occurs inside the hyperfragment, since both the initial $_\Lambda H^4$ and the residual H^4 have spin zero. The π^- just goes off in an S-wave. This simple mechanism is perhaps what makes the $_\Lambda H^4 \to He + \pi^-$ so predominant among the other modes of decay into π^-.

There is still another experiment that has been done concerning the determination of the spin of the $_\Lambda H^4$. BLOCK et al. [4] made the absorption of K^- at rest in helium and then looked at the angular distribution of the products of the two-body decay modes of ${}_{\Lambda}H^4$ with respect to the direction of the π^0 first produced (produced in the capture process):

$$K^- + He^4 \rightarrow {}_{\Lambda}H^4 + \pi^0$$
$$\hookrightarrow \begin{cases} He^4 + \pi^- \\ H^4 + \pi^0 \end{cases} .$$

Let us consider that the capture of K^- occurs from an S-wave (this will be discussed later). The spins and the total angular momentum in the left-hand side of the above reaction are all zero, so that if ${}_{\Lambda}H^4$ had spin 1, the π^0 and ${}_{\Lambda}H^4$ would have to be produced in a state of relative orbital angular momentum $\ell = 1$. If we quantize along the direction of the originally produced π^0, the z value of the ${}_{\Lambda}H^4$ spin must be zero. When the ${}_{\Lambda}H^4$ decays, the π^-(or π^0) and He^4 (or H^4) then produced, both having spin zero, would be in a state of relative orbital angular momentum 1, with component zero along the direction of the first π^0. The angular correlation between the π^0 produced in the capture and the π^- (or π^0) emitted in the decay would then be of the form $\cos^2 \theta$. Actually with about 50 events it seems that there is isotropy in the angular correlation. The statistical data are not overwhelming but do give some support to the assignment of spin zero to the ground state of ${}_{\Lambda}H^4$.

Let us now look at possibility (b) where the capture process may produce an excited state with quantum numbers that are not known and that cannot be studied by looking at the decays of the ground state. No theorist can tell whether excited states of these hyperfragments exist or not. If such an excited state exists, it is probably not very weakly bound since the hyperfragment formation probablilty here is above that expected from a binding energy of about 2 MeV (which is the binding energy in the ground state). Experimentalists will have to look for γ rays carefully to try to plug this loophole in the Λ parity argument; it seems probable, however, that the Λ parity is even.

Something should be said here about the orbital angular momentum state in the K^- capture, because this is important for several arguments to be made later. This will be based essentially on the theory of DAY et al. [5] which was produced three years ago and which was one of the major theoretical contributions to strange particle physics that particular year, even though it had little to do with the strong interactions. Only a very simple-minded explanation of the argument will be given here. This is one of those things that is very complicated in detail but very simple in effect. The question concerns, what happens to a K^- meson caught in a high coulomb orbit: what is the angular momentum of the state from which it is captured? Let us suppose the K^- meson is in an S-state orbit of some principal quantum number. We can ask the question of how long it will live before being captured. Knowing the probability for the K^- meson in such a coulomb orbit being found at the origin and also knowing the strength of the S-wave capture interaction from doing experiments on the capture of K^- in flight by nucleons, we can have an idea of the K^- lifetime in any S-wave orbit. We can also estimate the lifetime of the meson in a P-wave orbit. This is a rather rough estimate because, in the available data for K^- nucleon capture cross-section in flight, the P-wave contribution seems to come in very slowly, but an upper limit for the lifetime can be obtained. By doing this, we find that for a given principal quantum number the S-state lifetime is much shorter than the P-state lifetime. This is a result of the fact that the range of the strong interaction force responsible for the capture is much shorter than the radius of the coulomb orbit. In a P-state the probability of the K^- being within the force range is very small compared with that in the S-state. The ratio of the ranges essentially gets cubed in the expression for the rates of the processes, so that there is in fact a 10^5 or 10^6 difference, the S-wave being much more powerful in capturing the K^- meson than the P-wave. This might make one think immediately that the K^- is always captured in the S-wave, and that in fact would be the case, unless for some reason the P-states have a tremendous head start in the race to capture the K. What worried the physicists for quite a while was that the P-wave might have that head start, because it was believed that the mechanism necessary for the K^- to change from one coulomb orbit to another was simply radiative transitions. A particle reaches a P-state before an S-state by cascading down from a state of high ℓ value. It can also be argued that the P-state reached this way is almost always the 2P-state, and unfortunately the lifetime for radiative transition in this 2P-state is of the same order of magnitude as the lifetime for capture. What Day, Snow and Sucher did was simply to show that in a liquid the K^- molecules going near the electric fields of the other nuclei would be subject to a strong Stark effect, which causes transitions between the several ℓ-states. The mechanism of these transitions is quite complicated, but the essential point is that the transitions caused by this Stark effect occur in much shorter times than the lifetime for P-wave capture. Thus, even if a P-wave is reached first, it is most likely that there will soon be both P- and S-waves, and the natural power of capture from S-waves will assure that the capture will almost always be from an S-state. In detail this argument is certainly more valid for hydrogen (or deuterium) than for helium, but it is probably valid in all these cases.

1.2. The Σ-parity

There are no stationary states of total spin zero in which the Σ-hyperon is bound. Thus the method used in order to determine the Λ parity cannot be applied here. The reaction

$$K^- + p \rightarrow \Sigma + \pi \qquad (3)$$

is a simple as we can find to study the Σ [6] . The existence of the interaction does not indicate the Σ-parity because of the possibility of spin-flip.

It is well established that for K^- momentum (lab) < 250 MeV/c the angular distribution for all three final charge states in (3), as well as for the elastic and charge exchange process, are essentially isotropic[7] . However, at 400 MeV/c a strong forward-backward peaking is observed. We now know that these are the result of a J = 3/2 resonance (called the Y_0^{**}) [8] . However, we cannot distinguish among four possibilities from the angular distribution measurements in the resonance energy region. The resonance could be in any of the amplitudes $P_{3/2} \rightarrow P_{3/2}$, $D_{3/2} \rightarrow D_{3/2}$, $P_{3/2} \rightarrow D_{3/2}$ or $D_{3/2} \rightarrow P_{3/2}$, where the first symbol represents the K^--P state and the second symbol the π-Σ state.

The ambiguity is reduced to two-fold by the following argument. The large isotropic cross-section below 250 MeV/c follows the $^1/_v$ law and therefore must result from an S-wave of the $\bar{K}$- N system. The absence of odd terms in cos θ in the angular distribution anywhere in or below the resonance region then indicates that the resonance has the same parity as this low energy amplitude and must result fron a $\bar{K}$ -N D-wave. The two possibilities for the two important amplitudes are

$$\begin{array}{lcl} S_{1/2} \rightarrow S_{1/2} & & S_{1/2} \rightarrow P_{1/2} \\ & \text{or} & \\ \text{and } D_{3/2} \rightarrow D_{3/2} & & \text{and } D_{3/2} \rightarrow P_{3/2} \ . \end{array}$$

The angular dependence of the polarization in the $\Sigma^+ + \pi^-$ events, measured later, supports this assumption of two strong amplitudes of the same parity.

The remaining ambiguity is a generalization of the Minami-ambiguity for πN scattering. In this particular case it says that if the angular distribution and polarization data can be described in terms of the transitions,

$$\begin{array}{l} S_{1/2} \rightarrow S_{1/2} \\ D_{3/2} \rightarrow D_{3/2} \ , \end{array} \tag{4}$$

then an equivalent description can be obtained by replacing these amplitudes by the amplitudes,

$$\begin{array}{l} P^*_{1/2} \rightarrow P^*_{1/2} \\ P^*_{3/2} \rightarrow P^*_{3/2} \ , \end{array} \tag{5}$$

where the Σ-parity has now beenchanged. The asterisk indicates complex conjugate amplitudes. This ambiguity must be resolved if the Σ-parity is to be determined. A distinction between (4) and (5) is possible because the Wigner theorem [9] applied to the phase shift of a resonant state with narrow width has the form:

$$d\eta/dt > 0 . \tag{6}$$

The CM energy is called t.

If one also makes the reasonable assumption that the phase of the large non-resonant amplitude is changing less rapidly than that of the resonant amplitude, then the sign of the change in the relative phase is predicted, and this can be used to eliminate either possibility (4) or (5).

The radius of interaction must not be too large for (6) to be valid. As a consequence of the narrow width of ~ 16 MeV the upper bound is as much as 15 fermi.

One can prove (6) by considering the amplitude for (3) as an analytic function of t in the upper half plane of the complex energy plane. The pole, corresponding to the resonance, lies (in the unphysical sheet) just below the branch line in the t-plane which is along the real axis. (Causality forbids a pole above the branch line.) It is easy to see that a pole just below the real axis leads to a positive energy derivative of the phase, provided this pole is the dominant singularity.

If one wants to apply the Wigner theorem for the two possible cases (4) and (5), it is necessary to know something about the interference between the J = 1/2 and the J = 3/2 transitions in each case. This can be done by considering the polar-equatorial ratio:

$$\rho = (p - E)/(p + E) \ .$$

p and E stand for number of events, for which $|\cos\theta| > \frac{1}{2}$, resp. $< \frac{1}{2}$. Here θ is the polar angle in the CM system.

The measured values of ρ are as follows:

Energy (MeV)	370	390	410
ρ	0.36	0.50	0.36

for the $\Sigma^+ \pi^-$ events. This is very large. In fact even for a pure Y = 3/2 transition, ρ is only 0.375; and when one considers that the resonance bump here is smaller than the non- resonant background, one would expect a ρ of only about 0.15, if there is no interference. This suggests that the interference is very important in the resonance region. The interference term in the angular distribution is given by

$$(6\cos^2\theta - 2)\ f_{1/2}\, f_{3/2} \cos\eta \ . \qquad (7)$$

The magnitudes of the 1/2 and 3/2 amplitudes are represented by $f_{1/2}$ and $f_{3/2}$, whereas their relative phase equals η. From the large measured value of ρ one can conclude that

$$\cos\eta > 0 \qquad (8)$$

in the resonance region.

Finally, the Σ-polarization will also contain a term analogous to (7). This term is proportional to

$$\mp f_{1/2}\, f_{3/2} \sin\eta \ . \qquad (9)$$

This differs from (7) in that the angular dependence is left out here. It is not necessary to the argument, although it has to be taken into account in the experiment [10] . Moreover, a $\pm$ sign stands in front, which corresponds to the cases (4) and (5) respectively.

Assuming that the magnitudes f do not change rapidly with t near the resonance peak, the energy derivative of (7) is

$$\mp\ f_{1/2} f_{3/2} \cos \eta\ (d\eta/dt). \tag{10}$$

It can be seen by using (6), (8) and (10) that increase of (9) corresponds to odd Σ-parity, and decrease corresponds to even Σ-parity. One expects the polarization to change rapidly with t going through the resonance energy and this will enable one to distinguish experimentally whether (9) increases or decreases.

The experimental result is in agreement with even Σ-parity only [10] . Of course, the evidence obtained has still to be confirmed by independent determination of the Σ-parity. The experiment on the Σ^0 decay into Dalitz pair,

$$\Sigma^0 \rightarrow \Lambda^0 + e^+ + e^-,$$

seems to be the most promising attempt.

1.3. Ξ-spin

Several years ago the spins of the baryons N, Λ and Σ were all determined as 1/2; but only limited evidence exists for the spin of Ξ excluding spins $\geq 5/2$. SAMIOS et al. [11] and TICHO et al. [12] have studied the chain of reactions:

$$K^- + p \rightarrow \Xi^- + K + \pi, \tag{11}$$

$$K^- + p \rightarrow \Xi^0 + K + \pi, \tag{11a}$$

$$\Xi \rightarrow \Lambda + \pi, \tag{12}$$

$$\Lambda \rightarrow p + \pi^-. \tag{13}$$

The cascade particle will be polarized perpendicularly to the production plane. One can measure the up-down asymmetry in the decay process (13). This asymmetry will depend on the product of the parity-mixing parameters $\alpha_\Xi \cdot \alpha_\Lambda$. The results obtained are

$$\alpha_\Xi \cdot \alpha_\Lambda = \begin{cases} -0.63 \pm 0.20, & \text{SAMIOS et al. [11]} \\ -0.30 \pm 0.8\ , & \text{TICHO et al. [12]} \end{cases}$$

For Λ separately one has [3]

$$\alpha_\Lambda = 0.62 \pm 0.07.$$

This indicates that most probably the value of α_{Ξ} lies in between ~ -1 and ~ -0.4.

The test by LEE and YANG [13] can serve to eliminate values of the spin $J \geqslant 3/2$ only if the asymmetry $|\alpha \bar{p}|$, $\bar{p}$ = average polarization, is $> 1/3$.

As $\alpha \bar{p}$ in the case of optimal polarization ($\bar{p} = 1$) still may have a value $\sim 1/3$, it is not possible to exclude $J = 3/2$ on the basis of the present data. However, $J = 1/2$ seems to be more likely than $J = 3/2$.

2. THE P-WAVE INTERACTION

Let us now discuss the strong P-state interactions. I shall try to be objective about the experimental data, but the grouping together of certain resonances under the title of P-wave resonance is rather subjective. That is, not everything discussed here is necessarily a P-wave resonance, but it is hoped that there will be no difficulty in distinguishing the subjective statements from the others.

The first P-wave resonant interaction known was of course the 3-3 pion nucleon resonance. Global symmetry predicts two spin 3/2 pion-hyperon resonances, one with isotopic spin I = 1, the other with I = 2.

A pion-lambda resonance, which we are now calling Y_1^*, was discovered two years ago by ALSTON, GOOD, ALVAREZ et al. [14] and reported at the 1960 Rochester Conference [15]. Even though a lot of experimental work has already been done in studying this resonance, its parity and spin are not yet known. This is an example of all the pain and struggle that are sometimes necessary to determine whether a little number is 1/2 or 3/2. Alston et al. looked at the reaction

$$K^- + p \rightarrow \Lambda + \pi^+ + \pi^- \tag{14}$$

produced by a beam of 1.15 GeV/c K^- in a hydrogen bubble chamber and studied the energy distributions of the two pions in the K^-p centre-of-mass system. They found sharp peaks in these distributions and tried to interpret them in terms of the possible mechanisms of the reaction (14). They found that these peaks are those expected if first a two-body system is formed:

$$K^- + p \rightarrow Y_1^{*\pm} + \pi^{\mp}, \tag{14a}$$

where Y_1^* has a quasi-well defined mass of about 1385 MeV and decays into a lambda and a pion:

$$Y_1^{*\pm} \rightarrow \Lambda + \pi^{\pm} + 130 \text{ MeV}. \tag{14b}$$

The isotopic spin of the $Y_1^{*\pm}$ state is, of course, 1, since it decomposes into a Λ and a π. Then the question of determining the spin of this particle arose. The first problem was whether $J = 1/2$ or $J \geqslant 3/2$. Several kinds of anisotropies and angular correlations between the direction of production of the Y_1^* and the direction of emission of its decay could possibly be observed for $J \geqslant 3/2$, thus making a distinction between $J = 1/2$ and $J > 1/2$ possible. Thus, for spin $J = 3/2$ it is expected that the Λ's will have an angular distribution of the form $A + B \cos^2\eta$, where η is the angle between the direction of emission of the Λ and the normal to the plane in which Y_1^* and π are produced. Thus, the polar-to-equatorial ratio about the normal to the production plane may be different from 1 for $J \geqslant 3/2$ but must be equal to 1 for $J = 1/2$.

At that time, with limited statistics, Alston et al. thought they had seen a definite polar-to-equatorial ratio different from 1, thus giving an indication of spin 3/2 to the Y_1^*. But shortly after that, a lot of experiments were made applying several kinds of analysis of angular correlations, for example the famous ADAIR analysis [16], and they seem to have rather favoured spin 1/2. BLOCK [17] produced Y_1^* in He and also seemed to get arguments for spin 1/2. But then a few people began to point out that a lot of these experiments were not very significant. Particularly DALITZ and MILLER [18] showed that, because they neglected the effects of the symmetrization of the two pions to be introduced to account for Bose statistics, most of these experiments did not say anything about the spin of the Y_1^*. More recently in the last CERN Conference, Block presented new data, but still nothing conclusive could be extracted from them [4].

There is one experiment, however, which is fairly significant, though not conclusive. That is the experiment by ELY et al. [19], with 1.11 GeV/c K^- mesons in a propane bubble chamber. They looked at the distribution of the Λ's with respect to the normal to the production plane and found that the best fit for the law

$$1 + a \cos^2(\vec{\Lambda}, \vec{K} \times \vec{Y}_1^*)$$

is obtained with

$$a = 1.5 \pm 0.4 .$$

This result favours $J \geqslant 3/2$ but is not conclusive.

So it is still a matter of opinion what the Y_1^* spin is, but there is some evidence in favour of $J = 3/2$. One of the reasons why people tend to believe in this is that things are fitting together. For example, this fits our arguments that the Λ- and Σ-parities are probably positive, since in this case global symmetry predicts such a $J = 3/2$ resonance. Also, there is no longer any reason to expect that the resonance might be a $J = 1/2$ resonance of the Dalitz-Tuan type, since the most recent analysis of low energy $\bar{K}$-N data does not yield a solution consistent with such a resonance in the $I = 1$ state. This S-wave analysis will be discussed later.

The next resonance we shall discuss is one which has not been discovered, and thus it is not known if it exists or not. This is the isotopic spin 2, $P_{3/2}$, $\pi\Sigma$ resonance. This resonance is important because it is predicted by global symmetry.

There are some hints of the existence of this resonance which were reported about a year ago at the Aix-en-Provence Conference, but nothing has happened since then and it seems that nobody has really seen it. The

Alston group at Berkeley, who saw the Y_1^* resonance, has a large number of events of the type:

$$K^- + p \rightarrow \Sigma^+ + \pi^+ + \pi^- + \pi^-$$

and the same with all the charges in the final state reversed; the $I = 2, \pi\Sigma$ resonance could show up in the analysis of these events. Therefore it begins to appear that the thing may not exist, although we cannot be sure since we do not know what would be the cross-section for producing it in this particular process.

Now let us discuss one more resonance, the Ξ^*, $I = 1/2$ resonance. It is very subjective to group this together with the P 3/2 resonances, since its spin has not been measured.

This new resonance has been discovered by both TICHO et al.[12] and the Syracuse-Brookhaven collaboration group and reported at the last conference in CERN. The two groups found about the same mass of 1535 MeV (80 MeV above the $\pi\Xi$ threshold) but very different widths: Ticho et al. found 7 MeV and the other found 30 MeV. The surprising thing is that experiments seem to have indicated isotopic spin 1/2 for this resonance. Global symmetry believers again expected that there should appear an $I = 3/2$, $\pi\Xi$ resonance analogous to the πN one, because Ξ and N are both isotopic spin doublets.

Now, let us examine some numbers which were given by Samios at the CERN Conference. (The only reason for giving these numbers rather than those of Ticho et al. is that Samios talked first and the author was wide enough awake to write down his numbers.) They absorbed a beam of 2 GeV/c K^- mesons in a hydrogen bubble chamber, producing the reaction:

$$K^- + p \rightarrow \Xi + \pi + K.$$

They found by kinematic analysis of the final products that there should be an intermediate two-body system,

$$K^- + p \rightarrow \Xi^* + K,$$

with immediate decay of the Ξ^* into Ξ and π. They looked at the charge state $\Xi^{*0} + K^0$, measured the ratio,

$$R_1 = (\Xi^{0*} \rightarrow \Xi^- + \pi^+)/(\Xi^{0*} \rightarrow \Xi^0 + \pi^0),$$

and found 5/0. Then they looked at events producing the charge state $\Xi^{*-} + K^+$ and by observing the final products, they measured

$$R_2 = (\Xi^{*-} \to \Xi^0 + \pi^-)/(\Xi^{*-} \to \Xi^- + \pi^0) = 3/2.$$

By just writing Clebsch-Gordan coefficients, we find that, if the Ξ^* isotopic spin is $I = 1/2$, we obtain $R_1 = R_2 = 2$, and if $I = 3/2$, we obtain $R_1 = R_2 = 1/2$. The experimental results given above seem to indicate more the value 2 than the value 1/2. So we shall accept $I = 1/2$.

In the processes studied here there are only four possible charge states, two in the K^-p system and two in the Ξ^* K system, so that we can form only three independent ratios, the Ξ^{*-}/Ξ^{*0} ratio being independent of the two above. Now, if Ξ^* is an $I = 3/2$ object, then with the K produced it can form either isospin 2 or 1. If Ξ^* has $I = 1/2$, then the final state may have isotopic spin 1 or 0. But in the initial state we have 1 or 0, so that in the case of Ξ^* being isospin 3/2 the only possibility is that of total isotopic spin 1, and, since one has only one amplitude, the Ξ^{*-}/Ξ^{*0} ratio can be predicted under the conditions and turns out to be 1. The experimental value for this ratio is about 1. Of course no definite prediction can be made for the case of isotopic spin 1/2 assignment to Ξ^*, since then two amplitudes are involved. Thus this third ratio does not say anything.

Essentially, this is the evidence, which is meagre but supported by two independent groups, the evidence of Ticho et al. being similar to the above except they have more events. Very little can be said about the spin. Samios has reported that by measuring the polar-to-equatorial ratio with respect to the normal to the production plane of the final Ξ's, they found $P/E = 15/5$, which is still meagre evidence in favour of spin 3/2.

We group this resonance together with the P 3/2 resonances only because experiments slightly suggest it and because nobody has a theory which predicts an S-wave $\pi\Xi$ resonance. There might be something like a Dalitz-Tuan type resonance, but in this case the resonance energy is quite a way below the K_1 threshold, so that it looks as if this cannot be so. It has also been suggested that this might be the second $\pi\Xi$ resonance and not the first one. But it seems probable that, if this is the second resonance, the first one should have been seen in the same experiment. So we shall group the Ξ^* with the P 3/2 resonances just because this is how some people have expected it to be. This resonance seems to fit into a multiplet which is predicted by the ten-fold representation of the unitary symmetry.

Let us now very briefly examine the significance of this and in order to understand these things it is very important to know about both dispersion relations and group theory. Even if one prefers the former, something should be known about the latter. If one predicts something by group theory, a knowledge of dispersion relations - though maybe not much more than Chew-Low equations- is essential to check the prediction by experiments, because means of this some relations between widths of resonances and coupling constants, and so forth can be obtained. One can see from unitary symmetry that the π is analogous to the K's and the η, but they have quite different masses and this makes quite a difference; and these differences can best be seen when poles and dispersion relations are written down. Also if the reason for these mass differences is not known, the coupling constants, for the η

let us say, cannot really be known by comparison with the coupling constants for the π and K. This must be seen from the data.

On the other hand, if one has to operate with dispersion relations, there are certainly advantages in knowing in what symmetries to believe. For instance, consider the problem of the πN resonances as it was first discussed by Chew and Low. They could write down a dispersion equation and solve it essentially by the N/D method. They could not predict the position of the resonance, since it depended upon the radius of arbitrary cut-off they put in. But knowing the position, they could predict the width in terms of the coupling constant. This method was improved by Frautschi and Walecka, who made it relativistic and at the same time put in some other forces. By making it relativistic, they did not have to use an arbitrary cut-off, but one can see that the convergence obtained came about at energies in the integral of the order of the nucleon mass, so that essentially in an attempt to predict the position of the resonance, forces coming in at higher energies, i.e. in terms of configuration space forces of short range, are important and nobody knows what the short range forces are. This is very physical of course. It is well known that both long-range and short-range forces are important for determing whether particles are bound or where a resonance is. But something that has to do more with the details of the shape, like the width, may depend more particularly on the long-range forces, i.e. on the close singularities in the energy plane. So one cannot really predict the resonance position. On the other hand, people who write down formulae in group theory write down these magic mass formulae and say at what masses they expect resonances to exist, so it is worthwhile asking if there is any sense in these formulae, which there should seem to be. If only one resonance is being discussed, merely guessing about the high-energy region is a little wild, although it may be worthwhile. But if one has two resonances which belong to the same symmetry multiplet, it might be a little more reasonable to assume that the high-energy contributions might be the same for both. One might complain about this and point out that the long-range forces are very different for different members of the same symmetry multiplet, because π and η and so forth have different masses, but it could be that the short-range forces being made of many different contributions might be the same, or nearly the same. In trying to predict the position of the things, it might be that much can be learnt by comparing the different resonances which are at the same symmetry multiplet.

Here are a few speculative remarks about the forces that might be important in predicting the P-wave resonances. People like to believe that in the πN resonance the π poles which are close act as the main forces that produce the resonance. This is a hope, made because things are simpler if it is true than if it is not true.

Let us suppose then that it is true that in this whole family of resonances the poles which are caused by the interchange of the pseudoscalar mesons (π, K, η) are the main forces which cause the resonances. What can we learn from this? Which resonances exist, and which do not exist? We shall be concerned with the $J = 3/2$ resonances only because they seem to be the most important ones.

Let us write the simplest diagrams, as in Fig. 1, making the static approximation. If we do not worry about isotopic spin factors and the signs they introduce, a diagram like that in Fig. 1a, with intermediate state of

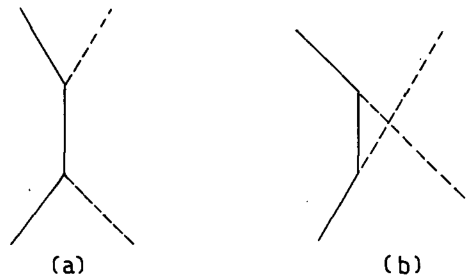

Fig. 1

less energy than the initial state, gives rise to a repulsive force; and a diagram as in Fig. 1b, with intermediate state with higher energy, contributes an attractive force. Both these diagrams contribute to a $J = 1/2$ amplitude. But for a $J = 3/2$ amplitude only the attractive graph exists. When we include the isospin factors, Fig. 1(b) may not always be attractive; but it is still true that the $J = 3/2$ is the most attractive in general.

Now let us look at some states that can be produced by some pairs of particles. Let us first consider those with hypercharge 2, which can be produced by a KN system. We know that in the K^+p system, which is a pure $I = 1$ state, no P-wave resonance occurs. Let us see what the pole terms would be, that is, what we would expect to come from diagrams of the above type. For the $I = 1$ state, neglecting mass factors and the $\Lambda\Sigma$ mass difference (because we do not know how big the coupling constants are anyway), the residue is proportional to

$$\tfrac{2}{3}\,(G^2_{K\Sigma N} + G^2_{K\Lambda N}).$$

This gives an attractive force, but we know from experiment that it is not strong enough to produce a resonance.

Now let us look at the $Y = -2$ states, which can be created by the $\bar{K}\Xi$ system. A resonance is predicted for $I = 0$ by unitary symmetry. In this state the residue of the pole is proportional to

$$\tfrac{2}{3}\,(3\,G^2_{K\Xi\Sigma} - G^2_{K\Xi\Lambda}).$$

This is of particular interest because, if this pole term is strong enough to produce a resonance, this might be an evidence for a strong K meson interaction. Till now there has been no indication that the pseudoscalar K-meson baryon interactions are strong, and this would be the first evidence of it.

Now, if we look at the other states, we run into the difficulty that we may have many pairs of particles that can produce them and so many channels open. For example, for hypercharge Y = -1, we have the following systems: $\pi\Xi$, $\bar{K}\Sigma$, $\bar{K}\Lambda$, $\eta\Xi$. In these cases the correspondence between poles and graphs is not so simple. If we use some N/D many-channel dispersion relation, we get a denominator that starts out with 1, includes terms that are quadratic in the coupling constants and have an energy dependence of the form $(W - W_0)$, and then follow terms which are of the fourth order in the coupling constants, and so forth. If there is only one channel open, then there are only the terms that are quadratic in the coupling constants. Where the denominator is zero we say that we have a resonance. The quadratic terms are what we have when we look at the elastic scattering diagrams separately, not worrying about their being coupled. To get an idea of what could happen, let us assume that a resonance can occur only if one of the elastic scattering diagrams is strongly attractive. This does not mean that the resonance would have to show up only in that particular state, since the states are all coupled. In other words, what we want to assume is that we need to have a strongly attractive term in one of the elastic diagrams to obtain a resonance in one or more of the coupled states.

Now for the Y = -1 systems in the I = 1/2 (the state of the recently discovered Ξ^*) state we have the following factors in the lowest order elastic diagrams:

$$\pi\Xi \quad : \quad -(2/3)\ G^2_{\Xi\Xi\pi} \ ,$$

$$\bar{K}\Sigma \quad : \quad -(2/3)\ G^2_{N\Sigma K} \ ,$$

$$\bar{K}\Lambda \quad : \quad (2/3)\ G^2_{N\Lambda K} \ ,$$

$$\eta\,\Xi \quad : \quad (2/3)\ G^2_{\eta\Xi\Xi} \ .$$

The first term, being strongly negative, is not able to produce a resonance in our model. The $K\Sigma N$ and the $K\Lambda N$ interactions were not strong enough to produce a resonance in the Y = +2 states, and so we may assume that they are not strong enough here either, although we have to admit that the poles are a little closer to the physical region here.

In the $\eta\Xi\Xi$ interaction we have the sign and perhaps the strength to produce a resonance. If this resonance occurs at an energy below $\bar{K}\Lambda$, $\bar{K}\Sigma$ and $\eta\Xi$ thresholds, it will decay into the only open channel, $\pi\Xi$.

Now let us look at the Y = 0 states. There we have, for I = 2, only the $\pi\Sigma$ channel, with a factor $\frac{2}{3}\,(G^2_{\pi\Lambda\Sigma} + G^2_{\pi\Sigma\Sigma})$. Since this is attractive, there arises the same question we had in the I = 1 state of the KN system: why is there no resonance? Perhaps, again, the coupling constants are not strong enough.

For I = 1, we have

$$\pi\Sigma \quad : (2/3)\,(G^2_{\pi\Sigma\Sigma} - G^2_{\pi\Lambda\Sigma}),$$

$$\pi\Lambda \quad : (2/3)\ G^2_{\pi\Lambda\Sigma} \ ,$$

$$\bar{K}N,\ K\Xi \ :\ 0\ ,$$

$$\eta\Sigma \ :\ (2/3)\, G^2_{\eta\Sigma\Sigma}\ .$$

Here the $\eta\Sigma$ interaction might well be partly responsible for the appearance of a resonance in one of the above states. Hence strong η interactions are one possible explanation for the fact that a Y_1^* exists, while a Y_2^* does not seem to exist.

Thus in the future, with more and more data coming in, we shall perhaps have to start being worried with the η and K interactions. Particularly, we shall perhaps have to see whether they are coupled to resonances that may be found in future experiments.

Let us look at one more argument. If the $\pi\Lambda\Sigma$ coupling is strong enough to produce a resonance, what happens to the analysis of the Λ-nucleon forces? De Swart and Iddings have analysed the ΛN interaction in terms of a few simple diagrams, and from that they constructed a potential to describe the ΛN interaction. From a comparison of these results with a potential obtained from hyperfragment data they conclude that the strength of the $\pi\Lambda\Sigma$ coupling is of the order of the πNN coupling:

$$f^2_{\pi\Lambda\Sigma} \approx 0.08\ .$$

A rough argument for remembering this result is the following: We know that the Λ in a hypernucleus is bound less deeply than a nucleon in a normal nucleus. But this does not mean a large difference in potentials because, in a three-body nucleus, a reduction of the depth of the potential by a factor of two causes the nucleons to fly apart, the binding energy being so small. And in fact the hyperfragment data indicate that the Λ-N potential is about 2/3 as strong as the N-N potential. On the other hand, the Λ does not have the one-pion-exchange diagram. If we take out the one-pion-exchange term in the nucleon force, the depth of the potential is reduced by about 1/3 (this really depends on the spin state; in the deuteron this number is about true). So here in the Λ-N case, as there is no one-pion-exchange and the potential depth is just about 2/3 of the nuclear potential, we may have the other things about equal, which implies $f^2_{\pi\Lambda\Sigma} \approx f^2_{\pi NN}$. But if this is so, why does no resonance occur? Maybe it is because $G_{\pi\Sigma\Sigma}$ is small, because the resonances are produced by other singularities, because this analysis is wrong or because η and K's are important in the Λ nucleon potential too.

3. THE S-WAVE INTERACTIONS

The strangeness +1 system will be first considered: the K^+p interaction in the pure T = 1 state. No P-wave resonances are present; in fact the elastic cross-section is isotropic to 640 MeV/c K^+ momentum. Some new data have recently emerged. GOLDHABER, GOLDHABER et al. [20] have made an analysis for scattering length. From data, for momenta up to 355 MeV/c, they get

$$a_1 = -0.29 \pm 0.2 \text{ fermi}.$$

The effective range could not be measured very well, and the result obtained was

$$r_1 = 0.6 \pm 0.6 \text{ fermi}.$$

The entire momentum range up to 640 MeV/c yields

$$a_1 = -0.29 \pm 0.2 \text{ fermi}$$

and

$$r_1 = 0.5 \pm 0.15 \text{ fermi}.$$

The phase shift η_1 goes up to -36°. This is just what is expected from a repulsive core interaction.

The T = 0 interaction for the strangeness +1 system cannot be measured as simply as the T = 1 interaction. All that is known is that it is very much weaker than the T = 1 interaction, and probably one has for the scattering length

$$a_0 < 0.10 \text{ fermi}.$$

There has been a hint from optical model analysis that there might be some P-wave interaction here. Also the Ticho group has found some indication that the P-wave might be as important as the S-wave for T = 0, but the strength of the P-wave effect is not known. Anyway, in the T = 1 channel there certainly is not appreciable P-wave interaction.

Next we will discuss the strangeness -1 $\bar{K}$N system. Large S-wave interaction was observed in meson-baryon systems for the first time in this system.

One can associate a resonance with the large S-wave $\bar{K}$N interaction, as first suggested by DALITZ and TUAN [21], and at the moment the only resonance one can think of in this connection is Y_0^* at 1405 MeV and width ~ 50 MeV. However, till now there is really no strong evidence that spin Y_0^* = 1/2. ALEXANDER et al. [22] have observed that the resonance peak is cut off more abruptly at the high-energy side than at the low-energy side, and this must be expected for a Dalitz-Tuan type of resonance not far below threshold. But as this data is sparse, this effect cannot be considered as strong evidence. The main reason why the Y_0^*-spin is thought to be 1/2 is that this fits with other experimental evidence on the $\bar{K}$N system, as will be explained shortly. However, there is at least one argument in favour of the assignment $P_{3/2}$ to the Y_0^*. That is, assuming that pion couplings are predominant in pion-hyperon interactions, one mechanism that might explain why the Y_1^* at 1385 MeV disintegrates almost completely in $\Lambda + \pi$ (the ratio $\Sigma\pi/\Lambda\pi$ is less than 3%) is that $f^2_{\pi\Lambda\Sigma} \gg f^2_{\pi\Sigma\Sigma}$. The residue of the Chew-Low pole term for T = 0, $\pi\Sigma$ scattering in the P 3/2 state, is essentially

$$\tfrac{2}{3}\,(f^2_{\pi\Lambda\Sigma} - 2 f^2_{\pi\Sigma\Sigma}).$$

Clearly, if $f^2_{\pi\Lambda\Sigma} \gg f^2_{\pi\Sigma\Sigma}$, this would give attractive interaction in the $P_{3/2}$ state, and a resonance Y_0^* is therefore expected in the $P_{3/2}$ state.

Recently some progress in understanding the S-wave interaction has been made. But before describing it let me review a little. We consider the absorption processes:

$$K^- + p \rightarrow \Sigma^+ + \pi^- , \tag{15}$$

$$K^- + p \rightarrow \Sigma^0 + \pi^0 , \tag{16}$$

$$K^- + p \rightarrow \Sigma^- + \pi^+ , \tag{17}$$

which can be described in terms of two amplitudes for isospin 0 and 1: T_0 and T_1 respectively.

At threshold, experimental data give $|T_0| \gg |T_1|$ and the relative phase $\phi_r = \phi_0 - \phi_1$ between these amplitudes can be determined in magnitude:

$$\phi_r = \pm 60^\circ. \tag{18}$$

At 175 MeV/c K^- momentum (lab), one finds about equal cross-sections for (15) and (17). Thus at this momentum the interference term between T_0 and T_1 vanishes, and therefore

$$\phi_r = \pm 90^\circ. \tag{19}$$

One expects that the positive phases at threshold and at 175 MeV/c belong together and similarly the negative phases, because the phase should not change too rapidly. In order to get information about ϕ_r at an intermediary energy the $\overline{K}^0 n$ system is considered. The threshold is here 5.3 MeV higher. The $\overline{K}^0 n$ - $K^- p$ mass difference causes a cusp, as can be deduced using the Dalitz-Tuan zero range approximation [22]. Because the T = 0 absorption is much bigger than the T = 1 absorption, one finds that the phase ϕ_r must increase between the $\overline{K}p$ and $\overline{K}^0 n$ thresholds. So one has at least the two sets of phases:

$\overline{K}$ p threshold	$\overline{K}^0$n threshold	175 MeV/c
60°	~ 80°	90°
- 60°	~ - 50°	-90°

Several years ago it was observed that K^- capture on deuterium gives the value of ϕ_r below threshold [21]. Assuming that the K^- is caught from an S atomic state, in accordance with the Day, Snow, Sucher argument, it was deduced from equal Σ^+ and Σ^- ratios in

$$K^- + d \rightarrow \Sigma^+ + \pi^- + n ,$$

$$K^- + d \rightarrow \Sigma^- + \pi^+ + n$$

that $\phi_r = \pm 90°$ at $E \sim -10$ MeV (below K^-p threshold). The $\Sigma + \pi$ energy in the deuterium experiment is that much below the hydrogen experiment because of the deuterium binding energy and the energies of recoil of the neutron and the $\Sigma + \pi$ pair. It was assumed in [23] that a strong dependence on the $\Sigma + \pi$ energy was responsible for the difference in the H and D experiments.

Now, in the zero range approximation, one cannot have ϕ_r first decreasing and then increasing around threshold. This therefore rules the positive set of phases out.

However, the fact that ϕ_r changes so rapidly below the $\bar{K}p$ threshold suggests a resonance Y_0^*. In fact the Y_0^* was predicted in this way [23].

Additional information has been obtained recently [24]. The Σ^+ and Σ^- ratios for the Y_0^{**} are such as to give $\phi_r = \pm 110°$. The sign can be obtained by studying the interference between the S-waves and the resonating $D\frac{3}{2}$ wave amplitude. The conclusion is that $\phi_r = -110°$ there, strongly suggesting the negative sign at lower energies as well. It is notices that this also indirectly supports the point of view that Y_0^* is an S-wave resonance.

Last year Humphrey and Ross determined two solutions in a zero-range approximation for low energy $\bar{K}N$ interaction. The solutions I and II correspond to the mentioned two possibilities of sign of ϕ_r.

One has complex scattering length in this analysis because there is absorption into the $\Sigma\pi$ channels, even at threshold $A = a + ib$. All the amplitudes have the energy-dependent factor $1/(1-ikA)$ above threshold.

Below threshold one has to replace k by $+i|k|$. If $a < 0$, then one might have a pole below threshold in the lower half plane which corresponds to a bound state of the $\bar{K}N$ system. If there were no connection with the $\Sigma\pi$ channel, $b = 0$, which then gives a bound state pole.

Solution I seems to be ruled out, because for this solution $a_0 \approx a_1 \approx 0$. So again this confirms $\phi_r < 0$. Solution II reads as follows:

$$a_0 \approx -0.6 \text{ fermi} ,$$

$$a_1 \approx 1.2 \text{ fermi} .$$

This is the most acceptable solution. However, the negative value of a_0 is not too well determined. It depends on the assumption that the effective range is very small. It may be that $a_0 \approx -1.2$ f, as predicted by Schult and Capps. A large negative a_0 can give a resonance of the Dalitz-Tuan type, and this may be the Y_0^*.

The nature of the forces leading to S-wave resonances is not too well understood. There is one model which tends to predict the signs of things correctly. This model, based on the exchange of vector mesons ρ and ω, has been discussed by Sakurai.

If the model is correct, the fact that the $\overline{K}N$ system is coupled to the $\Sigma\pi$ system suggests that the graph in Fig. 2 is important where the intermediate line is a vector meson of strangeness 1 or -1. It would be hard to apply

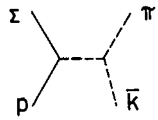

Fig. 2

the model if one only had zero strangeness vector mesons. Some years ago the Alston, Ticho group discovered the π-K resonance K^*. However, its spin is not, yet known, so we shall now discuss the evidence for the spin of K^*.

Two kinds of measurements have been done on the K^* spin, and the results were presented at the CERN Conference, 1962. The Ticho group studied the processes

$$K^- + p \to K^* + p$$

$$K^* \to K + \pi$$

by looking for any sort of asymmetry in the K^* decay. If spin $K^* = 0$, no asymmetry can occur, but asymmetry can exist for spin 1. No asymmetry was found.

The second measurement is the experiment on $\bar{p}p$ annihilation by Armenteros et al. at CERN. The analysis requires knowledge of the orbital state from which $\bar{p}$ is caught. If the Day, Snow and Sucher argument applied, this would be an S-state. There is, however, a better argument in favour of an S-state. Consider the process $\bar{p} + p \to K^0 + \overline{K}^0$. The K^0 and $\overline{K}^0$ being mixtures of the eigenstates K_1^0 and K_2^0 of Cp, one expects to see the decay modes of the following combinations:

$$K_1^0 \quad K_1^0 \tag{20}$$

$$K_2^0 \quad K_2^0 \tag{21}$$

$$K_1^0 \quad K_2^0 \tag{22}$$

Suppose the initial state is an S-state. Because $\bar{p}$ and p have opposite parities whereas K^0 and $\overline{K}^0$ have the same parity, the final state has odd orbital angular momentum. It has to be a p-state, and the initial state is $^3S_1$. This state is odd under charge conjugation. Because in the final state only K_1^0 K_2^0 is odd under C, only the decay modes of (22) should occur. The experiment gives

$$(20) : (22) = 0 : 54$$

The Padua group has seen one event.

If the initial state is a P-state, one finds in a similar way that type (1) is allowed. The experiment therefore gives strong evidence for annihilation in an S-state.

Before a discussion of the measurement on the K^* spin, it is noticed that the experimental result excluding (20) and (21) seems to contradict the Sakata model. In this model K^0 and $\bar{K}^0$ are composite particles ($N\bar{\Lambda}$) and ($\bar{N}\Lambda$) respectively. As p, n and Λ form the basic triplet of the model, there is symmetry for interchange of neutron and Λ and hence of K^0 and $\bar{K}^0$. In particular the amplitude for the process, in which K^0 moves in a given direction, is equal to the amplitude for $\bar{K}^0$ going the same way. This is not the case if the final state is a P-state.

After having determined that the $\bar{p}$ + p capture occurs in the S-state, Armenteros et al. complete the argument about the K^* spin in the following way: They look at the following type events:

$$\bar{p} + p \rightarrow K_1^0 + K_0^* \text{ and}$$
$$\rightarrow K_1^0 + \bar{K}_0^*.$$

They detect these events from the $\pi^+ + \pi^-$ decay of the K_1^0 and consider even events where the K_1^0 energy corresponds to K^* formation. Let us assume now that the K^* spin (and $\bar{K}^*$ spin) is 0. Since the K^* decays into a π + K, and the π is pseudoscalar, the K^* must then have the opposite parity from the K, so the intrinsic parities of $\bar{p}$ + p and $\bar{K} + K^*$ (or K + $\bar{K}^*$) are equal. Hence the K + $\bar{K}^*$ must occur in the S-states, and angular momentum conservation implies that the initial state is a singlet, i.e. $^1S_0$.

The $^1S_0$ state is even under charge conjugation so the final state must also be even under charge conjugation. This, together with the fact that the observed K produced with the K^* is a K_1^0, implies that the neutral decay mode of the K^*(or $\bar{K}^*$) must be $K_1^0 + \pi^0$. No $K_2^0 + \pi^0$ is allowed. Armenteros et al. measure the ratio,

$$R = \frac{K_1^0 + [K_1(\text{visible}) + \pi^0]}{K_1^0 + [K(\text{invisible}) + \pi^0]} ,$$

where the K in the square brackets is the K from the K^* decay. A K_2^0 will live so long as to be invisible and the $\pi^0 + \pi^0$ decay mode of the K_1^0 will be invisible. Now, if $J(K^*) = 0$, the K of the K^* decay is always the K_1^0; this ratio will be simply the ratio of the $(\pi^+ + \pi^-)/(\pi^0 + \pi^0)$ decay rates of the K_1^0, i.e. 2. R cannot be measured exactly by experiment because of the difficulty of separating K^* events from the non-resonant background, but the data (with limited statistics) clearly shows that R is appreciably less than one. Hence, it is reasoned, the $J(K^*) = 0$ assignment must be wrong.

This measurement is, of course, a long way from conclusive; and since the California data favours $J(K^*) = 0$, we must conclude that the spin of the K^* is not yet known.

4. THE 1815 MeV RESONANCE

The 1815 resonance has baryon number one and strangeness -1 and lies above the $\bar{K}$ + N threshold, so it may be produced without accompanying particles in interactions such as $\bar{K} + N \rightarrow \bar{K} + N$ and $\bar{K} + N \rightarrow \pi + \Sigma$ [25]. The I-spin of this resonance was previously known to be zero. Keefe et al. examined angular distribution in the resonance region carefully and concluded that, if waves of $J \geqslant 7/2$ can be neglected, the resonance must have angular momentum 5/2. Perhaps this resonance is part of a family that includes the F 5/2 π-N resonance.

In conclusion, three of the most interesting questions about strange particle physics will be repeated since much theoretical and experimental work should be done on these questions in the next few years:

(1) Is the exchange of vector mesons the source of the large S-wave meson-baryon interactions? If not, what is?

(2) Are the pseudoscalar η-baryon interactions strong and is the η a brother to the pion in some symmetry scheme such as the unitarity-symmetry?

(3) Are the pseudoscalar K-meson baryon interactions strong? The fact that certain processes involving K mesons are strong clearly shows that some K meson interactions are strong, but there is still no very good evidence that the pseudoscalar K baryon interactions are large at all. They may be nearly zero. According to unitary symmetry, of course, they are large.

As has been demonstrated, it would seem that the Σ and Λ parities are even. In any case it is clear that the rapid development of strange particle physics is not going to slow down in the next year or two.

REFERENCES

[1] DALITZ, R. H. and LIU, L., Phys. Rev. 116 (1959) 1312.
[2] AMMAR, R. G. et al., Nuovo Cim. 19 (1961) 20.
[3] BEALL, E. F., CORK, B., KEEFE, D., MURPHY, P. G. and WENZEL, W. A., Phys. Rev. Letters 8 (1962) 75.
[4] BLOCK, M. M. et al., Proc. Conf. on High Energy Physics, CERN (1962).
[5] DAY, T. B., SNOW, G. A. and SUCHER, J., Phys. Rev. Letters 3 (1959) 61.
[6] CAPPS, R. H., Phys. Rev. Letters 6 (1961) 375; Phys. Rev. 126 (1962) 1574.
[7] ALVAREZ, L. W., Ninth Int. Conf. on High Energy Physics, Kiev (1959).
[8] FERRO-LUZZI, M., TRIPP, R. D. and WATSON, M. B., Phys. Rev. Letters 8 (1962) 28.
[9] WIGNER, E. P., Phys. Rev. 98 (1955) 145.
[10] TRIPP, R. D., WATSON, M. B. and FERRO-LUZZI, M., Phys. Rev. Letters 8 (1962) 175.
[11] SAMIOS et al., Proc. Conf. on High Energy Physics, CERN (1962).
[12] TICHO, H. K. et al., Proc. Conf. on High Energy Physics, CERN (1962).
[13] LEE, T. D. and YANG, C. N., Phys. Rev. 109 (1958) 1755.
[14] ALSTON, M. et al., Phys. Rev. Letters 5 (1960) 520.
[15] Ibid., Preliminary rpt in Proc. Int. Conf. on High Energy Physics, Rochester (1960) 445.
[16] ADAIR, R. K., Phys. Rev. 100 (1955) 1540.
[17] BLOCK, M. M. et al., Nuovo Cim. 20 (1961) 724.
[18] DALITZ, R. H. and MILLER, D. H., Phys. Rev. Letters 6 (1961) 562.
[19] ELY, R. P. et al., Phys. Rev. Letters 7 (1961) 461.

[20] GOLDHABER, GOLDHABER et al., Proc. Conf. on High Energy Physics, CERN (1962).
[21] DALITZ, R.H. and TUAN, S.F., Ann. Phys. 8 (1959) 100; 10 (1960) 307; Phys. Rev. Letters 2 (1959) 425.
[22] ALEXANDER, G. et al., Phys. Rev. Letter 8 (1962) 447.
[23] SCHULT, R.L. and CAPPS, R.H., Phys. Rev. 122 (1961) 1659; Nuovo Cim. 23 (1962) 416.
[24] AKIBA, T. and CAPPS, R.H., Phys. Rev. Letters 8 (1962) 457.
[25] KEEFE, D. et al., Proc. Conf. on High Energy Physics, CERN (1962).