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*BETA DECAY AND THE WEAK INTERACTIONS**

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IN the last two or three years an important stage has been completed in the study of β decay, which began with the classic papers of Yang and Lee. Their work has had the result that we can now write the final form of the weak-interaction Hamiltonian. Up to this time only one interaction, the electromagnetic interaction, had been known for which there existed a closed theory. Now we also possess the foundations of the theory of β interactions. It is remarkable that in Fermi's very first paper[1] in 1934 the interaction was written in almost the same way as we now write it. If Fermi had known about parity nonconservation and the longitudinal neutrino, the vector form of the interaction, which he chose by analogy with the electromagnetic interaction, would have led him to the correct theory. Just this paper of Fermi, together with the additions on the theory of the longitudinal neutrino by Landau, Salam, and Lee and Yang,[†] provides the basic constituents of the theory of β decay. Practically all of the theoretical papers published in the interval from 1935 to 1957, discussing possible forms for the interaction, have turned out to be incorrect, just as many of the experimental papers devoted to this problem have also been incorrect.

The creation of the Fermi theory of β decay as completed by the theory of the longitudinal neutrino is the achievement of four physicists: Marshak and Sudarshan,[3] and Gell-Mann and Feynman.[4] Gell-Mann has published a paper[5] which shows the deep physical consequences to which Fermi's electromagnetic analogy leads.

The decay of μ mesons has the simplest description. This decay is subject to no other influences, since neither the electron, the neutrino, nor the μ meson is involved in the strong interactions, and the electromagnetic forces give only small radiative corrections. The interaction Hamiltonian for the μ decay is written in the form

$$H_\mu = \frac{g_\mu}{\sqrt{2}} \langle e \,|\, \gamma_\alpha (1+\gamma_5) \,|\, \nu \rangle \langle \nu / \gamma_\alpha (1+\gamma_5) \,|\, \mu \rangle .$$

All of the particles in this interaction are "longitudinal," and therefore the interaction is described by only one constant g_μ, whose value is determined from the lifetime of the μ meson and is $(1.38 \pm 0.02) \times 10^{-49}$ erg/cm^3.

The β decay of the neutron is described by an analogous formula. Since, however, the neutron is surrounded by a π-meson cloud, this leads to a "renormalization of the constants," because as a result of the strong interaction the nucleon does not appear as a two-component particle in the β decay. Owing to this the interaction Hamiltonian for this case involves two real constants (the reality of the constant follows from the conservation of time parity of the strong interaction), and has the form

$$H_\beta = \frac{g_\beta}{\sqrt{2}} \langle e \,|\, \gamma_\alpha (1+\gamma_5) \,|\, \nu \rangle \langle p \,|\, \gamma_\alpha (1+\Lambda\gamma_5) \,|\, n \rangle .$$

At present the best values of the constants g_β and Λ are determined from the measurements of Spivak and coworkers[6] on the lifetime of the neutron, which are confirmed by the data on the lifetime of tritium,[†] and measurements of the probability of $0 \longleftrightarrow 0$ transitions.

The value of the constant g_β is determined by the experiments of Gerhart, who measured the probability of the transition $O^{14} \rightarrow O^{14}$. These latter results give $g_\beta = (1.41 \pm 0.01) \times 10^{-49}$ erg/cm^3, which is remarkably close to the value of g_μ given above. When, however, one takes into account the radiative corrections,[13] one finds that the two constants must have different values. The most probable value of g_β is then the new one (larger by 2 or 3 percent) given by Gerhart in a later paper for the nuclei O^{14}, Al^{26*} and Cl^{34}. From these data one also gets a value for Λ, 1.25 or 1.15, depending on whether the old or the new value for the decay probability of O^{14} is the correct one. Except for this small uncertainty we can assert that the values of the constants that describe the β interaction can already be entered in lists of the fundamental constants in

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[*] Report at the Ninth All-Union Conference on Nuclear Spectroscopy, Khar'kov, January 1959.

[†] It is curious that the equation for the longitudinal particle (which does away with the symmetry between right and left) was itself found as early as 1929 by Weyl.[2]

[†] For the reduced lifetimes of the neutron and of tritium these authors give

$$ft_n = 1170 \pm 35 \text{ sec}$$
$$ft_T = 1132 \pm 40 \text{ sec}$$

the physics of elementary particles along with such constants as the charge, the mass, and so on. It is clear that whichever of the values of the constants turns out to be correct it is very improbable for such a close agreement between g_μ and g_β to be a pure coincidence; Gell-Mann was the first to point out that the reason for this lies in the deep analogy that exists between β decay and electrodynamics.

If we compare the β interaction written above with the interaction of nucleons with the electromagnetic field

$$H_{em} = e\langle p \mid \gamma_\alpha \mid p\rangle A_\alpha,$$

we see that for $\Lambda = 0$ these expressions are very similar, with the electron-neutrino field playing the part of the electromagnetic field, and the "transition current" $\langle p \mid \gamma_\alpha \mid n\rangle$ that of the electric current.* Here it must be remembered that the proportionality coefficients — the interaction strengths $g_\beta/\sqrt{2}$ and e — are very different. It is well known that in the case of the electromagnetic interaction the charge of the proton is not changed by its being surrounded by a π-meson cloud. Gell-Mann put forward the hypothesis that the "current" that describes β decay has the same form as the electric current, differing from it only by the replacement of neutrons by protons, which, owing to the charge invariance of nuclear forces, does not change the numerical coefficients. Then from the point of view of the Gell-Mann hypothesis the equality of the unrenormalized constant describing μ decay and the renormalized constant describing β decay is simply a consequence of the vector character of the interaction. According to the Gell-Mann theorem the difference between the values of g_β and g_μ must be determined by the degree of incorrectness of the charge independence and by the somewhat different radiative corrections (of the order of 2 percent, cf. reference 14).There are no arguments of this kind regarding the constant Λ, which describes the pseudovector β-decay interaction. Such an interaction has no analog in electrodynamics, and here nothing guarantees the nonrenormalizability of the charges. It is perhaps of interest to note that an analog of such an interaction would be the interaction of a magnetic pole with the electric field (for which one possible theory was discussed by Dirac as long ago as 1931).

Besides the decay of the μ meson and that of the neutron, other processes associated with the weak interactions are now known. Typical representatives of such processes are the decay of the π meson into an electron and a neutrino, the capture of a μ meson by a neutron, the β decay of hyperons, the weak decays of K mesons, etc. Beginning with a paper by Yukawa (1947), vain attempts have been made to set up a universal interaction that would describe all known weak processes in a unified way. It is now clear that the cause of the lack of success of such descriptions was the tangle of different interaction types. Indeed only now, after the establishment of the correct types in the theory of β decay, is it possible to write down such an interaction.

To make possible the construction of the universal interaction, a so-called "weak current" is introduced (Marshak, Sudarshan, Gell-Mann, Feynman), which is constructed in the following way:

Let us denote by the bracket $(\bar{e}\Gamma\nu)$ the expression $\langle e \mid \gamma_\alpha(1+\gamma_5) \mid \nu\rangle$. We shall also introduce other pairs of particles with analogous expressions. Furthermore, to simplify the notation we shall not indicate in any special way whether or not the constants involved in Γ are renormalized. Then what we call the weak current is the following expression:

$$j = (\bar{e}\Gamma\nu) + (\bar{\mu}\Gamma\nu) + (\bar{n}\Gamma p) + (\bar{\Lambda}\Gamma p).$$

This current describes processes in which two particles appear (or antiparticles disappear), and its four terms have the following common properties:

a) the total charge of the two particles that appear is -1: $\Delta Q = -1$;

b) the total nuclear charge is zero: $\Delta N = 0$;

c) the total lepton charge is zero: $\Delta n = 0$;

d) the first three terms do not change the strangeness, and the last term diminishes the strangeness by unity ($\Delta S = -1$ or 0).

The current j^+ which is Hermitian adjoins to this and describes the inverse processes with

$$\Delta Q = +1, \quad \Delta N = 0, \quad \Delta n = 0, \quad \Delta S = 0 \text{ or } 1,$$

obviously has the form

$$j^+ = (\bar{\nu}\Gamma e) + (\bar{\nu}\Gamma\mu) + (\bar{p}\Gamma n) + (\bar{p}\Gamma\Lambda).$$

In the first two terms the operators Γ are obviously not renormalized. In the third, the nucleon term, one constant Λ is renormalized, and in the fourth and last term both constants are renormalized, since it cannot be reduced to an electromagnetic current by any sort of rotation in isotopic space, and therefore for it the theorem

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*A similar remark had been made even earlier by Gershteĭn and Zel'dovich.[7]

j j^+	$(\bar{e}\Gamma\nu)$	$(\bar{\mu}\Gamma\nu)$	$(\bar{n}\Gamma p)$	$(\bar{\Lambda}\Gamma p)$
$(\bar{\nu}\Gamma e)$	$\nu + e \to \nu + e$			
$(\bar{\nu}\Gamma\mu)$	$\mu \to e + \nu + \tilde{\nu}$	$\nu + \mu \to \nu + \mu$		
$(\bar{p}\Gamma n)$	$n \to p + e + \tilde{\nu}$ $\pi \to e + \tilde{\nu}$	$p + \mu \to n + \nu$ $\pi \to \mu + \nu$	$p + n \to p + n$	
$(\bar{p}\Gamma\Lambda)$	$\Lambda \to p + e + \tilde{\nu}$ $K \to e + \tilde{\nu}$	$\Lambda \to p + \mu + \tilde{\nu}$ $K \to \mu + \tilde{\nu}$	$\Lambda \to \pi + p$	$\Lambda + p \to \Lambda + p$

of the nonrenormalizability of the vector constant is invalid.

In principle we should add to each of these two currents a term containing the other hyperons, Σ and Ξ^-. Simply for brevity we have not done this, since there are as yet no data on the decay of such hyperons, and the addition of the terms in question would not introduce any really new features. It may be remarked that if we confine ourselves to the SOM (Sakata-Okun'-Markov) model, in which all particles consist of nucleons and Λ particles, the currents as written describe all possible decays.* By the use of these currents all weak interactions can be written in the compact form:

$$H_w = \frac{g}{\sqrt{2}} jj^+.$$

The factor $\sqrt{2}$ is introduced in order not to change the old β-decay constant. This way of writing the formula has one important property: we have excluded all the possible combinations of particles that have no charge. Such combinations would have led to an interaction of the type

$$\frac{g^0}{\sqrt{2}} j^0 j^0$$

and would have described nonexistent processes, for example the decay of a μ meson into three electrons:

$$\mu^- \to e^- + e^+ - e^-.$$

It is easily seen that the expression for the weak interaction that has been written describes 10 different processes, which are obtained if we multiply each term appearing in the current j by each term appearing in the current j^+. All of these processes can be arranged in a table in which the rows and columns correspond to the different terms in the currents, and we indicate in the spaces of the table typical processes described by the corresponding products. Only half of the table is filled in, since the spaces on the other side of the diagonal correspond to the inverse processes.

It must be noted that in a number of cases the description of processes in terms of the product of two brackets is only of a provisional nature because of the renormalizations associated with the strong interaction.

Only three processes, in which only leptons are involved (the first two rows of the table), are described by unrenormalized constants. In the processes of neutron decay and μ-meson capture only the pseudovector constant is changed; in the leptonic decays of the Λ^0 hyperon there is no basis for keeping even the vector constant unchanged.

In the remaining three spaces in the table, which contain processes not involving leptons, even the general form of the interaction — the product of two currents — is not preserved.

Let us examine first the nondiagonal elements of this table. The 2 — 1 element obviously describes the decay of the μ meson; the 3 — 1 element describes the ordinary β decay of the neutron; and the 4 — 1 element describes the β decay $\Lambda^0 \to p + e^- + \tilde{\nu}$. Such a decay has actually been discovered recently. Its probability was found to be 10 to 20 times smaller than the probability calculated with the constants taken from the β decay of the neutron. This last fact is not very surprising, since we have already said that in this case there is no basis for supposing that the constants would remain the same. Moreover, the energy released in the β decay of the Λ^0 hyperon is so large that there can be effects of the form-factors of the particle, about which we shall speak later on.

Let us go on to the next column. The 3 — 2 element describes the capture of a μ meson by

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*Formally the expression adopted for the weak currents excludes weak processes with $|\Delta S| > 1$.

a nucleon. This process has been repeatedly observed in light nuclei, and although the corresponding probabilities have not been found very accurately, they are without doubt in agreement with the theory of the universal interaction. The 4 — 2 element describes the possible (not yet observed) μ-meson decay of the Λ^0 hyperon. This same interaction is responsible for the weak decay of the K mesons, $K \to \mu + \tilde{\nu}$, if we regard the K meson as consisting of an anti-Λ^0 and a proton. Finally, the 4 — 3 element describes the decay of a Λ hyperon with the emission of a π meson, which is regarded as a nucleon-antinucleon system.

Besides the nondiagonal processes we have described, there are four diagonal processes in the table, whose existence is a consequence of the theory of the universal interaction, and which have so far not been observed experimentally.

In this connection, we note that the scattering of neutrinos by μ mesons cannot be regarded as a possible experimental problem; the weak interaction of a Λ^0 with a nucleon is also beyond the bounds of experimental observation.

There remain the two processes in spaces 1 — 1 and 3 — 3, which we shall discuss in a little more detail. One of them is the scattering of neutrinos by electrons. It is surprising enough that despite the extremely small cross section of this process present experimental possibilities have come quite close to it. The possible ionization losses of neutrinos in matter have been studied in a paper by Cowan and Reines.[8] The writers attacked the problem of finding an upper limit on the magnitude of the magnetic moment of the neutrino. They found that the magnetic moment of the neutrino cannot in any case be larger than 10^{-9} of the Bohr magneton. Actually a longitudinal neutrino cannot have any magnetic moment, and ionization losses of the neutrino can only be due to the weak interaction between neutrinos and electrons. It can be shown that the amount of loss from this interaction would correspond to that of a neutral particle with a magnetic moment of 10^{-11} of the Bohr magneton. Thus the sensitivity of the experiment fell short of the region of the effect by only two orders of magnitude. Unfortunately, a simple refinement of the method of Reines and Cowan does not yield much advance, and new ideas are necessary. We may recall, however, that until quite recently the cross section for capture of neutrinos by protons was many orders of magnitude (scarcely less than 10) away from values that could be measured in the laboratory, and in Dirac's first papers it was supposed that the observation of pair production by γ rays was beyond the limits of experimental possibility. However this may be, observation of the processes of scattering of neutrinos by electrons is a very important problem, since it will confirm or overthrow the universal theory of the weak interaction in the form stated.[*]

The second diagonal process is the weak interaction of nucleons. It is clear that in this case it is senseless to think of measuring the total cross-section for the scattering caused by the weak interaction, since this interaction is superposed on the much more intense nuclear scattering, whose exact value we do not know. Therefore we can think only of effects that are absent in nuclear scattering, namely effects associated with parity nonconservation.

Three types of experiments are known so far from which one can get an estimate of an upper limit on the possible amount of admixture of states that do not conserve parity.[†]

1) Experiments on the longitudinal polarization of neutrons when they are scattered at zero angle by nuclei. The upper limit on the amount of admixture obtained from these experiments is of the order of 4×10^{-6} (Jones et al.[10]). In these experiments it would be of particular interest to learn the sign of the longitudinal polarization, since it would give information about the sign of q.

2) The production of π mesons by polarized protons in directions along and opposite to the polarization vector (Roberts et al.[9]). The admixture is smaller than 2×10^{-7}.

3) The study of parity nonconservation in nuclear reactions at low energies (Tanner,[11] Wilkinson[12]). The admixture is smaller than 5×10^{-8}.

It must be kept in mind, however, that all of these estimates are not very accurate and the exact values of the limits are subject to change, since they depend on a number of theoretical assumptions. However this may be, in all these cases the limits obtained are far from the region where a contribution from the weak interactions is to be expected. Even if we assume that the renormalizations of the weak-interaction constants in nucleon-collision processes are not too drastic, the sensitivity of the experiments must be increased by at least three orders of magnitude before one

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[*] It is a curious fact that in the theory of the universal interaction it is in principle possible to measure also the sign of the interaction constant, whereas in the simple β-decay scheme, in which the neutrino wave function occurs linearly, the sign still has no physical significance, owing to the invariance of the interaction under the replacements $\psi_\nu \to \psi_\nu e^{i\alpha}$, $\psi_\mu \to \psi_\mu e^{-i\alpha}$.

[†] The amount of admixture means the fraction of the time that the system is in states with the opposite parity.

could expect to notice these effects. Generally speaking it is a possibility, and this would be an extremely important discovery, that there exist some other causes of nonconservation of parity in the strong interactions, which will lead to the observation of effects of greater size than we expect. This still further increases the value of experiments in this domain, and therefore it is very important to find new experimental ways to approach the problem. It may also be remarked in conclusion that effects associated with parity nonconservation owing to the weak interactions will not be charge-invariant (the currents j^+ and j occur in the Hamiltonian, but not the current j^0), and therefore such effects in the collision of two neutrons will differ from the analogous effects in the neutron-proton system.

The weak-interaction Hamiltonian can be intuitively interpreted by means of the hypothesis of an intermediate meson with spin 1. This hypothesis also arises from the analogy with electrodynamics. The Coulomb interaction of a proton and an electron is described by the diagram shown in Fig. 1.

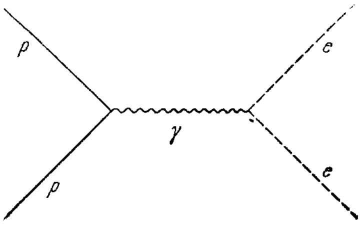

FIG. 1

The proton emits a photon — a particle with mass 0 and spin 1 — which is absorbed by the electron. We can conceive of the β decay of the neutron as described by an analogous diagram (Fig. 2), where the intermediate wavy line corresponds to some vector particle that differs from the photon in that its mass is not zero and its parity is indefinite. We call such a meson an X^- meson. Obviously for positron decay we must also introduce the X^+ meson (Fig. 3; the corresponding neutral meson need not exist, in view of the charge invariance of the process that was mentioned earlier). The effective introduction of the X meson means that strictly speaking the weak interaction ceases to be a point interaction, and is smeared out over a region of the order of the Compton wavelength of the X meson. It is clear that if we take the mass of this meson large enough, much larger than the mass of the nucleon, then the radius of the interaction will be very small and the scheme will be practically equivalent to that of an ordinary point interaction. Only for energies of the particles that are comparable with the rest mass of the X meson will there be any new effects (for example, just the actual production of X mesons). Although the existence of the X meson does not lead to any new effects (if we assume its mass large enough), nevertheless it is interesting to note that the very fact of the existence of the (virtual) X meson imposes a limitation on the sign of the β-decay constant in the "diagonal" effects. This can be seen easily if we note that if the decay were to go through the X meson the constant would be the product of the constants characterizing the two vertices in Fig. 2. In the case of a diagonal interaction the two vertices are identical, and this product would be simply the square of the absolute value of some number (or simply the square, if the combined parity is conserved). Thus,if the X mesons existed, the constant for the scattering of neutrinos, electrons, or neutrons by protons would have to be positive.

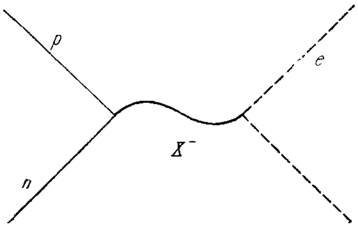

FIG. 2

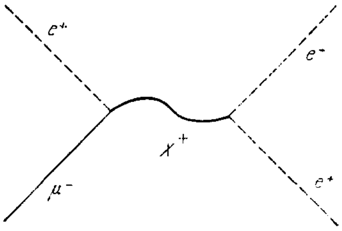

FIG 3

In principle this fact can be checked by finding the sign of the longitudinal polarization produced in the zero-angle scattering of neutrons by protons. The sign of this polarization is determined by the phase difference of the nuclear scattering and the weak interaction. If the phase of the nuclear scattering is known from the analysis of the scattering, this effect determines the sign of the amplitude of the weak interaction (Smorodinskiĭ and Fradkin[1]).

It is obvious that if the amplitude of the weak interaction turned out to be negative, this would disprove the hypothesis of the X meson.

There are objections that were raised by Gell-Mann at the last conference in Geneva and are connected with the emission of gamma rays by the virtual X mesons. An appreciable probability of such an effect would lead to the nonexistent decay $\mu \rightarrow e + \gamma$. Owing, however, to the fact that the theory of particles with spin 1 is itself poorly developed, it is hard to say to what extent there exist general theoretical considerations of this sort that would make it possible to reject the X-meson scheme at once. At any rate the X-meson scheme can be regarded as a very convenient mnemonic device for remembering the processes.

So far we have considered all phenomena as if the constants themselves did not depend on the energy of the particles, or more accurately on the momentum transferred. Actually already for the decay of the neutron one has to take into account the fact that nucleons have dimensions a bit smaller than a Fermi unit (10^{-13} cm), and this fact leads to an effective energy dependence of the β-decay constants. The corrections are very small, but in principle they are already significant for the decay of nucleons (where they amount to a few percent), and they can become quite important for the decay of nuclei; accordingly we shall discuss them in somewhat more detail.

Since a microscopic theory of the π-meson cloud surrounding a nucleon does not exist, we must confine ourselves to a phenomenological description of the decay, introducing the corresponding form-factors in analogy with atomic physics. The decay of an extended nucleon will not be described by the simple bracket $(\bar{p}\Gamma n)$, which holds for the decay of point particles; it is necessary to write the most general expression for the current (the vector V) and also for the pseudocurrent (the pseudovector A) that can be constructed from the Dirac matrices that describe the behavior of free particles with spin $\frac{1}{2}$. The general forms for these expressions are

$$V_\alpha = \langle p \,|\, V_1(q^2)\gamma_\alpha + V_2(q^2)\sigma_{\alpha\beta}q_\beta + V_3(q^2)q_\alpha \,|\, n\rangle,$$

$$A_\alpha = \langle p \,|\, A_1(q^2)\gamma_5\gamma_\alpha + A_2(q^2)\gamma_5 q_\alpha + A_3(q^2)\sigma_{\alpha\beta}q_\beta\gamma_5 \,|\, n\rangle.$$

The quantities V_α and A_α are functions of the invariant momentum transfer q (the square of the difference of the energy-momentum four-vectors of the proton and neutron) and are the form-factors for the decay of the nucleon. These expressions can be simplified if we impose the very natural condition that the β decay of the neutron and that of the antiproton must be described in the same way. This requirement is quite natural, because the neutron and antiproton have the same isotopic spin projection and, except for the Coulomb interaction, which we are neglecting, there is no reason for them to behave differently. Formally this assertion reduces to the requirement that the Hamiltonian function be invariant with respect to two successive transformations. The first makes the change $n \rightleftarrows p$ in the isotopic space and changes the signs of the charges of π mesons, and the second is charge conjugation, which changes nucleons into antinucleons and again changes the signs of the charges of π mesons (the G transformation of Lee and Yang). The requirement of invariance under the G transformation leads to the result that the coefficients V_3 and A_3 must be equal to zero. This can be seen, not altogether rigorously, if we note that in charge conjugation the electric current and the magnetic moment (which are the analogs of the first two expressions for A) change their signs, whereas the momentum (the analog of the third expression) does not change sign. Thus the decay of the neutron is described by four form-factors, and for a given value of q all the effects associated with the β decay of the neutron can be expressed in terms of four numbers. In particular this at once solves the problem of how many experiments are needed to establish the form of the interaction Hamiltonian. To arrive at the usual description of β decay, we must expand the form-factors in power series in qR (where R is the radius of the system); we then get the usual matrix elements, which arise when different degrees of forbiddenness are taken into account and involve the wavelengths of the light particles. It is interesting that in such a treatment one gets a clear view of the different roles of these kinds of forbiddenness and the so-called relativistic forbiddennesses, associated with the small components of the currents A and V, whose smallness is due to the small recoil velocity of the decaying system. The two kinds of forbiddenness have different manifestations in the various polarization effects, and a detailed study of this question must be the subject of a separate paper; cf. reference 14.

The considerations introduced in the description of the decay of the neutron can be extended also to the case of the decay of an arbitrary nucleus. Here the number of form-factors depends on the spins of the initial and final nuclei, and in general increases rapidly with the magnitude of the spin, so that, as commonly happens in nuclear physics, the complete treatment of the Hamiltonian of a nucleus with large spin involves considerable labor. We shall not write out the expressions for the currents here, but shall only remark that measurement of nuclear form-factors gives much additional information about the structure of the nucleus and can lead to the discovery of new effects. One of these effects must be a relatively large decay probability for elongated nuclei, associated with the large value of the quadrupole moment. This is due to the fact that in such a nucleus, besides the usual forbiddenness factors, qR and the v/c of the recoil nucleus, there is another quantity, namely the elongation $\Delta R/R$ of the nucleus, of the order of magnitude 0.1, which can make a contribution to the total decay probability that is comparable with and even larger than that of the other forbidden matrix elements. This effect is of the same nature as the relatively large probability of electric quadrupole transitions in elongated nuclei.

The study of the form-factors is especially interesting in the case of light nuclei for which the consequences of charge invariance are still valid. In such cases, in virtue of the Gell-Mann theorem, the vector form-factors $V_1(q^2)$ and $V_2(q^2)$ are of the same nature as the electromagnetic form-factors describing the scattering of electrons by the nucleus in question (for the same value of q^2, of course). It is easy to establish relations between the electromagnetic and β-decay form-factors, if one correctly takes into account their isotopic-spin dependence.* For just this reason the combined study of β decay and the scattering of electrons at not very high energies in principle makes it possible to progress rapidly with the determination of the form-factors in the light nuclei. Furthermore the determination of the number of independent form-factors by which the β decay of a nucleus is to be described also makes it possible to find the relations imposed on the various forbidden matrix elements by general considerations of symmetry. This must also serve as a topic for further studies.

In the case of hyperon decays the situation is much more complicated, since here there is no basis for reducing the number of form-factors in the general expression from six to four and therefore, for example, a complete study of the decay of the Λ^0 particle is an incomparably more difficult problem than the study of the decay of the neutron.

In conclusion we can emphasize once again that β decay is now an essential component part of the physics of elementary particles, and its study has close connections with the study of other processes in the domain that we usually assign to high-energy physics. On the other hand, our knowledge of the properties of β decay has by now become large enough so that it is time to attack the problem of a broader use of the properties of β decay for the study of nuclear structure.

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*Beta decay involves the operators $\tau^{\pm}$, corresponding to the transformation $n \rightleftarrows p$; the electromagnetic transitions involve $1 \pm \tau^3$.

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