(Wednesday Morning: <u>Elementary Particles</u>; J.R.Oppenheimer presiding)

Hyperons:

Particle	Products	Q (Mev)	M (m_e)	Lifetime (sec)
Λ^0	$\to p + \pi^-$ $\to (p + \mu + \nu$??)	37	2180	$3.8 \pm .5 \times 10^{-10}$
Σ^+	$\to p + \pi^0$ $\to n + \pi^+$	116 110	2327	$> 5 \times 10^{-10}$
Σ^-	$\to n + \pi^-$	110	2325	$\sim .5 \times 10^{-10}$
Ξ^-	$\to \Lambda^0 + \pi^-$	60	2570	$\sim 10^{-10}$?

K- Mesons:

Particle	Products	Q (Mev)	M (m_e)	Lifetime (sec)
τ	$\to 3\pi$ $\to \pi + 2\pi^0$ $\to 3\pi + \gamma$	75	964	$\sim 5 \times 10^{-9}$
θ^0	$\to \pi^+ + \pi^-$ ($\pi + \mu + \nu$??)	214	963	1.5×10^{-10}
τ^0	$\to \pi^+ + \pi^- + \pi^0$??	74.7	965	$< 10^{-8}$
K_{π_2} ($\chi, \theta^\pm$)	$\to \pi^\pm + \pi^0$	212	952	$\sim 10^{-9}$??
K_{μ_2}	$\to \mu + \nu$	235-255	920-960	$\sim 10^{-8}$
K_{μ_3} (κ)	$\to \mu + ? + ?$ ($K_{\pi_2} \to \mu + \nu + \pi^0$??)			
K_{e_3}	$\to e + ? + ?$			
K_{1400}	$\to$?			

Oppenheimer opened this session by remarking that there have been two questions which have been of unusually great help for us to talk over at these conferences. There has been on the one hand the general question of what truth there is, if any, in the Yukawa theory, and as to that we may have some intelligence this afternoon, and the question of how we can understand, how we can describe the properties of particles which emerge in high energy encounters. It is to that question that the principle part of this morning's session will be devoted. It is of course manifest that we are not very far in either program, but I believe here that we are so close to it that we miss, somewhat, an appreciation of how very much more we know now than we did a few years ago. It is only three years ago that we could raise somewhat foggily the question of were there selection rules which accounted for the stability of these particles. It is only two years ago that we noticed that rather peculiar structuring of the mean lives of the particles between 10^{-8} and 10^{-10} seconds. It is only last year that we were clear enough that the selection rules had some connection with isotopic spin, to be talking about charge doublets and charge triplets. And this year I think there is a new point which will come out, and that is that in addition to the charge degeneracy, there appear to be other degeneracies, or quasi-degeneracies which do have a connection with the theory of the stability of these particles.

Rossi then presented a summary of the two cosmic ray sessions. He started with the tabular summary of the various particles as given on the previous page. There is first the well known particle which decays into a proton and a negative pion. The new information with regard to this particle which has come out in this meeting is a very precise measurement of the Q value from one event observed in photoplates at Bombay which gives 37.1 .3 Mev. There hasn't been any new information about the anomalous (high or low) Q values reported by the California group, except that there are still two events which deviate considerably from this Q, and which might be explained by an alternative mode of decay into a proton, muon, and neutrino. There is a new precise measurement of the mean life from the Cal Tech group which is 3.86 .75 x 10^{-10} compared to the previous best value of 3.7 .6 . There is some indication from the Tata group for Q values slightly larger than given above, but I don't know how much reliance one can put on the findings

About the charged hyperons, the definitely exibits two alternative modes of decay as give above. There has been quite a bit of new information about this particle. There were previously only four events of the type $\Sigma^+ \rightarrow p + \pi^0$ observed in photoplates decaying at rest and giving a Q value of 116 ± 2 Mev. There are now two additional events from Bristol, two additional events from Padua, and one additional event from Ta ta; they all coincide with this 116 (also 2 from Wisconsin). With regard to the decay $\Sigma^+ \rightarrow n + \pi^+$, the data comes from photoplates. The particle decays sometimes at rest, but very often in flight, so it is not possible to tell whether it is a Σ^+ or a Σ^-. The measurements are not as accurate as for the first mode of decay, except when the emitted particle comes to rest at the end of its range, and you don't have to estimate its energy. But it is fairly sure now that this alternative mode of decay exists. As for the negative hyperon (Σ^-) before this meeting, there were only two events, of which I think only one was really good. They are from Shutt 's group. During this meeting two more such events have been presented by Fretter, negative hyperons that decay in flight in a cloud chamber. The Q value for this mode of decay seems to coincide with the Q value for the positive decay. There is also one decay in flight observed at Turin which is known to be negative since the pion makes a σ star. There is a new determination of the mean life from Bristol, giving it as shorted than 10^{-10} seconds.

There were previously five cases of the cascade particle $\Xi^- \rightarrow \Lambda^0 + \pi^-$ with a Q value of about 60 Mev. I know of one more case presented at this meeting from Princeton which gives a Q value of 59 ± 6 Mev. LePrince Ringuet also hase one case which fits. There is no determination of the mean life, but from the way it is observed (decay in flight in cloud chambers), it seems to be of the order of 10^{-10}.

Now we come to the well known τ meson, decaying into three pions with a Q value of 75 Mev. There are some new determinations of the Q value from the Bombay group which spread between 74 and 79 Mev with an average of about 75. There was no new information on the alternative mode of decay into one charged and two neutral mesons. However one very interesting event has come from the Bombay group in which the Q value appears to be much lower, and moreover the three particles are not coplanar. The neutral particle has its energy equal to its momentum, so it must be a massless particle, and it is reasonable to assume that it is a photon. There is a lifetime determination from Padua, where they found one case of a τ meson decaying in flight in photoplates compared with ten cases of decay at rest, and gives about 5×10^{-9} sec.

We come now to another well-known particle, the θ^o, which by now we are sure decays into two pions (not a pion and a muon) with a Q of 214 Mev. There is no new information on the lifetime; the value quoted is given by Page. As to anomalous decays which don't fit this scheme, there are two possible interpretations. One is an alternate mode of decay of the θ^o into $\pi + \mu + \nu$, and the other is to postulate a neutral counterpart of the τ decaying into $\pi^+ + \pi^- + \pi^o$. The only new information which has come out in this meeting are two new events from Indiana which fit either description. The majority of events available today could be asserted to be τ^o, but not all of them. Those that could not be τ^o could be $\theta^o \rightarrow \pi + \mu + \nu$. (Thomson noted that some could also be radiative decays.) Since some of the Q values are very low, Rossi believes a combination of these two explanations is probably required.

Now I come to the really difficult part. These are the charged heavy mesons that decay into a single charged particle. Let us forget about those that can be explained by the alternate mode of decay of the τ. There are quite a few, and I think that there id quite good evidence that this phenomenon exists. As for the rest, I think it best for the moment to stick to a phenomenological description, namely K_{π_2} K_{μ_2} K_{μ_3} and K_{e_3} . I would now like to go through the evidence for and properties of these modes of decay.

First of all, what is the evidence for a two body decay with a pion secondary? There are two pieces of evidence, one coming from photoplates, and the othr from cloud chambers. The evidence from photoplates is not very abundant, but is rather convincing. There are three very good cases presented by the Padua group, one by the Brookhaven group, and I am sure there are a few others around, in which the secondary particle is recognized to be a pion. One case from the Tata group is particularly important, because the secondary particle is recognized to be a π because it undergoes interaction in flight. In the other cases the secondary particle is recognized to be a π from grain counting and scattering. In these cases where the secondary particle is surely a π, and it is not of such low energy as to be applied to the alternate mode of decay of the τ, the Q value appears to be unique. You can also make a measurement of the primary mass, as has been done by the Padua group, and if you compare the mass of the primary with the energy of the secondary, the neutral particle turns out to have a mass of 269 ± 50, which makes it appear quite likely that it is a π^0. The Q value is then very close to that for the θ^0.

The other piece of evidence comes from cloud chamber work, the work with the multiplate chamber at MIT, and the work with the magnet chamber at Princeton. The MIT evidence is the following. If one looks at particles which come to rest in one of the plates of the chamber, and if one looks at the secondary particles which come out, there is a group of such secondary particles which stop at this range of about 60 gm/cm^2 of lead. In all of these cases but one, there is an electron shower, which is not due to a photon emitted directly, because it does not go in the opposite direction from the charged particle. Hence in the multiplate cloud chamber work, there is direct evidence for the π^0. The energy of the charged π also agrees with the value from photoplates. Then there is the very famous Princeton event where one sees the decay in flight of a charged particle into what appears to be one meson and two electron pairs. If one interprets the two electron pairs as being from the decay of the π^0 and if one makes momentum balance, one finds again the same mass. The very peculiar thing about this event, as you well know, is that it should never have been observed, because the probability of the direct decay of the π^0 into two electron pairs is really small. So I don't think there is much doubt about the existence of this K particle, which sometimes is called a χ by photoplate people, and sometimes a $\theta^{\pm}$ by the theorists. (Rossi could think of no <u>direct</u> evidence for θ^-; the general question of charge asymmetries is discussed below.)

There is some uncertainty as to just what the lifetime of the K_{π_2} is. Rossi would guess that the lifetime cannot be much shorter than 10^{-9}, because the time of stopping in his chamber is this long." I would put about 10^{-9} because I try to explain an apparent contradiction between our results and those of the group in Paris.

at the Ecole Polytechnique. There the time of stopping is 5×10^{-9} . One cannot overemphasize observational bias. Once you have found one event, you go back to your pictures and find five more. So, although this is an indication that the mean life is not far from 10^{-9}, I wouldn't be surprized if it came out to be 10^{-8}."

The very strong evidence for the K_{μ_2} comes from the multiplate cloud chamber work at the Ecole Polytechnique and MIT. After some initial apparent discrepancies, the results of the two groups agree quite well. First of all, if one looks at particles which stop in the plates and looks at the secondaries, there is among the secondaries a group with a range of about 100 gm/cm^2 of lead. There are nine such cases in the Ecole Polytechnique pictures, and five at MIT. Independent evaluations of the range are 99.5 at EP and 102 at MIT, which is the same within experimental error. Why do we say that the charged secondary is a μ? One should have seen at least five nuclear interactions at MIT if it were a π. Another argument is that the primary mass measurements (EP) are inconsistent with the secondary being a π. Why is the neutral particle a neutrino? Both a gamma ray and a π^0 are ruled out because there are never gamma rays (i.e. showers) associated with the decay of K_{μ_2}, and they would certainly have been seen if present. Also the mass argument again rules out the π^0. The mean life, according to estimates presented by LePrince-Ringuet, is of the order of 10^{-8} seconds. This is subject to some uncertainty, because the identity of the particles which decay in flight is not always well known. There is some uncertainty about the mass, which would not be very important if we did not want to be sure that it is different from the mass of the τ and θ. From an unbiased evaluation of all the experimental evidence, one would put the mass at about 940 m_e. That it should be as high as the τ mass of 965 seems less likely after this meeting than it did before. The difficulty with trying to get a precise value from the range of the is (a) uncertainty in range due to scattering in the plates, etc. and (b) uncertainty in the range-energy relation. The masses of the above K particles are:

$$\begin{array}{ll} \tau & 965 \\ \theta^{0} & 966 \\ K_{\pi_2} & 955 \pm 20 \\ K_{\mu_2} & \sim 940 \end{array}$$

There is essentially no new information on the K . There is no r ason to doubt its existence, since there are five or six cases of low energy 's stopping in emulsion. What makes it troublesome is that it appears rather prominently in photoplates, and we fail to see it in cloud chambers, at least if we look at particles which stop. Of course we would not get the low energy mesons, because these would, for the most part, be absorbed in the plates. However, the photoplate evidence seems to indicate that there are also mesons of higher energy which be seen in multiplate chambers; of course only the low energy mesons are identified by decay in emulsion. But high r energy 's have been identified by grain counting and scattering. It might be possible that the decay spectrum of this particle is very crouded toward the low energy end, so that the probability of detecting them in a cloud chamber is small. One possibility leading to this would be an alt rnative mode of decay of the K going into . The oth r possibility is that the mean life is too short or too long. If the lifetime were very short, you should see many decays in flight in the emulsions, which is not the case. If the life were of the order of several milliseconds, the cloud chamber would no longer be sensitive, and again it would not be seen, a rather strange possibility. I don't believe there is any direct by LePrince-Ringuet. This particle decays into a μ in flight 10^{-9} seconds after it is born, and has a transeverse momentum p* of 1.8 which is too small for a K_{μ_2}. Thompson noted that many of the events observed on photoplates could be capture proceeses rather than decays, which would help to remove the discrepancy. In reply to a suggestion of Shapiro's that perhaps too few K_{μ_3} have been seen to explain it as an alternative mode of decay of K_{π_2}, Oppenheimer noted that we have no way of knowning the branching ratio. We have only to look at the K_{μ_2}, with the same decay products and lifetime as the π meson but an enormously greater energy release, to realize that we have no idea at present how to handle such a question.

As to the K particle which decays into an electron and two neutral secondaries, the conference has added quite a bit of new information. Before this conference there were to Rossi's knowledge only two, and now there are about seven such cases. There are three from Bristol giving a $p\beta$ of 88, 49, and 81 Mev/c, two from Berkeley with $p\beta$ of 56 and 110, and two from Rochester giving a $p\beta$ of 20 and 261. One from Berkeley and one from Rochester are considered not completely sure, but very likely. Again, the particle is not seen in cloud chambers.

The evidence for the K_{1400} particle still rests only on mass measurement, and nothing is known about its decay. Menon reported that this mass measurement still stands, an there is some supporting evidence from Pickup. This question will be settled when these particles can be followed to the end of their range in the large emulsion stacks now coming into use.

Turning to the question of sign asymmetries, all cascade particles seen so far are negative. As to the τ meson, Leprince-Ringuet has presented cloud chamber evidence showing that positives and negatives are about equally abundant. Of eleven decays in flight, six are positive and five are negative. But the positive are all slow, and the negative are all, except one, fast; so there might be a different excitation curve for each. Also there might be a detection bias against the negatives.

The situation with regard to charged hyperons is not clear. Both positive and negative hyperons are seen, but since there are two decay modes for the positive and only one for the negative, this might introduce a bias against the positives. Positive information comes from Cal Tech and is confirmed by Indiana to the effect that there are a large number of short lived negative particles. If one attributes these to Σ^-, then they are much more abundant than Σ^+.

There is some circumstantial evidence that there are both positive and negative K_{π_2}. The group at the Ecole Polytechnique find 22 positive K_{μ_2} and only one negative. But of the decays in flight which are certainly not hyperons, and can be either K_{π_2} or K_{μ_2}, there are equal numbers of positive and negative. This would seem to indicate that all the K_{μ_2} are positive and all the K_{π_2} are negative; but the K_{π_2} which decay at rest must be positive. On the basis of this rather contradictory evidence there must be both positive and negative K_{π_2}. In these cases also, it appears that positives are much more abundant than negatives among the slow particles. In photoplate work presented by Menon ans Salant where secondary particles of low energy were selected there is again a great preponderence of positives. In the survey by Menon, in which there was no bias with respect

In Salant's experiment, where the detection efficiency is believed to be mcu higher for negatives than for positives, he finds 20 K^+ and 1 K^- indicating a tremendous +/- ratio.

There is a considerable amount of new information on interaction with and capture by nuclear matter. There are now a fairly large number of cases where a K particle undergoes some sort of nuclear interaction and emerges still as a K particle; of course whether the identity of the K particle has changed is not known. There are two such events from Bristol, four from Tata, and one from Berkeley. Powell has one K particle which disappears in flight, and Salant has three which cause small stars in flight and disappear. All this indicates a mean free path of nuclear dimensions. We already knew that when K^- come to rest they produce stars from which, very often, hyperons come out. (3 from MIT with a Λ^0, one from Manchester with a Λ^0, and one from Milan or Genoa with a charged hyperon.) There are now 8 additional K^- capture events presented by the Padua group; no hyperons were seen, but there were π meson secondaries with energies from 30 to 50 Mev. There is one event from Tata which is not sure because, if the Λ^0 came out, it decayed very close to the star. Salant reported on sixteen K^- captures in five of which was either a hyperon or an excited fragment emerged. A few new cases were reported of nuclear capture of negative hyperons (1 Bristol, 1 Padua, 1 Tata); not much happens, that is there is only a small star. Fry has one case which is of interest because the energy is above 100 Mev, which is too high for a Σ going into a Λ following charge exchange. Salant also has four cases which are too energetic for a Λ being produced.

The most illuminating results regarding the production of these articles come, obviously, from experiments in hydrogen. Unfortunately very few such events have been observed so far. There are only three cases of the type $\pi^- + p \rightarrow \Lambda^0 + \theta^0$, one analysed by Shutt and two by Bill Walker. Shutt's event and one of Walker's are normal. Walker's other event is abnormal in the sense that you cannot balance energy and momentum. It is consistent with either $\Lambda^0 + \theta^0 + \gamma$ or $\theta^0 + \Sigma^0$ with $\Sigma^0 \rightarrow \Lambda^0 + \gamma$. There are three events in which only the Λ^0 is observed; all of these are abnormal in that the unobserved particle cannot be just a θ^0. They can be eplained either by an additional γ-ray, and additional π^0 meson, or by the assumption that the Λ^0 comes from the decay of a heavier hyperon. There are two cases where only the θ^0 is seen, one normal and one abnormal in the above sense. Thus there is good evidence for associated production in hydrogen. As to the production of charged particles in hydrogen, Shutt has three cases of a charged hyperon and charged K meson; in one case the hyperon is negative, and in the other two it could have either sign. There are many examples of double production in heavy elements, which are, of course, difficult to analyse so directly. But it may be significant that in all cases where two particles are seen, they are a hyperon and a K meson. Another piece of indirect evidence comes from the threshold for production (Cf. Collins' report below). In nucleon-nucleus collisions, the energetic threshold corresponds to the production of a Λ^0 and a K particle, not to the production of two Λ^0's or a Λ^0 and a hyperon. Shapiro noted, however, that if one traces back a K meson to the star from which it originated, one rarely finds a hyperon associated with it. In eight cases examined so far, he has found no hyperons.

As to angular correlations in production, Cal Tech, MIT, and its decay plane. In the case of double production of a Λ^0 and a θ^0, the Princeton group find that when the decay plane of one of the particles makes a large angle with respect to the production plane, the decay plane of the other particle makes a small angle with respect to this plane. A correlation noted by Shutt is that in π^-p production, the Λ^0 tends to follow the line of flight of the nucleon.

Extensive work by Fry on excited fragments revealed two cases in which a K-meson was emitted. Most of the othr cases are consistent with a bound hyperon, for example a Λ^0, bound with an energy somewhat smaller than that of the nucleon it has replaced. In two case the energy release is too great for a Λ^0, but consistent with a Σ.

In discussion it was noted that Menon had four cases of associated production, and Leprince-Ringuet one ($1S + 1V^{\pm}$). Shutt noted that for 7 hyperons, the plane of decay always made an angle less than 40^0 relative to the plane of production, and that the average was about 20^0. Rossi noted that this is, of course, much more significant than the lack of correlation in heavy nuclei. Goldhaber noted that his K_e lived at least 1.5×10^{-9} seconds. He also reported that of 50 K particles at Berkeley, all but one have decay products; however, they have no idea of their efficiency for find such (negative) particles that do not decay. Fry noted that in the two cases where a K particle comes out, they cannot exclude the possibility that the particle connecting the stars is negative, undergoing nuclear capture; that is, these are not necessarily cases of excited fragments.

Rossi closed that there were a lot of stranger things reported that he had not included in his summary.

(5 minute break)

Pais reported on views which have been expressed with regard to the new particles, especially: what is the source of their remarkable stability, how might one order their various decay schemes, and how one might understand something about their production. I will try to emphasize certain views which have been expressed by different people, in particular by Gell-Mann and myself (Pais), and which at first sight may seem to be contradictory, but are, as a matter of fact, very intimately related.

Of course the great question really is, what is a particle? I don't think anyone will object if I say that a particle is characterized by mass and spin, which are the only properties we can define without talkking about interaction. If we talk about interaction, the gross properties with which the experimentalists deal are its electric charge, the only charge which we know is conserved, its relative intrinsic parity, and its lifetime. The question is if this list of entities is sufficient to lable a particle in a unique way.

To make a very broad distinction about ways of thought about the mew particles, one is "are they composites?" in a fairly conventional sense. For example, is the Λ^0 a bound system of a proton and a π^-? If it is so that we have to deal with composites and can describe everything in terms of conventional quantum numbers and conventional dynamics, we are certainly dealing with unconventional values of quantum numbers. That is if the Λ^0 is a π^- and a proton bound by an enormous potential barrier such that a π^- can come in at high energy, give up most of its energy in some way, and remain bound in a metastable state, the barrier has to be big for two reasons. In the first place you have to stabalize against pion emission, and in the second place because you have to stabalize against gamma emission. The proposition as to theoretical views about this particle is always the simultaneous stability for these two processes. This idea of high angular momentum makes it extremely important to find out about the angular correlations. The experimental situation is unclear and this question is still open. If you have such high angular momenta, then at not too high energy, you will also have the possibility of associated production. That is the system will want to emit two high angular momentum particles at a time so that they can compensate for each other, since the angular momentum in the beam itself is not so large. The experiments in hydrogen at Brookhaven are consistent with associated production, but this does not mean that associated production always takes place. Hydrogen experiments with the Bevatron, where we are so far above threshold that such arguments cannot help us out any more, will settle the question at medium (4-5 Bev) energies. It is remarkable that no one has yet seen the productoin of two Λ^0's, which has a low threshold, and to which, from the point of view of angular momentum, there is no objection. Another point which I think quite important, is the question of the +/- ratio.The situation is not clear, but perhaps Professor Rossi will not object if I say that at not too high energies the +/- ratio is marked, and that at very high energies it tends much more toward unity. This is really quite important from the point of view of composite theories, because if you use the nucleon-pion system to account for the new particles, and if you think this system is charge independent (certainly charge symmetric), it would be hard to get this marked asymmetry. Here one must be careful, because the a symmetry might be due to asymmetric initial conditions, rather than the nature of the interaction.

Pais knows of only one alternative to the composite system approach to the problem, where you have to deal with matrix elements which are steeply dependent on energy. In the other approach one says that there ate two basic interactions, sharply to be distinguished, a srtong production interaction and a weak decay interaction. Stability then comes about by assuming that associated production always takes place. This has certainly not been proved experimentally, and one counter-example would be enough to disprove it, but Pais feels the experimental situation is more encouraging than when he first suggested this idea. So associated production will be assumed in everything that follows.

According to this view, the following reactions <u>must</u> be slow:

$\pi + N \rightarrow Y + \pi$		N = nucleon
$N + N \rightarrow Y + N$		Y = hyperon
$\pi + N \rightarrow B + N$		B = heavy boson (K mass)
$N + N \rightarrow B + N$	N	

The reactions which <u>may</u> be fast are:

$\pi + N \rightarrow Y + B$	$\pi^- + p \rightarrow \Lambda^0 + \theta^0$ or $\Sigma^- + \theta^+$
$B + N \rightarrow Y + \pi$	$K^- + p \rightarrow \Lambda^0 + \pi^0$
$N + N \rightarrow Y + Y$	never seen
$N + N \rightarrow Y + B + N$	
$B + N \rightarrow B + N$	scattering
$Y + N \rightarrow Y + N$	$\Sigma^- + p \rightarrow \Lambda^0 + n$

The following things are to be noted about these reactions:

(1) The number of nucleons plus hyperons id conserved. One of the basic problems is to understand this conservation law, namely that the number of baryons minus the number of anti-baryons is conserved.

(2) Any number of pions or gamma rays can be added to either side of these equations without violating anything about this associated production.

(3) Menon say an event in which a Σ^-, pehaps, and a χ particle emerged from one star. If the χ particle is a fermion, it means

would like to know to what extent it is certain that the decay scheme is $K \to \mu + \nu + \nu$ rather than, say $K \to \mu + \nu + \pi^0$. As to why you do not always see associated production, there are a couple of trivial remarks. In the first place, a Λ^0 can decay invisibly into two π^0's about half the time. It is also important to remember that there is a spread of lifetimes from 10^{-8} to 10^{-10}, so that certain experimental setups may not detect the decay of both particles produced.

If there is associated production, why is it true? This is a type of conservation law. If you want to go beyond a purely phenomenological statement, you would like to have rules as to what may be fast and what may be slow. You would like then to have further rules that would lead to more detailed predictions, and so on. In order to sketch what the situation may be, let me make a distinction between three groups of interactions, namely strong, electromagnetic, and weak. The strong interactions comprise nuclear forces, new particle production, and hyperon bonding, and the weak ones are beta decay, muon decay, and the decay interactions of the new particles. We then have the following conservation laws:

Conservation Law		Strong	Electromagnetic	Weak
Absolute:	charge barvons	Yes	Yes	Yes
Charge Independence		Yes	No	?
Stability laws		Yes	Yes	No

The attempt has been made to understand these stability laws for the new particles in terms of the more familiar, but also not understood law of charge independence.

A couple of years ago I suggested that one could characterize the srong and weak interactions as even or odd, and it of dynamics by itroducing isotopic parity. This isotopic parity proved inadequate to stabilize enough particles. But here is the idea of assigning quantum nombers to particles and symmetry properties to interactions. Then if the quantum numbers work out, you can ask where they come from. The idea behind all this is to try to see a connection between the stability laws, and the symmetry of the "internal dynamics"of the particles. Just as in atoms, where you have a very complicated structure with very many levels, there are a few levels which are metastable, due to the symmetry of the object ant the kind of interactions you allow the object to have. I will therefore sharply distinguish between the problem of stability, and the problem of predicting the masses. We may be in reach of attempting to predict stability; the mass problem is much more intimately connected with the dynamics; there may well be many more short lived states we know nothing about.

Now let me come to an attempt by Gell-Mann of assigning quantum numbers to particles which seems to show promise. In the first place, what is charge independence in the conventional sense? One says that for the charge of the nucleon $Q = I_3 + \frac{1}{2}$, and that for the pion the charge $Q = I_3$. This is not charge independence, but part of the game, for trivial reasons, because charge is absolutely conserved, and the total number of nucleons minus anti-nucleons is conserved, so that the $\frac{1}{2}$ is also absolutely conserved. It is therefore trivial to say that I_3 is conserved. What is not trivial is that I_3 is the three component of an angular momentum I, and that I^2 is a good quantum number in interaction. The Gell-Mann idea is to relax the relation between Q and I_3, in a well defined way. This gives the following level scheme for baryons.

−	0	+	I	Q
Ξ^-	Ξ^0		$\frac{1}{2}$	$I_3 - \frac{1}{2}$
Σ^-	Σ^0	Σ^+	1	I_3
	$\downarrow \gamma$ Λ^0		0	I_3
	n	p	$\frac{1}{2}$	$I_3 + \frac{1}{2}$

The game we are now going to play is the following. Q is, of course, conserved in all interactions. We assume I_3 is conserved in strong and electromagnetic interactions, but not in weak interactions. But in order to play this game completely, we must also say something about the K particles. Here we shall be a little bit cautious and call them B, not θ^0, θ , etc. This level shceme is:

$I = \frac{1}{2}$, $Q = I_3 - \frac{1}{2}$	B^-	B^0	B^+	$I = \frac{1}{2}$, $Q = I_3 + \frac{1}{2}$
		$\bar{B}^0$		
	π^-	π^0	π^+	$I = 1$, $Q = I_3$

Under this shceme, which interactions are allowed (i.e. for strong or electromagnetic processes) and which forbidden? This gives immediately:

Associated Production

$$\left.\begin{array}{l} N + N \to Y + Y \\ \pi + N \to Y + B^- \ (\text{or } \bar{B}^0) \\ N + N \to N + Y \quad B^- \end{array}\right\} \text{forbidden}$$

$$\left.\begin{array}{l} \pi^- + p \to \Lambda^0 + B^0 \\ \qquad\quad\ \ \Sigma^- + B^+ \\ \qquad\quad\ \ \Sigma^0 + B^0 \end{array}\right\} \text{allowed}$$

Σ^0 unstable against gamma decay to Λ^0 ($\Delta I = {}^{\pm 1}_{0}$ for em if

$$\pi^- + p \to N + B^+ + B^- \qquad \text{allowed}$$

Note that the first time you can get a B^- you will also get a B^+. It is therefore very interesting that the +/- asymmetry at low energies seems to be wiped out at high energies as is predicted here. The essential point in all this is to introduce a dis-

There are several points to be made about the cascade particle. First of all, because of this charge displacement, there is Ξ^- but not Ξ^+. Secondly Ξ^- cannot rapidly decay into any other baryon. Thirdly, in order to make a Ξ^- in a pion-nucleon collision, it must be accompanied by at least two B particles. Finally, although Ξ^0 is not observed, its decay is to $\Lambda^0 + \pi^0$ or $n + \pi^0$, which is difficult to detect.

At this point Pais interrupted his talk to make a plea not to us words like strange or peculiar (in referring to the new particles). For a theoretician, a proton ought to be just as peculiar as a hyperon. This is only terminology, but one should bear it in mind.

Now comes the question, what id B? There we are, perhaps, in trouble. First of all, there are a great variety of K particles. We do not know how many of them are alternate decay modes of one kind of particle, but we do perhaps know (cf. Dalitz report below) that not all of them can be one kind of particle. That is, the τ and the θ seem to have different space-time properties. Up till now, when we talked about multiplets, it was kind of tacitly understood that within a multiplet the only distinguishing feature was the charge. For example, if the charged mesons were pseudoscalar and the neutral meson scalar, you would say it was nonsense to talk about this thing as a triplet. But if , as appears likely, we are dealing with multiplets that are mysteriously degenerate, we have something very new to worry about.

Oppenheimer noted that you would probably want to say that particles with different lifetimes are not the same particle. Pais commented that the θ^0 has about the same lifetime as the hyperons, which may be one reason why experimentally they are so oftem seen together. Further there is no evidence that among

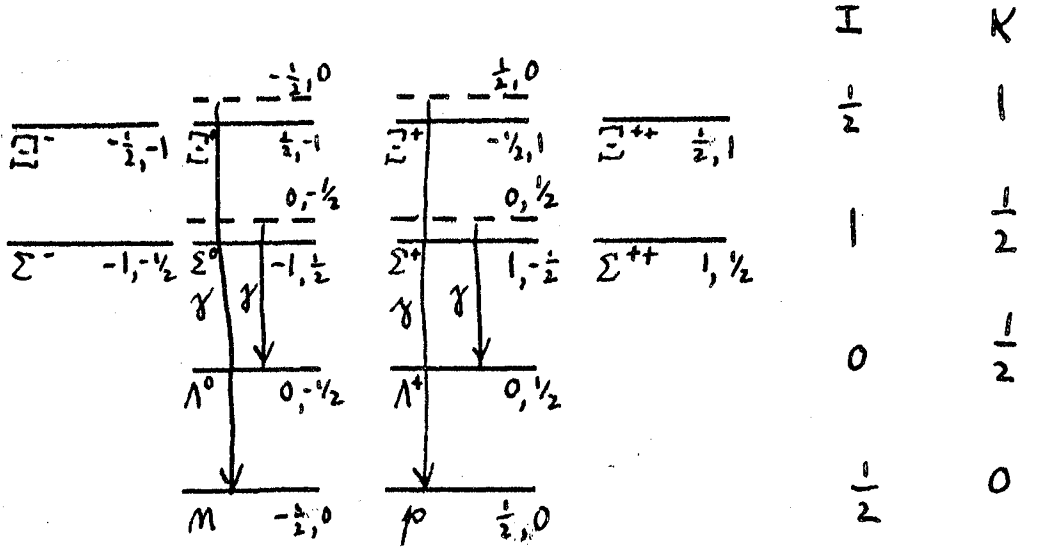
This is not in any way a contradiction; you need only think of the difference between π^0 and $\pi^{\pm}$. But of course if one finds more than one lifetime among K particles of the same charge, then there are at least two different kinds of particle. Feynman remarked that two particles which are produced in associated production ought not to have lifetimes which differ by many orders of magnitude, because they could then go backward through that strong interaction and come out the other side. But all the present experimental lifetimes are close enough so that this would not happen. Oppenheimer noted that one might turn this argument around and say that this scheme of associated production has in it, also, the virtual explanation of the fact that the lifetimes are about the same. Dyson noted that there is nothing to prevent the from having a very different lifetime from the other hyperons.

In worrying about what dynamics might be associated with this set of quantum numbers, Pais noted that in decay we might have the selection rule $\Delta I_3 = \pm\frac{1}{2}$ for weak interactions. This would then allow the cascade particle to decay to a Λ^0 but not to a neutron. (Then Ξ^0 would be long lived for the decay $\Lambda^0 + \pi^0$ and hard to detect). Gell-Mann noted that this might suggest the stronger rule $\Delta I = \pm\frac{1}{2}$. But what is behind this selection rule? In the first place we noted that the center of gravity of the nucleon Q and I was displaced by $\frac{1}{2}$ relative to the center of gravity of the pion Q and I. We could do this freely because the nucleons are conserved separately. This suggests that one might write down $Q = I_3 + K_3 + \frac{1}{2}$ for all the baryons, and $Q = I_3 + K_3$ for the bosons. That the $\frac{1}{2}$ is conserved is trivial since baryons are conserved. That Q is conserved is trivial; this is just conservation of charge. Hence it is trivial that $I_3 + K_3$ is conserved. There are now two third component of the isotopic spin, where I^2 is a good quantum number for strong interactions only, is not trivial. The second thing which is not trivial is that I_3 and and K_3 are conserved separately in strong and electromagnetic interactions. Note that if $\Delta I_3 = \pm\frac{1}{2}$ then $\Delta K_3 = \mp\frac{1}{2}$ for weak interactions. Therefore I wa lead to say that there is obviously another quantum number in this game, which I would like to attribute to certain state of angular momentum, or something, so that you know that it does belong here. The next point is that the isotopic spin for these various states is given integer and half-integer values. But you can easily convince yourself that if you have a particle which is capable of different states, that this particle cannot be allowed to have integer and half-integer states at the same time, as long as you work with the three dimensional rotation group. This simply because the integr and hal-integer states are orthogonal to each other. This was proved by Pauli in Helvitia Physica Acta , 1939. Finally, I have been unable to construct an iteraction which carries away $\Delta I_3 = \pm\frac{1}{2}$.

This leads to the idea that the internal dynamics of these particles is a four-dimensional dynamics. This may at first appear arbirrary and excessive, but I want to make it clear that though it may be wrong, it is not arbitrary. First consider an ordinary top in three dimensions. For this object we can write down an angular momentum L in the fixed system and an angular momentum K in the body system. Then we have the usual commutation relations: L_i: L_1, L_2, L_3 $[L_i, L_j] = iL_k$; K_i: K_1, K_2, K_3 $[K_i, K_j] = iK_k$; $[L_i, K_j] = 0$; further $L^2 = K^2$. Therefore if you have a spherically symmetric top, you have three quantum numbers: L^2, L_3, and K_3. That is why a standard top has $(2L+1)^2$ degeneracy. And these two three components begin to smell of something I was talking about before. What has this to do with the four-dimensional rotation the six components of an anti-symmetric tensor, and similarly for K. Then you can, of course, write the commutation relations for the L_{ij}, and what you find is that these are the commutation relations of a four-dimensional angular momentum. In particular you find that you are entitles to write $L_{ij} = i(x_i \frac{\partial}{\partial x_j} - x_j \frac{\partial}{\partial x_i})$ where now i,j run from one to four. In some sense there are two three-dimensional rotation groups, but they are connected in a very particular way. Now, what are the eigenvalues of the angular momentum? They are $K(K+1)$. If we have a physical top, eg the molecular approximation, K takes on only integral eigenvalues. What I want to use in this game is that K be amenable to integral and half-integral eigenvalues. You can in fact prove that if K is to take both integral and half-integral values, you are forced into the four-dimensional space and you make I span the full unit sphere in the four-dimensional space. This is the point where the transition is made from three to four dimensions, because if that were not so it would be unnecessary to talk about four dimensions.

Very simply then, the model is the following. For spin $\frac{1}{2}$ particles, I replace $\vec{L}$ by $\vec{L} + \vec{\tau}/2 = \vec{I}$, and I keep $\vec{K}$. Then I^2 is no longer equal to K^2, as in the case with no spin, but $\vec{I} = \vec{K} \pm \frac{1}{2}$. Then we can lable states by two quantum numbers (I,K). For the bosons we let $\vec{L}$ be replaced by $\vec{L} + \vec{T}$, and then $\vec{I} = \vec{K} \pm$ (1 or 0). Then you find something amusing, namely that if you take $L_3 + K_3$, this is equal to L_{12}. Here is something that smells very much like what goes on with the level scheme given before. You see the several understood decay processes give you an elementary rotation in four dimensions, namely the rotation in the 12 plane. It is just the rotation you have in the ordinary isotopic spin space, which is also in the 12 plane, but there it was around the 3 axis, while here it is around the 34 plane. if you

The resulting level scheme is given below, with the individual levels labeled by (I_3, K_3).

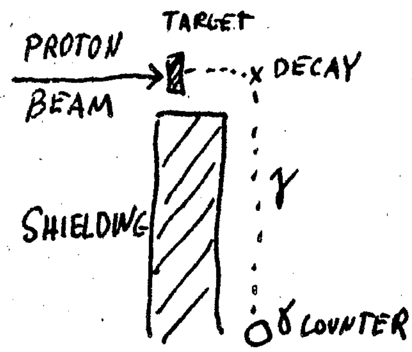


Clearly we have all the particles we had before, but many others as well. This is the point which always causes tremendous trouble, that is too much degeneracy and doubly charged particles. There is one way of getting out of this, which may not be the best way, whhich is to say that the spectrum is split with respect to K_3. You might say that instead of a spherical top, we have a symmetrical top. This affects the doubly charged particles in the following way. There is an important limit in this game, which I call the first K particle limit. As soon as you have a mass greater than a nucleon plus a K particle, you have to ask whether the particle is stable against this decay. And all the states we wish to get rid of are, in fact, unstable against this decay if they are massive enough. So if the K_3 splitting is large enough, you return to a level scheme which is identical with that given by the Gell-Mann phenomenological rules, if the level given above as Λ^+ is raised to about the level occupied originally by Σ^+, and all the other positive hyperons are raised above the first K particle limit.

This may or may not be important with respect to the question of the fragments. If I have a hyperon in nuclear matter, then I have to ask new stability questions. The following is true. A Λ^0 is stable inside a nucleus. (This raises an interesting point. If this scheme has anything to do with the truth, there is a remarkable property of the Λ^0. It has isotopic spin zero, which means tha t it cannot interact with a nucleon with the emission of an odd number of mesons, because zero-zero transitions are forbidden. So if the Λ^0 can interact with the nucleon via the pion field, this will sort out the even powers of this interaction from the odd powers!) But, although the Λ^0 is stable in nuclear matter, all the other levels are unstable because, for example $\Sigma^- + P \rightarrow \Lambda^0 + N$, $\Sigma^+ + N \rightarrow \Lambda^0 + P$, $\Xi^- + P \rightarrow 2\Lambda^0$, etc. So any hyperon in nuclear matter will degenerate immediately to the lowest hyperon state Λ^0. So stars corresponding to the energy release of a Λ^0 with appropriate corrections for its binding energy fit nicely into this picture. But if you have fragments which live a typical hyperon lifetime, but give an energy release bigger than this, according to this picture they cannot be due to bound Σ^-, Ξ^-. Two remarks can be made about this. In the first place there may be additional selection rules which are not yet included. Yama and Tabockman have written a very interesting little note in which they showed that if you make a certain restriction on the structure of the interaction, that space parity may serve to inhibit certain reactions, and hence one can arrange the relative intrinsic parity of hyperons in such a way that some of these states could be long lived in nuclear matter. The other point is that the positive hyperon, which we assumed came from the splitting of the Λ level, can be shown also to live long in nuclear matter.

Finally, one can ask if it is possible to have hyperons a bove the K particle limit which are stabalized against free decay both Eisenberg and Fry have pictures of particles which may be of this type. These particles should be accompanied by more than one K particle in production. They can be included into the Gell-Mann scheme without introducing any doubly charged particles, but in Pais four-dimensional scheme their existence would entail that of doubly charged particles as well.

Collins then reported on an experiment which lends support to the Gell-Mann, Pais prediction that in nucleon-nucleon collisions you will produce a hyperon and a K meson but not two hyperons. The experimental arrangement is sketched below.



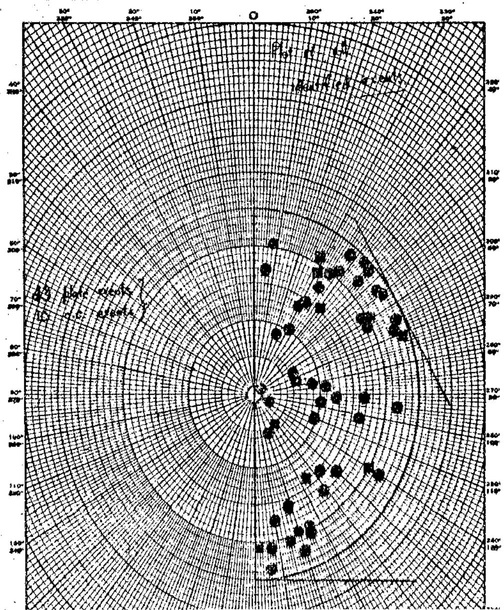
Since the counter detects gamma rays, this experiment is intended to pick up the gammas arising from π^0 decay, where the π^0 cannot have been produced in the target, but presumably comes from some heavy particle decay such as $\Lambda^0 \rightarrow \pi^0 + n$ or $\Sigma^+ \rightarrow \pi^0 + p + \gamma$, etc.
The counter is sensitive to gamma rays of an energy greater than about 30 Mev, and is rather insensitive to star products or charged particles in general. The target can be moved back and forth thus varying the diatance from the target to the decay point seen by the counter. Starting with the decay point 5 cm from the target, the number of counts falls to 1/e of its initial value when the target is muved upstream 2.5 cm. This is of the right order, since it corresponds to a decay lifetime of about 10^{-10} second for a particle moving with the velocity of the center of mass in the nucleon-nucleon collision. If one now examines the variation of the number of counts with the energy of the protons incident on the target, one gets a typical threshold curve with both carbon and copper targets, the threshold being about 1.1 to 1.2 Bev. If one looks directly

one gets a very different excitation function, which is one piece of evidence that the experiment is being correctly interpreted. There is, of course, a finite chance that some subtle mistake is being made. This threshold figure is to be compared with the calculated thresholds for various processes given by Sternheimer. We see that the threshold for the production of $\Lambda^0 + K$ is surprisingly close to the observed value, while processes in which a single K or one or two hyperons are produced should occur at much lower energies. The acid test of this will be when the experiment is repeated, taking a carbon-polyethylene difference. Then the threshold should shift up by just the 1.55 Bev point. The dependence of the threshold on assumed Fermi energy is given in the table at the left for the particular case $P + N \rightarrow P + \Lambda^0 + K$.

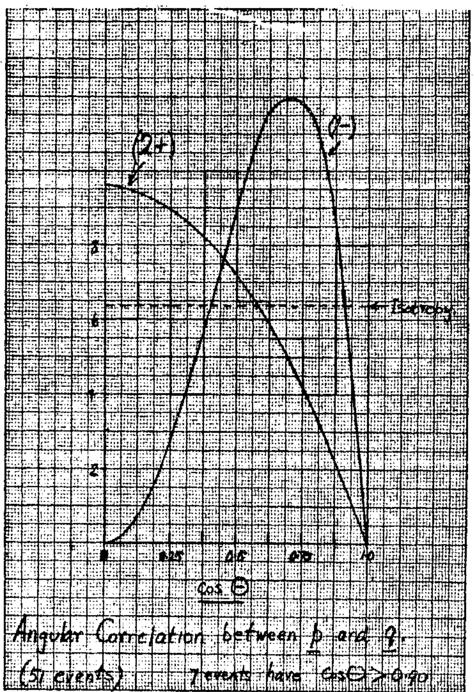
		Free	25 Mev Fermi Energy
$P+N$ or $P+P \rightarrow$	$P+\Lambda^0$	.37	.23
	$P+N+K$	1.15	.80
	$\Sigma^0+\Lambda^0$	.96	.69
	$\Sigma^+ + \Sigma^+$	1.15	.80
	$P+\Lambda^0+K$	1.55	1.14
	$N+\Sigma^+ + K$	1.80	1.34
	$P+\Sigma^- + K$	2.10	1.58
	$P+N+2K$	2.7	1.85
	$P+N+K+\pi$	1.45	1.08

E_{Fermi}	$E_{Threshold}$
0	1.55
10	1.3
20	1.18
30	1.09
40	.97

Dalitz reported on the analysis of the 53 τ meson decays in which the sign of all three of the π mesons is known. Figure 1 gives a plot of these events, the distance from the horizontal tangent to the circle being proportional to the energy of the negative meson, and the distance to the other tangent being proportional to the energy of one of the two positive mesons. The density of the distribution is directly



decay, the statistical factors being automatically accounted for. The observed distribution does not show any marked difference from isotropy, and has certain specific features which bear on the question of the spin and parity of the τ meson. In the first place, there are a number of events in which the positive π which is emitted is rather slow. If the spin and parity of the τ meson were such that it could decay into two π mesons, then when it decays into three pions, the third pion cannot be at rest, because the angular momentum is the same, but the parity is opposite in the two situations. A more general statement of the same type is that in this case the probability density (square of the matrix element) in this diagram must vanish on the boundary, if the spin and parity of the τ meson ar such that it can decay into two pions. This is emphasized in Figure 2, which is a plot of the angle between the relative motion of the two positive mesons and the motion of the negative meson; in this diagram the density should vanish at cos $\theta = 1$. If the matrix element is given by centrifugal barrier penetration, one obtains the curves given for (1-) and (2+). There are seven events in which cos θ is greater than .9, and three in which it is greater than .95 .



Angular Correlation between p and q. (51 events) 7 events have cos Θ > 0.90
2 events " cos Θ > 0.95
Fig. 2

Figure 2

It is difficult to exclude (1-) on this basis alone, but it is excluded by the large number of events near cos $\theta = 0$. (2+) also fits very badly and statistical analysis shows that it is very improbable.

The second argument deals with the distribution of the a number of slow negative pions. Again, the centrifugal barriers are such that one would expect very few events in this region. But if the negative pion comes out in an S wave, the relative angular momentum of the (identical) positive pions must be even, and the spin of the τ meson must be even and its parity odd. The evidence for this is plotted in Figure 3. It can be seen from these curves that this argument is not quite so strong as the first one. Again, however, isotropy is very reasonable. So for low spin values, it is very improbable that the τ meson has a spin and parity such that it can decay into two pions. But if you are willing to consider much higher spin values, it is not possible to make a strong statement, since the question becomes one of how fast the distribution vanishes on the boundary.

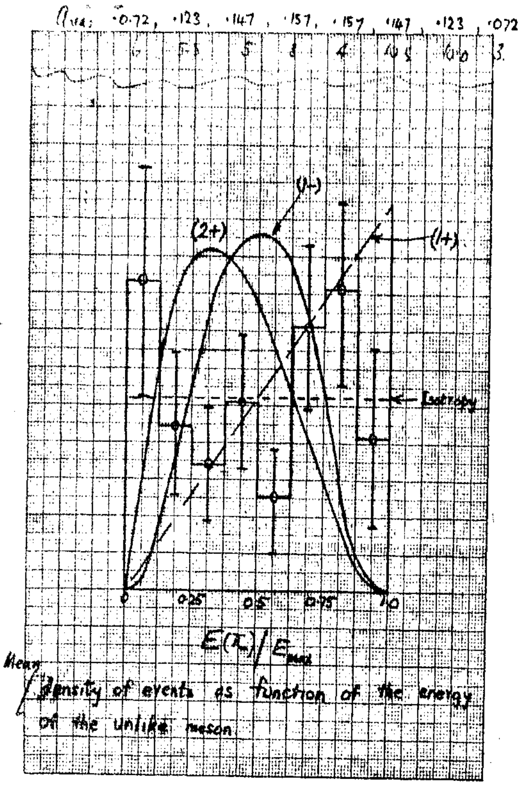


Figure 3

Dalitz concludes: (1) If the spin of the τ meson is less than 5, it cannot decay into two π mesons. (2) If the spin is small, the parity is certainly odd, and the spin value could be 0, 2, 4, or 6.

(end of session)