# Status of Weak Interactions

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THE invited speakers have done an excellent job of describing the various topics within the field of weak interactions. The contributed papers have presented many fascinating results. Furthermore, what is rare these days at a physics conference, there has been plenty of discussion, which has brought out, I think, every point that was overlooked in the speeches. Evidently, there is no need for a summary.

A few words about what appear to me to be the principal questions that we would like to have answered in the future are given in the following.

Let us begin with those two beautiful and mysterious particles, the electron and the muon. The recent revolution in weak interactions has brought about measurements of the muon magnetic moment, confirming to a high degree of accuracy that the muon, like the electron, is a pure Dirac particle with electrodynamic coupling of the conventional form. It now seems clear also that the weak couplings of electron and muon are identical in form and strength, both involving the neutrino (presumably the same neutrino, although we have no way of proving that at the moment). Both electron and muon lack, so far as is known, any other interaction whatever, except the gravitational. And here appears the only known difference between them, their masses. Why do these two otherwise identical particles have different masses? No one has the slightest idea. This is perhaps the most interesting question in particle physics today. If it were not for this example, we might say that differences in mass among the elementary particles are always owing to differences in interaction. Or at least we might say that all the different particles are distinguished from one another by the values of symmetry quantum numbers. But the electron and muon seem to provide the first inkling of a radial quantum number in particle physics.

It is evidently important to refine existing measurements of the muon and electron still further, and to compare electron and muon scattering from the same target, in order to see whether the equivalence of the two particles really persists down to small distances.

The decay of the muon, involving just $\mu$, $e$, and $\nu$, offers an example of a pure weak interaction. The only known corrections are the electrodynamic ones, which are finite, have been calculated, and are easily taken into account. To within present accuracies, all our knowledge of the muon decay agrees with the very simple theory of the interaction given by the following formula for the Lagrangian density:

$$\mathcal{L}_\mu=\sqrt{2}G\left(\bar{e}\gamma_\alpha\frac{1+\gamma_5}{\sqrt{2}}\nu\right)\left(\bar{\mu}\gamma_\alpha\frac{1+\gamma_5}{\sqrt{2}}\nu\right)^+ + \text{Hermitian conjugate (h.c.)}$$

or, for short,

$$\mathcal{L}_\mu=\sqrt{2}G(\bar{e}\nu)(\bar{\mu}\nu)^+ + \text{h.c.} \tag{1}$$

We may describe this interaction by saying that it is the direct coupling in which $e^-$, $\mu^-$, and $\nu$ appear with negative helicity only.

It seems, in fact, that in all weak interactions these particles appear with negative helicity and their antiparticles with positive helicity. It is a remarkable fact that this same grouping is followed by the law of conservation of leptons, which states that the number of leptons minus the number of antileptons is always conserved. The leptons all have negative helicity in the weak interactions, the antileptons all positive helicity.

Now there is a law of baryon conservation, too, and therefore we suspect that all baryons enter the weak interactions with the same helicity. Future experiments, suitably interpreted, will enable us to test this idea.

To return to the $\mu$ decay, it is of the highest importance to refine all experiments on the spectrum and asymmetries of $\mu$ decay in order to see whether any departures from the simple contact-interaction theory of Eq. (1) can be found. Accurate knowledge of the rate of decay is also valuable, because only in the $\mu$ decay can we be reasonably sure of measuring the true Fermi constant $G$, unaltered by the effects of strong couplings.

It is just these strong couplings that make $\beta$ decay complicated. It is now well established that the $\beta$-decay interaction resembles that in $\mu$ decay; it is vector and axial vector and the strength is about the same. We do not, however measure the interaction Lagrangian directly, because of the strong couplings. At low momentum transfers, such as we have in nuclear $\beta$ decay, we measure an *effective* Lagrangian density

$$\{\bar{n}[G_V\gamma_\alpha+(-G_A)\gamma_\alpha\gamma_5]p\}^+\left(e\gamma_\alpha\frac{1+\gamma_5}{\sqrt{2}}\nu\right)+\text{h.c.} \tag{2}$$

to be compared with

$$\{\bar{\mu}(G\gamma_\alpha+G\gamma_\alpha\gamma_5)\nu\}^+\left(\bar{e}\gamma_\alpha\frac{1+\gamma_5}{\sqrt{2}}\nu\right)+\text{h.c.}$$

as in Eq. (1) for $\mu$ decay. Here $G_V$ and $-G_A$ are the effective or renormalized Fermi constants, containing effects of the strong interactions of nucleons.

$G_V$ is determined experimentally from the rate of a $0\rightarrow 0$ transition such as the decay of $O^{14}$. Remarkably, it appears to be within one or two percent of the "pure" Fermi constant $G$ determined from $\mu$ decay. There are two methods of measuring $-G_A/G_V$ without estimating nuclear matrix elements. One is the Argonne experiment on the asymmetry of electrons in the decay of polarized neutrons and gives $-G_A/G_V=1.25\pm0.04$. The other is a comparison of neutron and $O^{14}$ lifetimes; it gives only the absolute value and yields

$$|-G_A/G_V|=1.19\pm0.04.$$

It is very tempting, then, to guess that the original Lagrangian for $\beta$ decay is just like that for $\mu$ decay,

$$\mathfrak{L}_\beta=\sqrt{2}G(\bar{n}p)(\bar{e}\nu)^{+}+\text{h.c.}, \tag{3}$$

with negative helicity for the nucleon. It is surprising, though, that the vector and axial vector renormalization factors are about 0.99 and 1.2, respectively; nearly 1 in spite of the strength of nuclear interactions. No one has any explanation for the closeness of the latter to unity. For the former, the closeness to unity is really striking, and a possible explanation has been suggested —the speculation that there is a "conserved vector current."

This speculation is suggested by an analogy between the vector weak interaction of baryons and mesons (without change of strangeness) and electromagnetism. For electromagnetism, a law of universality holds—all charged elementary particles have the same charge $\pm e$. The universality is not disturbed by strong interactions, which are present for the proton, for example, and not for the positron. The reason is that the electromagnetic current $j_\alpha$ is a conserved quantity: $\partial j_\alpha/\partial x_\alpha=0$.

Now the vector operator describing the nucleons in $\beta$ decay is $\bar{n}\gamma_\alpha p$, which is not, in the Yukawa theory of strong interactions, a conserved quantity. It is, however, one term of a conserved quantity, the $x+iy$ component of the isotopic spin current,

$$\mathfrak{g}_\alpha=\bar{n}\gamma_\alpha p+\sqrt{2}\frac{\partial\pi^{+}}{\partial x_\alpha}\pi^{0}-\sqrt{2}\pi^{+}\frac{\partial\pi^{0}}{\partial x_\alpha} +\sqrt{2}\bar{\Sigma}^{-}\gamma_\alpha\Sigma^{0}-\sqrt{2}\bar{\Sigma}^{0}\gamma_\alpha\Sigma^{+}+\cdots, \tag{4}$$

which obeys the conservation law $\partial\mathfrak{g}_\alpha/\partial x_\alpha=0$ apart from electromagnetic effects.

If, then, in the original $\beta$-decay Lagrangian we replace $\bar{n}\gamma_\alpha(1+\gamma_5)p$ by the expression

$$\bar{n}\gamma_\alpha(1+\gamma_5)p+\sqrt{2}\frac{\partial\pi^{+}}{\partial x_\alpha}\pi^{0}-\sqrt{2}\pi^{+}\frac{\partial\pi^{0}}{\partial x_\alpha} +\sqrt{2}\bar{\Sigma}^{-}\gamma_\alpha(1+\gamma_5)\Sigma^{0}-\sqrt{2}\bar{\Sigma}^{0}\gamma_\alpha(1+\gamma_5)\Sigma^{+}+\cdots, \tag{5}$$

we have a theory in which $G_V$ must equal $G$ to within an electromagnetic correction of a percent or so. It is evidently worthwhile to refine the measurements and calculations involved in the determination of $G_V/G$.

It would also be good to have independent tests of the conserved current hypothesis. The simplest one is unfortunately very difficult; it involves measuring the rate of the rare decay $\pi^{+}\rightarrow\pi^{0}+e^{+}+\nu$, never so far observed. If the conserved current hypothesis is correct, the rate* must be $0.37\pm0.07$/sec giving a branching ratio of $1.0\pm0.2\times10^{-8}$. Other $\beta$-decay theories will also lead to decay rates of this order of magnitude, but not (except accidentally) to the same number.

An easier test of the conserved current idea has been proposed, involving the ratio of the $\beta$-decay spectra of $B^{12}$ and $N^{12}$. At this meeting, certain theoretical corrections have been presented that must be applied to the analysis of the results, but they do not vitiate the conclusion that the experiment can distinguish whether or not pions participate directly in the $\beta$-decay interaction as in Eq. (5). The $B^{12}-N^{12}$ experiment is being performed at the California Institute of Technology by Hilton and Sörgel, who will announce their results shortly. I would like to encourage other groups to do the same experiment, however, since it is a hard one and recent experience should have taught us that hard experiments should be repeated.

We have seen how the vector and axial vector coupling constants in $\beta$ decay can be renormalized by effects of the pion cloud around the nucleon, giving, at low momentum transfer, the effective Lagrangian of Eq. (2). When we take into account finite momentum transfer to the nucleon, other pionic effects must show up, so that $G\gamma_\alpha(1+\gamma_5)$ is replaced, not simply by $G_V\gamma_\alpha+(-G_A)\gamma_\alpha\gamma_5$, but by the more complicated expression

$$G_VF_1(q^2)\gamma_\alpha+(-G_A)F_2(q^2)\gamma_\alpha\gamma_5 +AF_3(q^2)\sigma_{\alpha\beta}q_\beta+BF_4(q^2)\gamma_5q_\alpha. \tag{6}$$

Here $q_\alpha$ is the four-momentum transfer and the form factors $F_i(q^2)$ all have $F_i(0)=1$. Besides the renormalizations and the form factors, the pion cloud has induced two new interactions. The first, with coefficient $A$, we might call "weak magnetism," since it bears the same relation to the vector coupling that an anomalous Pauli moment bears to the electric charge. In fact, in the conserved current theory, the value of $A$ can be predicted from the anomalous moments of proton and neutron. It is just this weak magnetism that is tested in the $B^{12}-N^{12}$ experiment. (The conserved current theory, by the way, also permits $F_1$ and $F_3$ to be calculated from the electromagnetic form factors of the nucleon.)

The last interaction, with coefficient $B$, is sometimes called the induced pseudoscalar. It can be shown that in the calculation of $B$ by field theory, one particular type of diagram predominates, in which the nucleon radiates a virtual pion, which decays into electron and neutrino. This contribution can be evaluated exactly,

* The principal uncertainty arises from the mass difference of $\pi^{+}$ and $\pi^{0}$.

giving a fairly reliable estimate of $B$, or at least its absolute value.

All these effects are barely detectible in $\beta$ decay, because of the low energies involved. They may, however, be studied in the absorption of $\mu^-$ by nuclei. But how is the basic interaction of nucleons with $\mu$ and $\nu$ related to that with $e$ and $\nu$? The simplest assumption is that it is absolutely identical. There is very little evidence on this point from $\mu^-$ absorption itself. It has not even been proved experimentally that the interaction is $V$-$A$ or that parity conservation is violated. However, the theory of identical $\mu$ and $e$ couplings leads to the famous prediction of the branching ratio for $\pi \rightarrow e+\nu$, which has now been confirmed experimentally with an accuracy that is constantly increasing.

Pending further experimental work, we are certainly justified in supposing that the basic coupling in $\mu^-$ absorption is known. The absorption rates and other quantities may then be used to yield information about the pionic corrections of Eq. (6). For this purpose, the ideal nucleus would be the proton, but that poses tremendous experimental problems, and for a while we will have to be content with the current experiments on $C^{12}$ and other light nuclei.

There remains the problem of calculating the absolute rate of the charged pion decay. We have heard from Professor Goldberger an excellent account of a recent attempt to do that. I think we will agree that the remarkable success of the calculation is greater than might have been expected from the approximations involved. But it is very instructive in any case, particularly the result that for large meson coupling constant $g^2$, the rate of pion decay is inversely proportional to $g^2$.

All the phenomena we have discussed so far involve the interaction of $e\nu$, $\mu\nu$, and a series of particle pairs beginning with $np$. The structure of the interaction is rather peculiar; pairs of particles, one neutral and one charged, interacting with one another in identical fashion. It suggests that the coupling Lagrangian is of the form $J_\alpha{}^+ J_\alpha$, where

$$J_\alpha = 2^{\frac{1}{4}}\sqrt{G}\left\{ \bar{e}\gamma_\alpha \frac{1+\gamma_5}{\sqrt{2}}\nu + \bar{\mu}\gamma_\alpha \frac{1+\gamma_5}{\sqrt{2}}\nu + \bar{n}\gamma_\alpha \frac{1+\gamma_5}{\sqrt{2}} p + \cdots \right\}. \quad (7)$$

This idea of a current coupled to itself has certain new consequences, but they are very hard to detect by experiment. One is neutrino-electron scattering with a cross section comparable to that of neutrino absorption by nuclei. (Of course, the absorption has been detected by a coincidence technique, while the scattering gives only electron recoils.) It should be noted that the modern longitudinal or "two-component" neutrino cannot have a magnetic moment, so that if neutrino-electron scattering is ever found with the predicted cross section, it should be attributed to the direct $(e\nu)(e\nu)$ coupling.

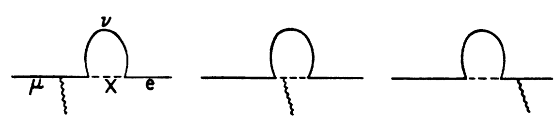
A second consequence, just as difficult to test, is the existence of a parity nonconserving nuclear force arising from the $(np)(np)$ term of the weak coupling. The violation of parity conservation should amount to something like $10^{-7}$ in amplitude. Present experiments are capable of measuring only one part in $10^3$ or $10^4$.

If we accept the form $J_\alpha{}^+ J_\alpha$ for the weak interactions, we are still puzzled by it. True, it is reminiscent of electromagnetism, although weaker, of short range, and not parity conserving. But the electromagnetic current $j_\alpha$ interacts with itself through the photon. Is there a boson to carry the weak interactions?

Let us examine the properties of such a hypothetical boson, a particle that Feynman and I like to call the *uxl* (symbol $X^\pm$). It must be a charged vector meson, say of mass $M$, with coupling constant (analogous to 1/137) equal to $\sqrt{2}(GM^2/4\pi)$. If $M$ is of the order of the nucleon mass, this comes to around $10^{-6}$. Processes involving creation or destruction of the *uxl* have probabilities proportional to this coupling constant, while ordinary weak processes involve the square. Thus a $K$ particle, for example, would much rather decay into $X+\pi$ or even $X+\gamma$ than into its actual disintegration products, provided these channels involving $X$ were open. It follows that $M$ must be $\gtrsim m_K$.

If $M$ is really around the nucleon mass, then the cross section for *uxl* production in, for example, nucleon-nucleon collisions of several Bev, must be around $10^{-6}$ of geometrical. The time of decay into, say, $e+\nu$, must be something like $10^{-18}$ sec. Evidently the direct observation of a particle that is rarely produced and decays immediately is a most difficult matter. If $M$ is very much greater than 1 Bev, then the threshold for *uxl* production becomes a problem.

Fortunately, an indirect test of the existence of the *uxl* can be made. If $X$ exists, it induces the decay $\mu \rightarrow e+\gamma$ with a rate that can be estimated. The mechanism is best described by the Feynman diagrams involved:




The rate comes out logarithmically divergent, so that we must introduce a cutoff momentum $\Lambda$. The fraction of muon decays into $e+\gamma$ then comes out

$$\Gamma(\mu \rightarrow e+\gamma)/\Gamma(\mu \rightarrow e+\nu+\bar{\nu}) = 3/8\pi\, 1/137\, f(M/\Lambda), \quad (8)$$

where for large cutoffs $\Lambda \gg M$, we have $f \rightarrow (\ln \Lambda^2/M^2)^2$. For reasonable values of the cutoff, we should expect a fraction like $10^{-3}$ or maybe $10^{-4}$. Experimentally the branching ratio is less than $2\times 10^{-5}$. It appears, then, that the *uxl* has flunked the only test of its existence that is available so far. (Of course, if the neutrinos associated with $e$ and $\mu$ are not identical, then this was no test at all.)

Formula (8) can also be used to describe what happens when there is no $uxl$ but instead a point coupling of $(\mu\nu)$ to $(e\nu)$. Mathematically, that corresponds to the limit of infinite $M$ with the cutoff $\Lambda$ held fixed. Under these conditions $f(M/\Lambda)\rightarrow 0$ and there is no decay $\mu\rightarrow e+\gamma$.

We have not succeeded, then, in understanding the proposed form $J_\alpha^+J_\alpha$ of the weak couplings. Nevertheless, I shall assume it in the remaining discussion, which concerns the weak decays of strange particles.

In order to describe decays involving a change of strangeness, we must add new terms to Eq. (7) for the current $J_\alpha$, which already consists of two parts: the leptonic current $J_\alpha{}^L$ and the current $J_\alpha{}^{(1)}$ comprising $(\bar{n}p)$ and probably other terms like $(\bar{\pi}^0\pi^+)$, $(\bar{\Sigma}^-\Sigma^0)$, etc., all involving baryons or mesons, but with no change of strangeness.

The existence of decays like $K^+\rightarrow\mu^++\nu$ requires us to add a current $J_\alpha{}^{(2)}$ consisting of pairs like $(\bar{\Lambda}p)$, $(\bar{\Sigma}^-n)$, etc., in which the partner with higher charge also has strangeness higher by one unit. It is easy to see that the interaction of $J_\alpha{}^{(2)}$ with $J_\alpha{}^{(1)}$ and $J_\alpha{}^L$ is sufficient to account qualitatively for all known weak decays of the strange particles.

The question now arises whether the current $J_\alpha{}^L+J_\alpha{}^{(1)}+J_\alpha{}^{(2)}$ is complete, or whether other terms of still a different character must be included. Such additional terms could be of two kinds: pairs like $(\bar{n}\Sigma^+)$ in which the partner with higher charge has strangeness lower by one unit and pairs like $(\bar{\Xi}^-n)$ in which the partners differ by two units of strangeness. Let us call the corresponding currents $J_\alpha{}^{(3)}$ and $J_\alpha{}^{(4)}$, respectively. There are a number of experimental tests of the existence of $J_\alpha{}^{(3)}$ and $J_\alpha{}^{(4)}$:

(1) The decay $\Sigma^+\rightarrow n+e^++\nu$ will have appreciable probability if and only if $J^{(3)}$ is present. (Abbreviated, $\Sigma^+\rightarrow n+e^++\nu\sim J^{(3)}$.)

(2) $\Xi^-\rightarrow n+e^-+\bar{\nu}$, $\Xi^0\rightarrow p+e^-+\bar{\nu}\sim J^{(4)}$.

(3) $\Xi^-\rightarrow n+\pi^-$, $\Xi^0\rightarrow p+\pi^-\sim J^{(3)}$ or $J^{(4)}$.

(4) If $J^{(3)}$ or $J^{(4)}$ exists, so that the weak interactions can induce strangeness changes of two units in the lowest order of $G$, then the transitions $K^0\leftrightarrow\bar{K}^0$ occur with an amplitude proportional to $G$ instead of $G^2$. The mass difference between $K_1{}^0$ and $K_2{}^0$ is then of order $G$ instead of $G^2$, corresponding to a frequency of, say, $10^{17}$/sec instead of, say, $10^{10}$/sec. A beam of $K^0$ particles, then, will be converted immediately (that is, in something like $10^{-17}$ sec) into a rapidly oscillating half-and-half mixture of $K^0$ and $\bar{K}^0$. Thus a $K^0$ produced in a reaction like $\pi^-+p\rightarrow\Lambda+K^0$ will be "immediately" capable of behaving like a $\bar{K}^0$ in, for example, the reaction $\bar{K}^0+p\rightarrow\Lambda+\pi^+$.

(5) Only if $J^{(3)}$ exists can the leptonic decay rates of $K_1{}^0$ and $K_2{}^0$ be different. If they are the same, the probability of a neutral $K$ particle decaying into leptons during the lifetime of the $K_1{}^0$ component ($\sim 10^{-10}$ sec) is only around $10^{-3}$. (It should be noted, of course, that during the first $10^{-10}$ sec the amplitudes for leptonic decay of $K_1{}^0$ and $K_2{}^0$ interfere with each other.)

None of these tests has yet given conclusive results. There is some evidence that a beam of $K^0$ particles does not immediately behave like a 50–50 mixture of $K^0$ and $\bar{K}^0$. If this is confirmed, we can presumably throw out both $J^{(3)}$ and $J^{(4)}$, but at the moment we cannot be sure. Let us continue, however, on the assumption that $J^{(3)}$ and $J^{(4)}$ are not present.

We must still clear up the forms of $J^{(1)}$ and $J^{(2)}$. The conserved vector current hypothesis, if we take it altogether seriously, together with the assumption that baryons always occur with the factor $1+\gamma_5$ (negative helicity), gives a definite form for $J^{(1)}$, but we are far from being able to test such an assertion today.

However, we can test a much less specific suggestion, in the form of a symmetry rule, that $J^{(1)}$ behaves like an isotopic vector and $J^{(2)}$ like an isotopic spinor. Such a rule is obeyed, for example, by the term $(\bar{n}p)$ in $J^{(1)}$ and the hypothetical term $(\bar{\Lambda}p)$ in $J^{(2)}$. If this rule is right, then apart from electromagnetic corrections, we have $|\Delta\mathbf{I}|=\frac{1}{2}$ or $\frac{3}{2}$ in nonleptonic decays and $|\Delta\mathbf{I}|=\frac{1}{2}$ in leptonic decays (with the leptons defined to carry no isotopic spin). Some experimental consequences are the following.

(1) The fraction of $K^+\rightarrow 3\pi$ decays that yield $\pi^++2\pi^0$ is $\frac{1}{5}$, assuming a totally symmetric spatial wave function.

(2) The fraction of $K_2{}^0\rightarrow 3\pi$ decays that yield $3\pi^0$ is $\frac{3}{5}$, assuming a totally symmetric spatial wave function.

(3) The fraction of $K_1{}^0\rightarrow 2\pi$ decays that yield $2\pi^0$ is between 0.28 and 0.38. (We make use here of the experimental rates of $K_1{}^0\rightarrow 2\pi$ and $K^+\rightarrow 2\pi$.)

(4) The rate of leptonic decay of $K_2{}^0$ (or of $K_1{}^0$, if we forget interference) is twice that of $K^+$ and the spectra, relative proportions of $e$ and $\mu$, etc., are all the same for $K_2{}^0$ and $K^+$.

All these statements seem to be roughly true except perhaps the third one, but more experiments are necessary.

We come now to some mysterious features of strange particle decay, which, if we could understand them, would probably help us to pin down the interactions further. The most striking is the fact that $K_1{}^0$ decays into $2\pi$ at a rate about 500 times faster than that of $K^+\rightarrow 2\pi$. An explanation has been suggested in the form of an approximate rule (supposedly good to 5% or so in amplitude) that $|\Delta\mathbf{I}|=\frac{1}{2}$ in nonleptonic decays. However, it is not known how to derive any such rule in a convincing way from an interaction of the form $J_\alpha{}^+J_\alpha$. Several ideas have been discussed, e.g., (a) to divide the strong interactions into classes, of which one is assumed to be less strong and approximately negligible. The stronger one may have a higher symmetry than charge independence, and this symmetry, together with a hypothetical symmetry of the weak currents $J_\alpha^{(1)}$ and $J_\alpha^{(2)}$ may lead to something like the $|\Delta\mathbf{I}|=\frac{1}{2}$ rule. (b) to add to the interaction $J_\alpha^+J_\alpha$ a term $K_\alpha K_\alpha$ in which the particle pairs have the same charge. The "neutral" current $K_\alpha$ must not contain leptons, however, since emission of pairs like $\bar{\nu}\nu$ and $\bar{\mu}e$ has never been observed. An interaction $J_\alpha^+J_\alpha+K_\alpha K_\alpha$ can be made to yield the $|\Delta\mathbf{I}|=\frac{1}{2}$ rule.

The first suggestion seems much more attractive than the second. Actually, neither has so far resulted in a convincing theory. For a third suggestion, see below.

In any case, it is worthwhile to see whether the approximate $|\Delta\mathbf{I}|=\frac{1}{2}$ rule works experimentally. Besides the $K\rightarrow 2\pi$ situation, it explains the fact that $\Lambda\rightarrow n+\pi^0$ occurs at about half the rate of $\Lambda\rightarrow p+\pi^-$ and certain relations among the nonleptonic decays of $\Sigma^\pm$. It may be further tested by other predictions, including the following:

(1) The asymmetry of $\Lambda\rightarrow n+\pi^0$ for polarized $\Lambda$ must be the same as that of $\Lambda\rightarrow p+\pi^-$.

(2) The rate of $K_2^0\rightarrow 3\pi$ must be twice that of $K^+\rightarrow 3\pi$. At the moment, there seems to be some difficulty with the second prediction, but again more experiments are needed.

Another mystery involves the rate of leptonic decays of hyperons. The decay $\Lambda\rightarrow p+e^-+\bar{\nu}$ has been observed, but it is reported to be very rare, occurring in much less than 1% of all $\Lambda$ disintegrations. The decay $\Sigma^-\rightarrow n+e^-+\bar{\nu}$ seems also to be very rare, and has never been detected for certain. Now if the current $J_2$ contains terms $(\bar{\Lambda}p)$ or $(\bar{\Sigma}^-n)$, if the coefficient of each of these terms is unity, and if renormalization effects are not large (and they seem to be small in the $\beta$ decay of nucleons), then the fractions of $\beta$ disintegrations of $\Lambda$ and $\Sigma^-$ should be 1.6 and 5.6%, respectively.

While awaiting further experimental results, let us assume the discrepancy is real. If it is really large, it is unlikely to be a renormalization effect but rather an indication that the strangeness-changing weak couplings are even weaker (by a factor $f$, perhaps $\sim 1/20$) than those that conserve strangeness. Such a situation would permit another explanation of the approximate $|\Delta I|=\frac{1}{2}$ rule, namely that it characterizes a special set of diagrams, occurring only in nonleptonic decays, which are so much larger than other diagrams that they make up for the small factor $f$ and give a "normal" rate for such a process as $\Lambda\rightarrow N+\pi$.

It is clear, in any case, that we have an enormous body of information about the weak decays of strange particles but that we need still more information if we are to understand them.