VIII. Saturday Morning: <u>Theoretical Interpretation of New Particles</u>,

J. R. Oppenheimer presiding.

The chairman opened the session with a few general remarks. The first report of the session, by Yang, was to be a summary of the theories of new particles. These have been discussed at all of the recent Rochester conferences. Our first and major puzzle was to reconcile copious production of strange particles with slow and rather peculiar decay. This problem has reached a temporary kind of solution in the theory of strangeness. Perhaps, using an analogy, one may say that we are at a stage corresponding to the finding of the duplexity of atomic spectra, but not yet at the point of the discovery of electron spin, and certainly not at the stage of Dirac's theory of the electron. There are then two branches of new particle theory that have a certain amount of activity. One attempts to understand the theory of strangeness, a little less abruptly than by just writing it down. The papers of Markov and d'Espagnat are concerned with this problem. The other attempts to look at the pattern of slow reactions (the decays). There are the five objects $K_{\pi 3}$, $K_{\pi 2}$, $K_{\mu 2}$, $K_{\mu 3}$, K_{e3}. They have equal, or nearly equal, masses, and identical, or apparently identical, lifetimes. One tries to discover whether in fact one is dealing with five, four, three, two, or one particle. Difficult problems arise no matter what assumption is made. It is to this problem of the identity of the K particles that a larger part of the present section is devoted.

<u>YANG'S</u> introductory talk followed: "After being introduced to the (subnuclear) zoo last Wednesday (Ed: in a public lecture by Dr. Oppenheimer) we have taken excursions in it for two days. This morning, before we leave

the zoo, we want to ask, what have we learned? I am supposed to present to you the theoretical arguments in this direction. What I shall tell you will not form a clear picture: a clear picture does not exist. But I do hope I can present to you an exciting and challenging picture that provokes further experiments and further speculations.

"The past year has witnessed very interesting developments in our knowledge of the strange particles. Perhaps the most important of these is the firm establishment of the "strangeness" quantum number. The starting point of these considerations was, as you remember, the puzzle that while the strange particles are produced quite abundantly (say 5 per cent of the pions) at Bev energies and up, their decays into pions and nucleons are rather slow (10^{-10}sec). Since the time scale of pion-nucleon interactions is of the order of 10^{-23} sec, it was very puzzling how to reconcile the abundance of these objects with their longevity (10^{13} units of time scale). In 1952 Pais proposed that a way out of this difficulty is to assume that a strange particle is always produced in association with other strange particles. This proposition was very soon supported by direct experimental evidence.

"A natural way to explain the associated production phenomena is to say that there are some selection rules which prevent the strong interactions from being operative in the decay mechanism. A glance at the many observed production, reaction and decay schemes shows indeed that one could assign to each strange particle a strangeness quantum number and stipulate that in all fast interactions the strangeness is additively conserved, and that in all observed decays it is not. This was first discussed by Gell-Mann and by Nishijima in 1953. The assignment is:

S = 0: ordinary particles (π, N, P, and γ)

S = +1: θ^0, K^+

S = -1: Λ^0, $\Sigma^\pm$, Σ^0(?), K^-, $\overline{\theta}^0$

S = -2: Ξ^- .

"One remark is proper here: two charge conjugate particles must have equal and opposite values of S. This is because, in a fast reaction, a particle can always be moved to the other side of the reaction and become its antiparticle, keeping the reaction fast.

"The use of the concept of conservation of strangeness is as follows: A reaction is fast (time scale 10^{-23} sec) if it satisfies all conservation laws, namely, of energy, momentum, angular momentum, parity, charge, heavy particle number and strangeness, and if it does not contain a γ-ray. It is weaker by a factor of 1/137 if it involves a γ-ray. If it violates the strangeness selection rule it is weaker by a factor of, say, 10^{-12}. μ, e and ν are not assigned any strangeness, but, except for electromagnetic interactions, they are supposed to interact with a strength 10^{-12} weaker than the strong interactions. We shall return to this point later.

"This conservation of strangeness was proposed by Gell-Mann and by Nishijima in 1953, and during the past year it was given very strong experimental support. These supports are:

a. Associated production seems to be the general rule. But the associated production $N + N \rightarrow \Lambda^0 + \Lambda^0$, although of the lowest threshold, is definitely of much lower probability. The significance of this is that it makes any multiplicative selection rule modeled after parity impossible.

b. To stabilize the cascade particle Ξ^- in the strangeness scheme it was proposed that its strangeness is -2. The observation of a reaction producing $\Xi^- + K^0 + K^0$ is in conformity with this proposal.

c. K^+ and K^- behave very differently in matter: K^+ scatters, but does not cause big stars, K^- causes big stars and oftentimes changes into a Λ^0 or $\Sigma^\pm$. This is evident in the strangeness scheme, because K^+ is of the lowest excitation in the family $S = 1$, while K^- is very vulnerable in that in its family $S = -1$ there are many particles (Σ, Λ^0) which have much lower excitation.

d. K^+/K^- is very large (> 50) at cosmotron energies. This was predicted on the strangeness scheme as due to the fact that K^- with $S = -1$ must be produced with a partner with $S = +1$, i.e., a partner with at least the excitation of K^+ mass ($= 965 m_e$) while a K^+ with $S = +1$ is produced with a partner with $S = -1$, such as Λ^0 with an excitation of only $340 m_e$. The large ratio K^+/K^- is therefore a threshold effect.

e. There are no known violations of the strangeness selection rule.

"On the strength of these experimental findings it seems that the conservation of strangeness gives such a consistent picture of the interaction of strange particles that it is certainly part of the truth in this subject.

"Actually, the Gell-Mann-Nishijima scheme finds experimental support from another set of experimental results. This concerns the charge degeneracy of the strange particle states, and its relationship to the isotopic spin, a concept familiar in nuclear and pion physics.

"We recall that in pion physics there was the relationship

$$Q = I_3 + \frac{N}{2} \tag{1}$$

between the charge, the third component I_3 of the I-spin and the number of nucleons N. Suppose, for strange particles, the conservation law of $\vec{I}$ holds in strong interactions, but this relation breaks down. Then the balance

$$(Q - I_3 - \frac{N}{2})$$

would, for strange particles, not be zero. However, it still must be a quantity which is additively conserved in any strong interactions, since Q, I_3 and N all are. This in fact was the starting point of the Gell-Mann-Nishijima scheme; namely, to ask whether the new quantum number, defined to be

$$S = 2(Q - I_3 - \frac{N}{2}) \qquad (2)$$

could stabilize the strange particles.

"This connection between the strangeness and isotopic spin provides us with three more kinds of results that can be directly checked with experiments. They are all related to the conservation of the total I-spin, not only of I_3:

a. The assignment of S leads immediately to a value for I_3, which, if non-vanishing, in turn would imply the existence of other particles of approximately the same mass but different charges. E.g. the particle Σ^- has $S = -1$, $Q = -1$, and $N = 1$. Therefore, $I_3 = -1$. Therefore, it must have at least two partners of approximately the same mass with $I_3 = 0, 1$ respectively, and charge 0 and +1. The latter is indeed found, experimentally called Σ^+. The other one, Σ^0, is perhaps on the way to be found. Applied to the particle Λ^0 one gets the result that

$S = -1$ is consistent with an $I = 0$ assignment for Λ^o. This agrees with the experimental picture of no observed charged particles degenerate with Λ^o. One may ask, of course, in this connection, whether different particles of the same multiplet may not be separated by several hundred Mev in mass values. It seems, however, that such a separation would in itself indicate that the interactions that violate conservation of I are large and would render I meaningless.

b. The light hyperfragments would form isotopic spin multiplets, such as $_\Lambda He^4$ and $_\Lambda H^4$. This was discussed by Dalitz. Experimental evidence of such multiplets is expected to be found.

c. The existence of certain relationships between different reaction rates. E.g.

$$K^- + d \rightarrow \Sigma^- + p$$
$$K^- + d \rightarrow \Sigma^o + n$$

would be in the ratio of 2:1. No direct experimental evidence of this kind yet exists to my knowledge.

"Before I conclude this discussion of the strangeness scheme, two remarks are in order:

a. There was, in the preceding discussion, the implicit assumption that all particles of the same multiplet have the same strangeness quantum number. It is tortuous not to have this assumption. But it is important to recognize that this is one of the fundamental points that we do not understand at all.

b. As we just said, the origin of the strangeness quantum number is the question whether the un-understood empirical relation (1) could be violated. Now there exists another un-understood empirical relation which has not been found violated so far, and that is that all particles with $N = 1$ (i.e. those particles which are conserved together with the nucleons) have half integral spin and all particles participating in fast interactions with $N = 0$ (e.g. mesons) have integral spin. Violation of this rule would immediately lead to new kinds of quantum numbers. It is perhaps useful to bear this in mind when puzzling new stabilities occur.

"We might say that our knowledge of the strange particles at the moment consists of a convergent part and a divergent part. The convergent part I have just given a description of and constitutes an essentially closed chapter. More will be added to it, to be sure; but until an over-all understanding is gained, the pattern of this chapter will most probably remain as it is.

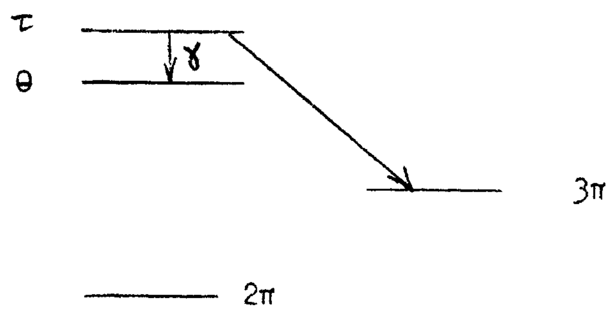
"There have been many theoretical papers written about schemes that do not differ essentially in their conclusions from the Gell-Mann-Nishijima scheme. The authors include M. Goldhaber, Sachs, Salam, d'Espagnat and others. We shall not have time to go into them in detail.

2. Now we come to the divergent part of the subject. This consists of the many loose ends that need be tied together. Foremost among these is the question of the K-mesons ($K_{\pi 2}^+$, $K_{\mu 2}^+$, $K_{\pi 3}^+$, $K_{\mu 3}^+$, K_{e3}^+). The puzzle, about which we have heard so much in the last two days, is that they have very approximately the same masses and the same life times. The latter were measured both at rest and in flight. Of course, if they are all different decay modes of the same particle, the puzzlement would vanish. (Even then one still needs to understand how this multitude of decay modes comes about.) However the situation is that Dalitz's argument strongly

suggests that it is not likely that $K_{\pi 3}^{+}$ ($\equiv \tau^{+}$) and $K_{\pi 2}^{+}$ ($\equiv \theta^{+}$) are the same particle. I hope we may have some discussion of this point this morning.

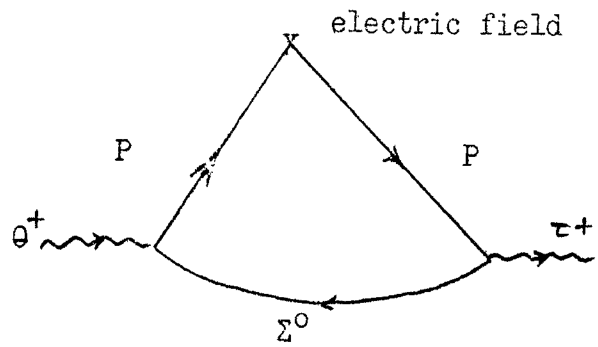
"If θ and τ do not have the same spin and parity, one needs to explain (a) why the masses are so close to each other and (b) why the measured life times are so close to each other.

"A few months ago, Lee and Orear suggested that the life time identity may be due to a genetic relationship between the two particles. E.g., the decay diagram may be like:



If the true life time of θ is short compared to 10^{-9} seconds, but that of the τ is the observed 10^{-8} sec, then a few meters from the source, the θ's, if originally produced, would all have decayed and one would observe the well-known single-life-time phenomena familiar in radioactivity. This suggestion has been extensively discussed by many people. At the moment, the experimental conclusion seems to be against the existence of γ-rays >1 Mev, as we heard from Alvarez. Theoretically, if τ and θ are 0^{-} and 0^{+} particles, and if their masses do get within, say, 1 Mev of each other, the electromagnetic transition (double γ emission) would become so slow that this explanation would not be tenable. If, on the other hand, they are 0^{-} and 2^{+} particles, single γ-ray transition would be possible (magnetic quadrupole) and a mass difference of, say, 1 Mev would be appropriate.

"A relevant suggestion has recently been made by Weinstein that when the mass difference is small, say $< 10^{-5}$ ev, the two states may get mixed in passing through matter. The measured life times would then become identical. For illustration let us take the spin parity assignment to be 2^- and 2^+. There would then be, in general, a static electric dipole strength between the two states. It arises, for example, from processes like this



This strength of such electric dipoles is expected to be $\sim e\hbar/mc$ on dimensional grounds. We take m to be the mass of the θ. This causes an energy split $\sim (e\hbar/mc)E \sim 10^{-3}$ ev in an atomic electric field. This is bigger than the mass difference, so the two split states are complete mixtures of the two states θ and τ. Their relative phase would change with time as $(10^{-3}\text{ ev})t/\hbar \sim t/10^{-12}$ sec. If the field were uniform, the two particles would then be completely mixed in 10^{-12} sec. Actually the problem is very involved as E is a vector and is not uniform. It is even more involved if a mixed magnetic dipole moment is the cause of the transitions. This question should be examined in closer detail. Also the problem of the two different methods of life time measurement, namely at rest and in flight, should be examined if the Weinstein suggestion is operative.

"If one takes the two most likely assignments, (0^-, 0^+) and (0^-, 2^+), however, the coupling with the electric and magnetic fields would be so weak that no mixing occurs in 10^{-8} sec, and this explanation of the equality of the life times would not work.

"Concerning the mass degeneracy of the τ and θ, assuming that they are 0^- and 0^+ particles, Lee and I had discussed the following point: if this degeneracy is <u>not</u> accidental, then it follows that all particles whose strangeness is odd must exist in two states of opposite parity. In particular, there would then have to be two Λ^0's: Λ_1^0 and Λ_2^0 of opposite relative parity such that

$$\pi^+ + n \rightarrow \Lambda^0{}_1 + \theta^+$$

and

$$\pi^+ + n \rightarrow \Lambda^0{}_2 + \tau^+$$

occur with equal amplitude. In fact, the symmetry must extend to all fast interactions so that one can define the simultaneous switching of θ and τ, and of $\Lambda^0{}_1$ and $\Lambda^0{}_2$, etc. as an operation that commutes with the strong part of the Hamiltonian. We shall call this operation parity conjugation and shall denote it by C_p. All ordinary particles are eigenstates of C_p with $C_p = +1$. All particles with odd strangeness would exist as a parity multiplet, i.e., two particles with opposite parity that switch into each other under C_p.

The following remarks are in order:

a. If θ and τ have different spins, the whole concept does not work.

b. Particles with $S = 0$ change into themselves under C_p. They may therefore have $C_p = \pm 1$. The possibility of a particle with $S = 0$, $C_p = -1$ therefore offers itself as a selection rule to stabilize particles.

c. The reactions

$$\pi^+ + n \rightarrow \Lambda^o{}_2 + \theta^+$$

$$\pi^+ + n \rightarrow \Lambda^o{}_1 + \tau^+$$

have equal amplitudes. They may occur together with the two reactions listed before. Their relative rates are not fixed by the invariance requirements. However, it is evident that θ^+ and τ^+ are always produced with equal abundance.

d. The symmetry elements <u>may</u> be much more numerous than C_p alone. But C_p represents the minimum symmetry to have equal masses.

e. The electromagnetic interaction may or may not be conserved under parity conjugation. If it is, the only interactions that violate C_p conservation would be the weak interactions. The mass difference between two elements of a parity multiplet would then be exceedingly small (say $< 10^{-5}$ ev). In such a case the Lee-Orear scheme would not be tenable. To illustrate the fact that the electromagnetic interaction may not conserve C_p, we may mention, for example, that $\Lambda^o{}_1$ and $\Lambda^o{}_2$ may have different magnetic moments.

"Let me summarize the situation now as I visualize it in the following table:

Spin and parity τ	θ	Fit Dalitz plot?	Mass degeneracy could be due to	Life time identity could be due to	Remarks
same particle		??			
0^-	0^+	easily	C_p conservation	?	
	odd				$\theta^0 \not\to \pi^0+\pi^0$
0^-	2^+	easily	?	Cascade ($E_\gamma \sim$ Mev)	Alvarez say no $\gamma \sim$ 1 Me
2^-	0^+	O.K.	?	Same	"
2^-	2^+	O.K.	C_p conservation	Cascade ($E_\gamma \sim$ kev) Weinstein's idea (?)	
Others					

3. I shall now call your attention to the following problems:

a. The $\theta\ \bar{\theta}$ problem. This was discussed in the published work of Gell-Mann and Pais, and Pais and Piccioni.

b. Possible ways of measuring the spin of strange particles. Adair, Treiman, and others have discussed this problem. We heard, Thursday, Karplus and Primakoff's suggestion in this connection.

c. What are the weak interactions? As far as the ones responsible for the decay of the strange particles are concerned, it is evident that, to facilitate the discussion of selection rules, it is best to split the weak coupling constants into many additive parts, each of which, if thought of as carrying an isotopic spin, would leave the weak interactions invariant. The simplest possibility would then be to have only one such constant with $I = \frac{1}{2}$, so that $\Delta I = \pm \frac{1}{2}$, $\Delta I_3 = \pm \frac{1}{2}$ in decays. This has been discussed by Gell-Mann in some unpublished preprints, and more recently by Wentzel, by Gatto and by Nishijima. I believe Professor Wentzel will discuss this later.

d. There are, in addition, the well-known weak interactions involving π-decay, μ-decay, β-decay and μ-nucleon interactions. It is very remarkable that the strange particle decays and these interactions all have comparable strength, i.e.

Strong interactions	strength ~ 1
Electromagnetic interactions	strength $\sim 10^{-2}$
Strange particle decay	
π^-, μ^-, β-decays	strength $\sim 10^{-12}$-10^{-14}
μ-nucleon interactions	

"One should notice that the bunching of the interaction strength into these widely separated regions can not be explained as due to the time scale of available experimental techniques.

"4. I shall conclude with a discussion of the over-all view of all the known conservation laws. We first list the conserved quantities other than those related to space time invariance: (C_p is not included here.)

1. For all interactions: N, Q and $\mathcal{C}$ (charge conjugation).
2. For all but the weak interactions: N, Q, $\mathcal{C}$ and S.
3. For strong interactions only: N, (Q), $\mathcal{C}$, S and $\vec{I}$.

We put Q in parentheses because its conservation in case (3) follows from those of $\vec{I}$, N and S.

"One can write down all the commutation rules between these quantities straightforwardly. It is then found to be more convenient in case (3) to use a quantity G defined by

$$G = \mathcal{C}\, e^{i\pi I_2}$$

in place of $\mathcal{C}$. This is because G commutes with $\vec{I}$ while $\mathcal{C}$ does not. The commutation rules can be realized as follows:

Case 1: Two independent axes of rotation, the 'angular momenta' around which are Q and N: Q N

$\mathcal{C}$ is an operation that turns both axes simultaneously through 180°.

Case 2: Three axes: Q N S, with $\mathcal{C}$ simultaneously turning all three axes through 180°.

Case 3: Two axes: S N and a spherical symmetry $\vec{I}$.

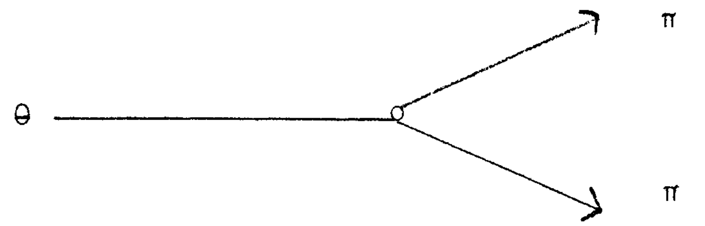
G turns the S and N axes simultaneously through 180°.

"In algebraic language, the mass degeneracies are related to the irreducible representations of the group of symmetries named above. Additional symmetries, such as C_p, would enlarge such irreducible representations and consequently increase the degeneracy.

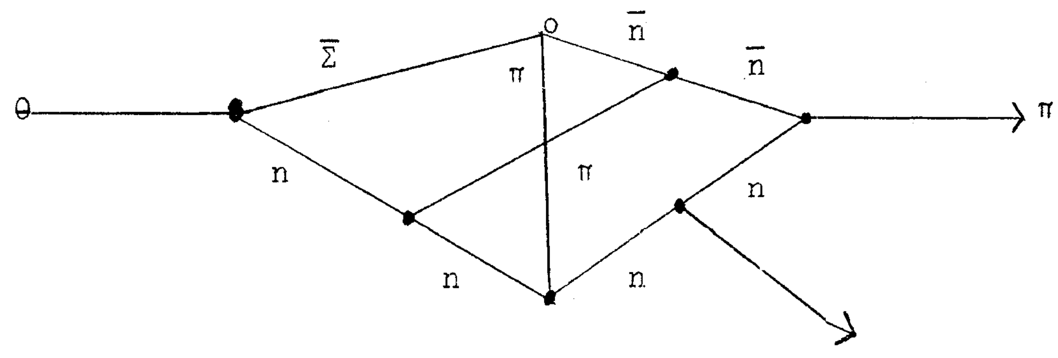
"The purpose of this visualization of the symmetries is to see whether a general, integrated pattern would emerge. E.g., one of Pais' schemes is in this picture equivalent to proposing that in cases (2) and (3) the axis for S is really one of three, forming a spherical symmetry. The difficulty with such a scheme is that the increased symmetry gives rise to a greater degeneracy than that which is observed. (E.g., it would imply the existence of a Λ^+ .) In contrast, experimentally we are peculiarly beset with rather strange degeneracies. More symmetries appear to be called for. It is very interesting that these further symmetries seem to get entangled with space-time concepts. Let us hope that this entanglement would lead rapidly to a resolution of the present situation which is characterized by a directionless growth of more and more quantum numbers."

WENTZEL made a few remarks on the selection rule $|\Delta I| = \frac{1}{2}$. The evidence for the validity of this selection rule in slow transitions is, at best, rather fragmentary. In its favor, the observed branching ratio τ/τ' has been quoted [G. Wentzel, Phys. Rev. 101, 1215 (1956)], but Steinberger's data on the Λ^0 and θ^0 branching ratios, as reported above, lend little support. However, it may still be worth while to discuss some consequences of this selection rule. If nothing else, such contemplations are "useful," as Dr. McMillan says, "in keeping theoreticians off the streets."

If it should be true that the rule $|\Delta I| = \frac{1}{2}$ governs all slow processes, the following problem arises. Taking the θ decay as an example:

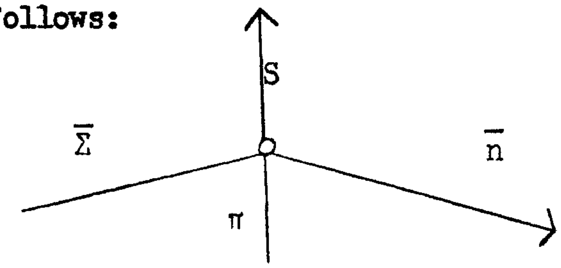


a multitude of more complicated Feynman diagrams will contribute to the matrix element, for instance the following one:



For the final two pion state we want to forbid I = 2 (since the θ has I spin $\frac{1}{2}$). There is one obvious way to achieve this, and there can be no other way, essentially.

Let us, for merely formal purposes, imagine that in every weak vertex (open circles in the figures) a spurious particle is emitted which carries away an I spin $\frac{1}{2}$ but carries no charge, or spin, or energy-momentum. It would be represented by an isospinor (corresponding to zero charge) with constant amplitude in space-time. In the above diagram, the weak vertex would then look as follows:



(S for spurion), and it should be of such nature as to conserve I spin. Then, for each simple or complicated diagram, I spin is conserved for the system including the spurion; or, discounting the latter, we have, obviously, $|\Delta I| = \frac{1}{2}$. Formally, this recipe can be expressed in various ways (Nishijima, Gatto, d'Espagnat and Prentki).

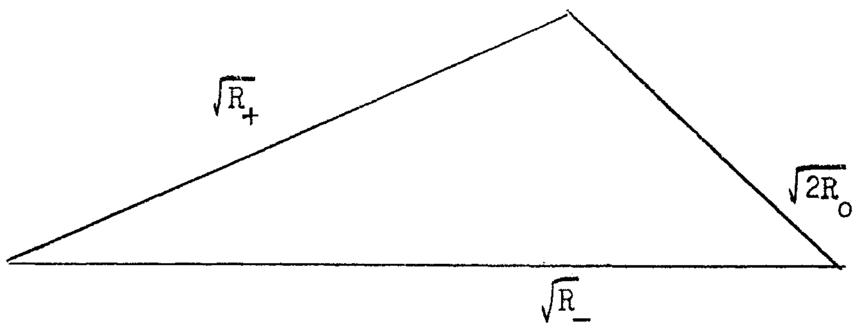
The interesting point is that this formalism implies new relationships for branching ratios and relative decay rates. The reason for this can be seen from the complicated diagram above: if we prohibit the final state I = 2, this must impose some correlation upon the various charge channels going through the weak vertex. Indeed, one finds by familiar methods, that the three decay rates

R_+ for $\Sigma^+ \rightarrow N + \pi^+$

R_0 for $\Sigma^+ \rightarrow P + \pi^0$

R_- for $\Sigma^- \rightarrow N + \pi^-$

are correlated according to the triangular figure.



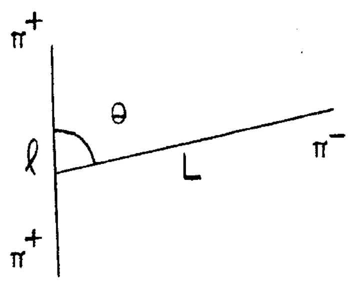
and give rise to inequalities. Moreover, since the final nucleon-pion states are known from the scattering experiments (phase shifts), one further relation for the angles in the triangle can be set up, depending on the spin and parity of the Σ.

Of course, the selection rule holds only in the approximation neglecting electromagnetic effects and, also, the mass differences of the members of an isotopic multiplet, like $\pi^{\pm} + \pi^0$. For instance, a θ^+ of even parity and spin may decay into $\pi^+ + \pi^0$ with a probability proportional to the square of the mass difference $(\pi^+ - \pi^0)$. The life time ratio of θ^+ and θ^0 cannot be predicted without additional assumptions, but the observed value ($\sim$ 100) does not seem very much out of proportion.

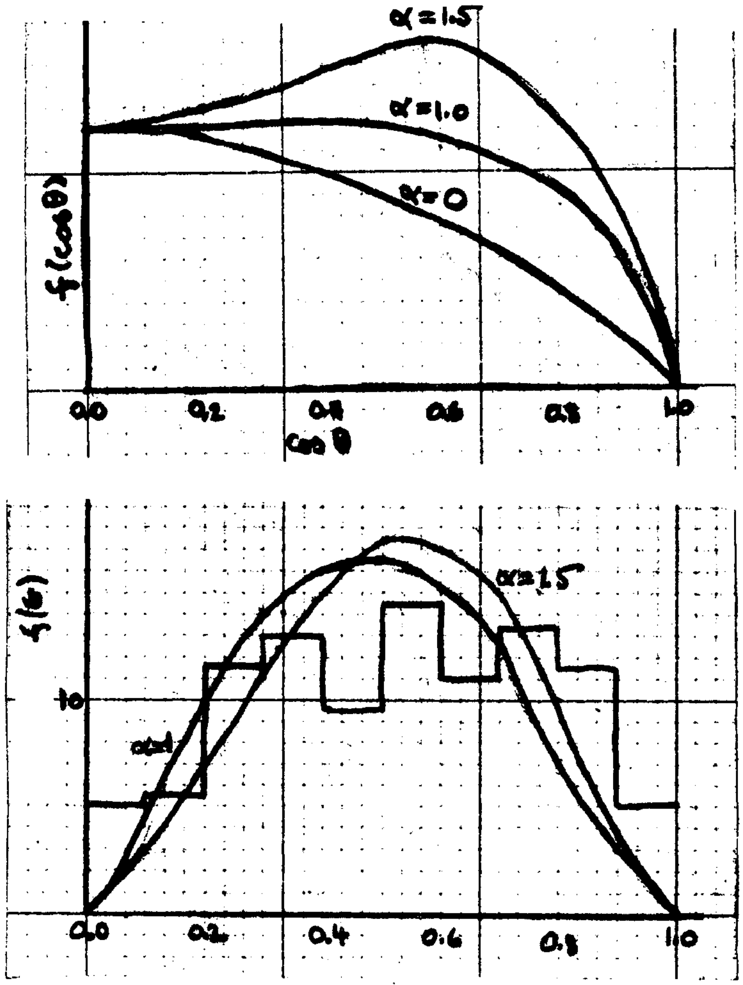
Yang made two comments on branching ratios in general. Firstly, the Λ^0 and θ^0 decay branching ratios would throw light on the problem of the existence of the two θ^0-s and two Λ^0-s. Secondly, since there is only one adjustable real parameter involved, a measurement of the ratio $\tau_{\Sigma^-}/\tau_{\Sigma^+}$

could be used to obtain the branching ratio for Σ^+ decay. D'Espagnat commented that in order to carry out Yang's second suggestion one also requires the known final state interaction of the decay products and the unknown spin and relative parity of the Σ. Oppenheimer commented that the idea of such a program as Wentzel's is to order the slow reactions with a finite number of selection rules. We are nowhere near this goal. Phase space considerations alone in many cases show that reactions are compatible in their rates, while experimentally these rates are not compatible.

MARSHAK reported briefly on an attempt to explain the apparent identity of θ and τ meson masses and lifetimes in terms of a single particle, even if one has to use a larger spin value. He felt that a last effort should be made in this direction, before introducing any startling new assumptions. The lowest spin compatible with the single particle assumption is 2^+ (in view of evidence for the existence of the process $\theta^0 \longrightarrow 2\pi^0$, reported above. If one fixes the notation for the variable involved in meson decay, as indicated in the diagram,



the lowest set of (ℓ,L) values giving a 2^+ is (2,1), as discussed in Dalitz's paper. This set gives a π^- angular distribution $\sin^2\theta$, in disagreement with experiment. However, the angular momentum set (2,3) with a π^- angular distribution $\sin^2\theta\ (1+15\cos^2\theta)$, can also yield a spin 2^+. As far as the energy spectrum of the π^- is concerned, the set (2,1) favors the slow π^- -s, since the centrifugal barrier is bigger for the π^+ -s than the π^- -s. By the same argument, the set (2,3) favors the fast π^- -s. Perhaps one can think of the τ as the superposition of these two sets of angular momenta. This possibility is explored in the figures, the first of which shows angular distributions of the negative pions for values of a mixture parameter α for the two amplitudes, and the second gives the energy spectrum of these pions for two values of this parameter, as compared to the spectrum obtained from Harris' summary of 200 τ events.



DALITZ discussed the τ - θ problem next. As Marshak indicated, there are an infinite number of possibilities for combining the two angular momenta which appear in τ decay to give a desired spin-parity. In past estimates of angular distributions in this decay, it has been natural to adopt the view that configurations in which the least possible angular momentum is carried away by the two degrees of freedom are favored. If the τ has internal structure, then, in analogy with nuclear physics, the simplest decay channels in fact may not be the ones that are favored. Therefore, the simplest estimates serve only as a guide.

The experimental data now total 600 events, including 200 recently received by Dallaporta. All these events, when plotted on the "Dalitz diagram," give a remarkably uniform distribution. No apparent correlations are seen, though the density (per unit phase space) of fast π^--s, going up to the maximum energy of about 48 Mev, is about 30% higher than that of slow π^--s. The matrix element for the process, plotted as a function of the negative pion energy, can well be approximated by a straight line with slope $.15 \pm .1$, which differs by 30% from one end to the other. For a pseudoscalar meson, some such variation is not surprising, since the ratio of the τ meson radius to the de Broglie wavelength of the outgoing pions is not negligible. Also, meson-meson forces would slightly distort the distribution. The simple-minded interpretation is that the distribution is uniform. This would point to a τ meson of spin-parity 0^-, though other possibilities, such as 2^- are not excluded. The establishment or exclusion of a 2^- distribution requires much more information than is presently available.

Some rigorous statements can however be made (these have been made before). If the τ is equivalent to the θ, then the following decay events cannot take place:

1. Events in which the π^- is at rest.
2. Events in which the π^- has maximum energy.
3. Collinear events: the angular distribution vanishes at $\cos\theta = 1$.

These rigorous statements go together with threshold statements to the effect that the density of π^- events rises with energy in a way characteristic of the angular momentum carried away by that degree of freedom. Simple-minded estimates are intended as a guide to indicate how fast this rise should be. The table below represents a study of threshold values of the negative pion energy spectrum and angular correlation. The analysis of the energies is based on 400 events, that of the angles on 297 events. The column labeled "Phase space" refers to the uniform angular distribution corresponding to spin 0; the values of the Marshak theory used have been based on the set (2,3) alone. Of all mixtures of sets (2,1) and (2,3), as proposed by Marshak, this case gives the most favorable densities for fast π^- -mesons and for the angular correlation near $\cos\theta = 1$ (of course, the set (2,3) disagrees violently strongly with the data for slow π^- -s or for small $\cos\theta$). Even so, there appears to be some disagreement of the theory with experiment for the energy spectra. The disagreement in the values given for the angular correlations is not significant and if one goes above 4 Mev and below 44 Mev, there is no very strong disagreement of the π^- -energy distribution with Marshak's results. It should be added here that a mixture of (2,1) and (2,3) will imply correlations between energy and angular distributions which should be sought in the data.

Threshold data for π^- energy spectra and angular correlations in τ decay

ϵ_-	(Mev)	Expt.	Theory	
			Phase Space	Marshak
Fast π^-	> 44	24	16	3.5
	> 40	61	44	39.5
Slow π^-	< 4	20	16	
	< 8	36	44	
Angular correlation:	$\cos\theta$			
	$> .95$	12	15	4.5
	$> .9$	26	30	18

The above results once again suggest that the τ meson has spin zero. However, if one made the particle sufficiently complicated, the present data could probably be fitted by a number of spin values, although this is particularly difficult for low spin values (especially 1-). Disagreement with experiment of predictions for high spins, based on a complicated structure, would probably not be found until the amount of data is much larger than that presently available.

Oppenheimer: "The τ meson will have either domestic or foreign complications. It will not be simple on both fronts."

Brueckner asked Dalitz about his calculations of the decay rate for the process $\tau \rightarrow \pi + \gamma$ for the spin 2 τ meson, and the indication that this rate is expected to be large in comparison with π decay. Dalitz replied that γ decay was expected to be favored, since the phase space available for it is about 10^3 larger than that available for the π decay.

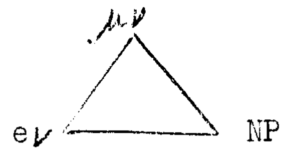
The factor of α cuts this down to a ratio (of radiative to non-radiative decay rates) of about ten. However, no detailed predictions can be made. The partial width for the radiative process may well be ten times smaller than for the non-radiative decay so that the radiative decay could turn out to be ten times smaller, rather than ten times as large as the non-radiative rate. Thus, the fact that the radiative decay mode has not been observed need not be inconsistent with the assumption of a spin 2 for the τ. One may also point out that for such a spin value, the process $\tau \rightarrow \pi + e + e$ also has a finite relative probability of occurring, though hitherto it has not been observed.

Teller mentioned that Bludman at Berkeley has attempted to explain the other decay modes of the K mesons. His work has the disadvantage that it has not led to any visible difficulties, and is therefore just reassuring. He assumes an interaction for which the transition matrix vanishes if the particle disintegrates into two particles of zero mass. If one then takes account of deviations when one of the particles does not have zero mass, or when neither does, one gets reasonable values for K_{μ_2} and K_{π_2} decay respectively. In fact, if one uses the same interaction to discuss K_{π_3} and even $\pi \rightarrow \mu + \nu$ decay, one still gets reasonable values.

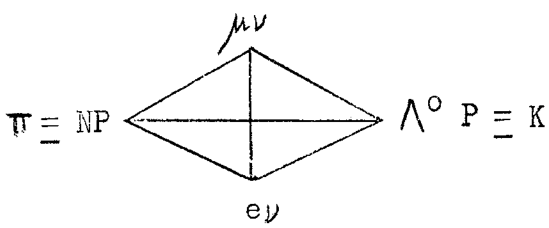
GELL-MANN made a few extended remarks on the principal talk of Yang. They fall into two parts, the first dealing with some independent and unpublished work, similar to the proposal of Yang and Lee on the degeneracy of the τ and θ. The similarities are that Gell-Mann, too, assumes that there is a symmetry principle which has the consequence: $\theta \leftrightarrow \tau$, $\Lambda^0 \leftrightarrow \Lambda^{0'}$, $\Sigma \leftrightarrow \Sigma'$, $N \leftrightarrow N$, $\pi \leftrightarrow \pi$, etc. (Incidentally, the notation θ and τ, as far as most theoreticians use it, refers to the particles, and $K_{\pi 2}$, $K_{\pi 3}$, etc. to the decay modes. Thus θ has the decay modes $K_{\pi 2}$, and possibly $K_{\mu 2}$, $K_{\mu 3}$, and K_{e_3}; τ has the decay modes K_{π_3} and so on.) This symmetry principle, assumed to govern strong interactions, allows the θ and τ, though they are <u>different</u> particles, to have the same mass and spin, but opposite parity. Nature, at least as far as strong interactions go, is completely symmetric between them. Thus the θ and τ (also the Λ^o and $\Lambda^{o'}$, the Σ and Σ') will occur equally in all processes. They will have the same angular distributions and cross-sections (though not necessarily the same angular correlations). If observed at the same age, the ratios of the various decay modes are the same. The equality of τ and θ lifetimes is a "miracle," not explained by this theory. In combination with the symmetry principle, it leads to the result that the ratios of decay modes are the same in all experiments. The difference between Gell-Mann, and Yang and Lee arises from their views of the electromagnetic field. Gell-Mann, along with most people, takes for granted as an apparent law of nature that his field interacts only with charges and currents, and has no peculiar interactions with matter. (For example one could introduce a Pauli term in the Dirac equation to explain the anomalous magnetic moments of the proton and neutron. But the view, first propounded by Wick, that these anomalous moments are due to the interaction of the e.m. field with the charges and currents of the virtual meson cloud around the nucleons, and of the recoiling core, is much more widely accepted. There are other examples of the acceptance of this principle.)

It follows, therefore, that not only the strong, but also the e.m. interactions are invariant under the symmetry operator C_p (Gell-Mann calls it R). That is, the e.m. field cannot tell the difference between θ^+ and τ^+, since they have the same strong interactions and the same charge. Consequently there cannot be e.m. mass differences between the θ and τ (or any other anomalies of electromagnetic origin between any of the pairs of particles connected by the symmetry operator). (Editor's note: Yang and Lee would say that C_p may not commute with the e.m. field and therefore there may be an e.m. mass difference.) The mass difference between the θ and τ would arise entirely from the weak interactions, and would, on the basis of crude estimates, be expected to be a fraction of an electron volt. The equality of lifetimes is still a miracle, since the weak interactions must violate the symmetry principle in order that there be decay.

Turning to the weak interactions, Gell-Mann discussed attempts to include them in a single scheme devised by himself and by Dallaporta and collaborators. One starts with the familiar triangle proposed to account for processes like β decay, μ decay, and μ absorption in nuclei:



We add to these the strange particles by additional linkages:



The triple linkages represent strong interactions. The single linkages represent 4-fermion interactions. We say nothing about the character of the weak interactions, but do assume that they have roughly the same strength. The other hyperons can be thought to belong to the $\Lambda^0 P$ corner. (Of course, this picture may make no sense if one thinks of the Λ^0 and $\Lambda^{0'}$, related by C_p. The two parts of Gell-Mann's remarks are disjoint.) Processes such as $K \rightarrow \mu + \nu$, $\pi \rightarrow \mu + \nu$, etc. can now take place. An attempt, made last year to find a universal form for such weak interactions failed, and did so even without the consideration of strange particles, because of the small value of the ratio $\frac{\pi \rightarrow e + \nu}{\pi \rightarrow \mu + \nu}$. There are still general consequences of this scheme, however, if one only maintains the assumption of a universal strength for the interaction, but allows its form to vary from linkage to linkage. Two of these consequences can be summarized by the following selection rules for decay:

1) stronglys $\longrightarrow$ stronglys $\qquad |\Delta S| = 1 \qquad |\Delta I| = \frac{1}{2}$ or $\frac{3}{2}$

2) stronglys $\longrightarrow$ stronglys + leptons $\qquad |\Delta S| = 1 \qquad |\Delta I| = \frac{1}{2}$

The stronglys refer to strongly interacting particles, such as Λ, N, π, and the leptons to μ, ν and e. The second rule refers only to the relation between the strongly interacting particles. The leptons are assumed to carry away no isotopic spin. If one uses rule 1), one may obtain the same result for the τ / τ' ratio as that obtained on the basis of Wentzel's selection rule (see above). On the other hand Wentzel's rule would predict an infinite lifetime for the θ^+. The finiteness of the lifetime arises only from electromagnetic corrections of order e^4. Use of the above Gell-Mann selection rules would lead, perhaps more naturally, to a finite lifetime. Further, for processes like $\Lambda^0 \rightarrow P + \pi^-$, $\Lambda^0 \rightarrow n + \pi^0$, etc., the above weak rule has no consequences, while Wentzel's rule has very strong consequences. As far as rule 2) above is concerned, it would give essentially a one-to-one partial lifetime for the processes $\theta^+ \rightarrow \pi + e + \nu$ and $\theta^0 \rightarrow \pi + e + \nu$. (An exact statement is hard to make in view of the complicated situation of the neutral θ.) This assertion is subject to experimental test. We know the lifetime and branching ratios of the charged K particle and thus can compute the partial lifetime of the process $\theta^+ \longrightarrow \pi + e + \nu$. We know the lifetime of the θ^o. If we can find the branching ratio of the process $\theta^o \longrightarrow \pi + e + \nu$ (events such as the one mentioned by Peyrou above) we can obtain the partial lifetime for this process as well.

Gell-Mann doesn't necessarily advocate this approach to the weak interactions. He merely wished to point out its existence. More detailed rules, involving specific interactions for the various linkages, are hard to state at present, since, except for nuclear β decay, the interactions are not known.

An extensive discussion followed. In connection with Gell-Mann's idea of assuming that C_p commutes with the e.m. field, Yang felt that so long as we understand as little as we do about the $\theta - \tau$ degeneracy, it may perhaps be best to keep an open mind on the subject. Pursuing the open mind approach, Feynman brought up a question of Block's: Could it be that the θ and τ are different parity states of the same particle which has no definite parity, i.e., that parity is not conserved. That is, does nature have a way of defining right of left-handedness uniquely? Yang stated that he and Lee looked into this matter without arriving at any definite conclusions. Wigner (as discussed in some notes prepared by Michel and Wightman) has been aware of the possible existence of two states of opposite parity, degenerate with respect to each other because of space-time transformation properties. So perhaps a particle having both parities could exist. But how could it decay, if one continues to believe that there is absolute invariance with respect to space-time transformations? Perhaps one could say that parity conservation, or else time inversion invariance, could be violated. Perhaps the weak interactions could all come from this same source, a violation of space-time symmetries. The most attractive way out is the nonsensical idea that perhaps a particle is emitted which has no mass, charge, and energy-momentum but only carries away some strange space-time transformation properties. Gell-Mann felt that one should also keep an open mind about possibilities like the suggestion by Marshak (see above) that the θ and τ may, without requiring radical assumptions, turn out to be the same particle.

Michel suggested another way out of the difficulty. What is seemingly well known from experiment is the parity of the τ^+ and θ^0. If one assumes that the π^0 emitted in the process $\theta^+ \rightarrow \pi^+ + \pi^0$ is a "nearly real π^0" in the same sense that the pair emitted in the process $\pi^0 \rightarrow \gamma + e + e$ is a "nearly real γ," there is nothing to prevent θ^+ from having spin-parity 0^-. This "nearly real π^0" would appear only virtually, perhaps due to some selection rules.

The chairman felt that the moment had come to close our minds...

Primakoff returned to the subject of the e.m. interactions with matter--the law of "minimal electromagnetic couplings." One can set limits from experiment to the e.m. couplings associated with other than charge and current interactions. (For example, there is no evidence of the radiative decay of the μ mesons without the emission of neutrinos, or for the (radiative) annihilation of stopped positive μ mesons against electrons in matter.) These couplings, on the basis of present evidence, are very much smaller than the fine structure constant, in fact considerably smaller than the

β decay coupling constant, and the limits on them could be pushed even lower with presently available experimental techniques.

Oppenheimer professed himself a believer in the principle of minimal e.m. couplings without understanding it. He suggested: "Perhaps some oscillation between learning from the past and being surprised by the future of this [θ - τ dilemma] is the only way to mediate the battle."

Turning to the weak interaction selection rule, Oppenheimer commented that the mass differences of the various pions are large compared to fine structure constant orders of magnitude; and so Wentzel's suggestion for explaining the ratio of θ^o and θ^+ lifetimes is in fact more acceptable than Gell-Mann's argument, based on the magnitude of e.m. interactions, would tend to indicate. Marshak stated that he did not believe in the $|\Delta I| = \frac{1}{2}$ selection rule. As a possible explanation of the difference between the θ^o and θ^+ lifetimes, he referred to the theory he worked out with Okuba (see abstract, last Berkeley meeting). They suggest that this difference could be due to an interaction between π^+ and π^- in the $T = 0$ state (the interaction suggested by Dyson and Takeda to account for the second resonance in π - P scattering), provided the range of interaction is of order $\frac{\hbar}{\mu c}$, and not $\frac{\hbar}{Mc}$.

Lindenbaum asked if there were any reason for the asymmetry of the strangeness assignments between the heavy ($|S| \leq 2$) and light ($|S| \leq 1$) particles. Weisskopf replied that this was a reflection of the non-existence of doubly charged particles--a fact that he hoped reflected another law of nature. Oppenheimer expressed the wish, and Weisskopf concurred, that by next year we will also add the law that the maximum spin of fundamental particles is no greater than $\frac{1}{2}$.

MARKOV (interpreted by G. Volkoff) made a few observations concerning an algebra of the elementary particles, built up from a few simple assumptions, which is to some extent similar to Gell-Mann's scheme. The considerations are close to those expressed by Levy and Marshak at one time.

Altogether, there are four basic assumptions. First, one assumes that there exist excited states of nucleons (antinucleons) which can be identified with the hyperons (antihyperons), as indicated in the list below. The Gell-Mann strangeness quantum number equals the excitation number in this system. There is room for as yet undiscovered particles in the present scheme.

State label:	N_o	N_1	N_2	..................N_S
Particle identification:	n,p	$\Lambda_o, \Sigma^{\pm}$	Ξ^o,	Ξ^- ....?
Notation:	N_o, N_o^+	$N_1, N_1^{\pm}$	N_2,	N_2^-

This postulate gives one the hope that some future theory will enable one to obtain these states as solutions of some sort of eigenvalue equation (M. Markov, Report at Pisa Conference (1955)).

The second postulate is that the electromagnetic, nuclear and beta coupling are the same in all the states listed above. The states of given excitation correspond to a given value of the strangeness S.

Third, as it may happen in other systems, transitions from one state to another are strongly forbidden. Transitions in fact do take place, with a small probability and with $\Delta S = \pm 1$. Perhaps, as it happens in other cases, the forbiddenness of the transitions is related to some ratio $r_o/\lambda\!\!\!^-$, where r_o is some length and $\lambda\!\!\!^-$ is the wavelength of the interacting particle (P. Isaev and M. Markov, J. Exp. and Theor. Phys. 29, 111 (1955)).

This suggests that at high energies, the interactions that are responsible for the slow decays may become strong.

The fourth postulate is that nucleons and antinucleons of various excitations may join into bosons. One could think of the particle and antiparticle annihilating and producing bosons, or else, view the bosons, in an extension of the Fermi-Yang theory, as compounded of strongly interacting nucleons and antinucleons. Thus the π^0 meson is conceived of as a compound of neutron and antineutron [the notation is $(N^+{}_0\tilde{N}^+{}_0) \equiv \pi^0$], the θ^0 is thought of in the fashion $(N^+{}_0\tilde{N}^+{}_1) \equiv \theta^0$, and the excitation of the S^{th} state may form some as yet unknown particle $[(N_0\tilde{N}_s) = X_{os}]$. The typical reaction leading to associated production of Λ^0 and θ^0 may be symbolized as follows:

$$\pi^- + N^+{}_0 \longrightarrow \underset{\displaystyle\theta^0}{\underset{\downarrow}{(N^+{}_0 + \tilde{N}^+{}_1)}} + \underset{\displaystyle\Lambda^0}{\underset{\downarrow}{N_1}}$$

There are two uncharged θ particles in this system, the $\theta^0 = (N^+{}_0\tilde{N}^+{}_1)$ and the $\theta^0 \equiv (\tilde{N}^+{}_0N^+{}_1)$. The reaction $\theta^0 + p \longrightarrow \pi^+ + \Lambda^0$ does not go, while the reaction $\tilde{\theta}^0 + p \equiv (\tilde{N}^+{}_0N^+{}_1) + p \longrightarrow (\tilde{N}_0\ N_0{}^+) + \Lambda^0 \equiv \pi^+ + \Lambda^0$ can in fact take place. The structure of the θ^+ and θ^- mesons is as follows: $\theta^+_1 \equiv (N_0{}^+\tilde{N}_1)$; $\theta^-_1 \equiv (\tilde{N}_0{}^+N_1)$, or $\theta^+ \equiv (N_0\tilde{\Sigma}_-)$ and $\theta^- = (\tilde{N}_0\Sigma_-)$. Clearly θ^- can give rise to Λ^0 and θ^+ cannot. The reaction $N + N \rightarrow \Lambda^0 + \Lambda^0$ is also forbidden. Most of these consequences agree with those of Gell-Mann's scheme. There are some differences. For example, it is possible to have still another θ^0 whose structure is given by $\theta^0{}_1 \equiv (N_0\tilde{N}_1)$. One might suppose that this particle would have a different mass, and θ^0 would convert itself to $\theta^0{}_1$ with the emission of a γ quantum. Thus one may have the reaction $\pi^- + p \rightarrow \Lambda^o + \theta^o$, or else, one may have $\pi^- + p \rightarrow \Sigma^o + \theta^o \rightarrow (\Lambda^o + \gamma) + (\theta^o{}_1 + \gamma)$, or $\pi^- + p \rightarrow \Lambda^o + \theta^o \rightarrow \Lambda^o + (\theta_1{}^o + \gamma)$. It is Markov's understanding that there is some experimental indication for the second or for the third possibility. Turning to the reaction producing the Ξ^- ($\pi^o + N_o \rightarrow N_o + \widetilde{\Xi}^- + \Xi^-$) it is perhaps possible that the combination $(N_o\widetilde{N}_2{}^-)$ may give an unknown particle, X. Or else, the system could exchange excitations, and we could have $X^+ \equiv (N_o\widetilde{N}_2{}^-) \longrightarrow (N^+{}_1\widetilde{N}_1) \equiv (\Sigma_+ \widetilde{\Lambda}_o)$. This in turn may go further: $(\Sigma_+ \widetilde{\Lambda}_o) \rightarrow (N_1\widetilde{N}_1) + (N^+{}_o\widetilde{N}_o) \rightarrow (N_1\widetilde{N}_o) + (N^+{}_o\widetilde{N}_1) \equiv \widetilde{\theta}^o{}_1 + \theta^+$. Gell-Mann's proposition that the production of a cascade particle is accompanied by the production of two similar θ_1 contradicts this algebra of strong interactions.

One can write down many reactions (M. Markov, Report of Indian Scientific Congress, Agra (1956)). Perhaps this scheme does not have too much physical content. However, one should keep it in mind because of its simplicity and the transparent way in which the reactions go. Taking the scheme seriously, one sees that a nucleon must always emit a pair (particle and antiparticle) in the S^{th} excited state. (For instance: $\left\{\gamma_\mu P_\mu + M + L \sum_s g_s \psi_s + L \psi_s\right\} \psi_o$, S - strangeness number.) If one passes to the Bethe-Salpeter equation with tensor and vector interaction (operator L vector or tensor), one obtains a bound state which has the spin-parity of the π meson and gives the correct interaction for particles in the deuteron. Unfortunately the "glue" is so strong that the integrals which enter the calculation all diverge and must be cut off. There is also the same danger present here as in Teller's considerations (see above) that the glue would prove to be too strong with three particles present and would lead to the disappearance of nucleons. But perhaps this doesn't quite happen, so that not only π mesons, but also μ mesons and even lighter particles are combinations of nucleon-antinucleon groups with very high mass defects. If, for example, the structure of the positron is: $e^+ = (N_o^+ \tilde{N}_o N_n)$, then after a long time, the proton might transform itself into a positron. If n is big enough (n = 3 or 4), the lifetime of the proton may be as great as 10^{20} years. This is either a consequence of the original assumption of contact interactions, or it is not. No further hypotheses are required. Perhaps--and here Markov asked for his audience's indulgence--all bosons, even the photon, can be considered as a combination of an even number of nucleons and antinucleons. The electromagnetic field would then be a higher order effect of nuclear fields and the fine structure constant could be expressed as a function of nuclear couplings: $\frac{e^2}{\hbar c} = f(g)$. Markov closed his talk by saying: "Please excuse me for dreams of a future theory. But Teller's hypothesis (Ed. see antinucleon session, above) emboldened me to express such ideas anyway."

Koba stated that a model similar to Markov's has been proposed by Sakata in Japan and is now being extensively studied by him and his co-workers. Sakata, too, regards the nucleons and Λ^o particles (but not other hyperons), together with their antiparticles, as elementary, and the remaining particles as composites of them.

Oppenheimer felt that it wasn't clear that the notion of composing objects out of particles had much meaning in the domain of elementary particles. As an algorithm, Markov's suggestions have much more room than Gell-Mann's scheme allows. At the moment there seems to be no great need for the room, but it may always come.

Gell-Mann felt that part of Markov's assumption three, implying that the strangeness selection rule becomes less stringent as one goes to higher and higher energies, was a very interesting suggestion.

The final report of the session was given by D'ESPAGNAT, who discussed a reformulation of selection rules in strong interactions, developed in collaboration with Prentki. First they postulate rotation and reflection invariance in I space. One is then led to distinguish many possible fields with different transformation properties in this space. From these fields, we select only fields with the transformation properties in the table.

Transformation Property	Particle	U	P
Isoscalar	Λ	0	1
Isopseudovector	Σ, π	0	1
Isospinor, 1^{st} kind	Θ, N	1	i
Isospinor, 2^{nd} kind	Ξ	-1	-i

(Isospinors of the first kind transform like $\xi \rightarrow i\ \xi$, those of the second kind like $\xi \rightarrow -i\ \xi$ in an inversion through the origin.) In ordinary space a physical field is taken to be either a boson or a fermion field, as usual. The second postulate is that all possible isoscalars of the Yukawa type (all isoscalars involving two fermion and one boson operator) should appear in the interaction Lagrangian, and these only. If the most general Lagrangian, satisfying the two postulates, and containing only the field types listed in the table, is written down, one observes that along with the invariants I^2 and I_3, a third constant of motion, labeled U, also appears. The values of U for the various field types are listed above. If we identify Λ with U = 0 and the nucleons with U = 1, we see that U is just $U = S + N$, where S is Gell-Mann's "strangeness" and N is the baryon number. This assignment determines U values of the other particles. The various particle assignments are listed in the table. Assuming that the neutron has positive I spin, the charge is given by $Q = -I_3 + \frac{U}{2}$. If more than the listed types of fields are introduced, then the invariant U no longer exists. For such a case, the second postulate is incompatible with the conservation of charge.

Racah has recently suggested that one should consider a parity operator p, referring to inversion through the origin. p will have the values indicated in the table. The conservation of p is equivalent to the strict conservation of U, if one defines U through $p = e^{i(U/2)\pi}$, $-2 < U \leq 2$. (Of course, p is conserved if U is conserved modulo 4, but with elementary interactions of the Yukawa type, containing only 3 fields, none of which has $|U| > 1$, one can never achieve a change of 4 units.)

D'Espagnat observed that if one takes this p of Racah and expresses it in terms of a reflection in the I_1-I_2 plane (induced by an operator B), followed by a rotation of 180° about the I_3 axis, one has $p = e^{iI_3\pi}B$. In view of the definitions of p and Q in terms of U, given above, one finally gets: $B = e^{iQ\pi}$. This is a general relation, independent of the kind of field considered, and throws some light on the connection between charge and isotopic spin space.

Discussion between Williams and d'Espagnat brought out the fact that this scheme is more restrictive than the Gell-Mann scheme. In fact, since $|U| \leq 1$, we have $-2 \leq S \leq 0$ for hyperons, $0 \leq S \leq 2$ for antihyperons and $|S| \leq 1$ for heavy mesons. If, therefore, the Eisenberg particle turned out to be real and to have $S = -3$, then this scheme would be wrong.

The chairman's concluding remarks dealt with the third session on Wednesday morning and have been reported there.