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*ON THE THEORY OF THE WEAK INTERACTIONS. I*

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A scheme for a universal four-fermion interaction is constructed which differs from the usual schemes in the way the quantized fields are introduced into the theory. The electron and positron $\beta$-decays are described by different variants of the Fermi interaction. The CPT theorem does not hold, but the theory is invariant with respect to the transformations CP, CT, and PT. Various experimental and theoretical consequences are discussed.

## 1. INTRODUCTION

THE hypothesis of the universal character of the four-fermion interaction seems extremely plausible in the light of the latest studies in the field of weak-interaction physics.[1] The existing experimental data on $\beta$-decay are not, however, in agreement with any of the variants of the Fermi interaction, and the possibility cannot be excluded that this situation will not change as the experimental results become even more precise. It is therefore of interest to try to construct a universal theory of the weak interactions that differs from the usual theoretical schemes.

In the construction of the theory of elementary particles quantum electrodynamics is taken as a model. Moreover, the methods and concepts of quantum electrodynamics are to a considerable extent carried over into the other theories. In particular, the quantization of the fermion fields is carried out like the quantization of the electron-positron field, and this imposes certain limitations on the structure of the theory. In the present paper the quantized fields are introduced into the theory in a different way, and owing to this the nature of the theory is qualitatively changed. For example, in the theory of $\beta$-decay the electron and positron decays are described by different variants of the four-fermion interaction.

The construction of a theory of the weak interactions with the degree of completeness inherent in contemporary field theories is not the purpose of the present paper. On the contrary, in this paper we consider only the most primitive aspects of the theory. The theoretical scheme is based on certain assumptions that give a unique way of constructing the Hamiltonian of the weak interactions, which enables us (at any rate in the framework of the perturbation theory) to obtain from the theory consequences that can be subjected to comparison with experiment. Relatively little attention is given in this paper to general theoretical questions. Thus the theory has the character of a working hypothesis that makes it possible to check by experiment the correctness or incorrectness of certain theoretical ideas and to obtain a general orientation in the group of phenomena that are due to the weak interactions.

## 2. THE HAMILTONIAN OF THE WEAK INTERACTIONS

The proposed scheme is a certain form of universal theory of contact four-fermion interaction. We assume that all fermions have the spin $1/2$. The requirement of relativistic invariance determines essentially uniquely (i.e., apart from the charge and isotopic variables) the possible states of a free particle. When, however, we come to associate with the particles quantized fields, in terms of which the interaction Hamiltonian is expressed, there is a lack of uniqueness, to remove which it is necessary to formulate a number of additional rules.

Since at the present time no general principle is known from which the nonconservation of parity in weak interactions would follow, we are forced to introduce the requirement of nonconservation of parity into the theory as an additional postulate. The simplest way to do this is to assume that in the theory of the weak interactions all particles are described by two-component fields. To give an exact meaning to this concept, let us first consider a four-component spinor $\psi$ independent of x. With respect to Lorentz transformations (without reflections) $\psi$ separates into two two-component quantities. If we choose a representation of the Dirac matrices in which the matrix $\gamma_5$ is diagonal, this separation has the form

$$\psi = \begin{pmatrix} \varphi \\ \dot{\varphi} \end{pmatrix}. \qquad (2.1)$$

The quantities $\varphi$ and $\dot{\varphi}$ transform according to nonequivalent representations of the Lorentz group. More precisely, the quantity $\dot{\varphi}$ transforms in the same way as the quantity $\epsilon\varphi^*$, where the asterisk means that the complex-conjugate quantity is taken and use in made of the matrix

$$\varepsilon = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}.$$

In the case of a field depending on x one can further decompose quantities $\psi(x)$ into parts corresponding to the creation and annihilation of particles.

The two-component fields of creation and of annihilation of particles already admit of no further decomposition. These fields will be used for the construction of the interaction Hamiltonian. We write down the explicit forms of the fields for the creation of particles:

$$\begin{aligned} \varphi_c(x) &= \sum \sqrt{(1-\sigma \mathbf{v})/2}\, \varepsilon a^+(\mathbf{p})\, e^{ipx}, \\ \dot{\varphi}_c(x) &= \sum \sqrt{(1+\sigma \mathbf{v})/2}\, \varepsilon a^+(\mathbf{p})\, e^{ipx}, \end{aligned} \qquad (2.2)$$

and of those for the annihilation of particles:

$$\begin{aligned} \varphi_a(x) &= \sum \sqrt{(1-\sigma \mathbf{v})/2}\, a(\mathbf{p})\, e^{-ipx}, \\ \dot{\varphi}_a(x) &= \sum \sqrt{(1+\sigma \mathbf{v})/2}\, a(\mathbf{p})\, e^{-ipx}, \end{aligned} \qquad (2.3)$$

where $\sigma$ denotes the Pauli matrices, $\mathbf{v} = \mathbf{p}/E$ is the velocity vector of the particle (we use everywhere a system of units in which $\hbar = c = 1$), and $a^+(\mathbf{p})$ and $a(\mathbf{p})$ are creation and annihilation operators. The connection between the fields (2.2) and (2.3) and the ordinary spinor fields is established in the Appendix.

From the quantities $\varphi(x)$ and $\dot{\varphi}(x)$ we can construct two types of scalars:

$$\varphi_1 \varepsilon \varphi_2, \quad \dot{\varphi}_1 \varepsilon \dot{\varphi}_2. \qquad (2.4)$$

We adopt the hypothesis of a scalar interaction, which states that each possible weak-interaction process corresponds to the presence in the Hamiltonian of a single term which is the product of two scalars of the type (2.4). We note that although our assumption imposes serious limitations on the form of the interaction it contains in principle nothing new in comparison with the usual form of the theory, since in any variant of the four-fermion theory the Hamiltonian can be transformed into a sum of terms of the type indicated. The limitation lies in the fact that one here chooses a single term from each such sum.

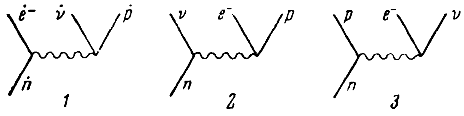


FIG. 1

It is convenient to use a graphical description of the processes. Figure 1 shows three possible diagrams for the process $n \rightarrow p + e^- + \nu$. We agree to associate with the solid lines scalars of the type (2.4). The wavy line does not correspond to any intermediate field; it is introduced just to separate the solid lines. The three diagrams of Fig. 1 correspond to three different variants of the theory of $\beta$-decay.

To get a unique variant of the theory, we introduce the rule of change of charge, according to which the electric charge must change by unity along each solid line, and the nuclear charge must suffer the maximum possible change.

From the three possible diagrams of Fig. 1 the rule of change of charge selects diagram 1. It is easy to see that an analogous situation exists for the other processes.

For complete uniqueness of the choice of the interaction variant it is still necessary to specify the types of fields corresponding to a given process. This is done by the rule of polarization of the lines, according to which fields of definite types always correspond to the charged particles, namely

to $e^-$, $\mu^+$, $p$ correspond fields $\dot{\varphi}_c(x)$ and $\dot{\varphi}_a(x)$,

to $e^+$, $\mu^-$, $\tilde{p}$ correspond fields $\varphi_c(x)$ and $\varphi_a(x)$.

There is no need to specify the types of fields for the neutral particles, since according to the rule of change of charge only one charged particle corresponds to each line. Thus by the forms (2.4) the types of field for the neutral particles in a given process are uniquely determined. We note that the type of field for a neutral particle can change, depending on the process in which it occurs. In Fig. 1, diagram 1, dots are placed over the symbols for the particles, since according to the rule of polarization of lines in this case fields of the type $\dot{\varphi}(x)$ correspond to all of the particles.

The rules formulated above uniquely determine the form of the interaction Hamiltonian, since the character of a process determines the required choice of the creation and annihilation fields, the rule of change of charge determines the distribution of these fields in scalar expressions of the types (2.4), and the rule of polarization of the lines determines which of the scalars (2.4) is to be used in each case.

The last assumption is that the interaction constant g is the same in absolute value for all processes.

## 3. SOME GENERAL PROPERTIES OF THE THEORY

The essential difference between the proposed scheme and all theories based on the usual way of quantizing fields is due to the rule of polarization of lines (Sec. 2). For example, in the theory of Feynman and Gell-Mann,[1] which is also based on two-component fields, to the creation of an electron there corresponds the field $\dot{\varphi}_c(x)$, and to the annihilation of an electron the field $\varphi_a(x)$. In our theory fields of the type $\dot{\varphi}(x)$ correspond to both the creation and the annihilation of an electron. As a result of this kind of construction the part of the Hamiltonian that corresponds to the weak interactions is non-Hermitian. As an illustration of this fact let us consider two mutually inverse processes, for example

$$p \to n + e^+ + \nu, \tag{3.1}$$

$$n + e^+ + \nu \to p. \tag{3.2}$$

Corresponding to the process (3.1) the Hamiltonian contans the term

$$g(\varphi_{cn}\varepsilon\varphi_{ce^+})(\dot{\varphi}_{c\nu}\varepsilon\dot{\varphi}_{ap}), \tag{3.3}$$

and for the process (3.2) the term

$$g(\varphi_{ae^+}\varepsilon\varphi_{an})(\dot{\varphi}_{cp}\varepsilon\dot{\varphi}_{a\nu}). \tag{3.4}$$

Using the obvious relations

$$\varepsilon\varphi_a^+(x) = \dot{\varphi}_c(x), \qquad \varepsilon\dot{\varphi}_a^+(x) = \varphi_c(x)$$

we find that the expression Hermitian adjoint to (3.3) is

$$-g(\dot{\varphi}_{ae^+}\varepsilon\dot{\varphi}_{an})(\varphi_{cp}\varepsilon\varphi_{a\nu}), \tag{3.5}$$

which is not the same as (3.4).

Generally speaking the non-Hermitian character of the Hamiltonian could lead to the appearance of imaginary additions to the masses of particles. We shall show that in the present case such imaginary terms cannot arise. For this purpose we examine the symmetry properties of our scheme with respect to reflections. Obviously the theory is not invariant with respect to the space inversion P and the charge conjugation C, since these transformations are not allowed by the rule of polarization of lines. We shall show that the theory is invariant with respect to the combined inversion CP.

Let $\varphi(x)$ be any one of the two-component fields for a certain particle; we denote the corresponding field for the antiparticle by $\varphi'(x)$. Under the action of CP the fields transform in the following way:

$$\begin{aligned} &\varphi_a(x) \to \dot{\varphi}'_a(x), \ \varphi_c(x) \to -\dot{\varphi}'_c(x), \\ &\dot{\varphi}_a(x) \to \varphi'_a(x), \ \dot{\varphi}_c(x) \to -\varphi'_c(x). \end{aligned} \tag{3.6}$$

The rule of polarization of lines is invariant with respect to the transformations (3.6), and consequently the theory is invariant with respect to the CP transformation. Besides the combined inversion, the theory is also invariant with respect to the transformation PT — the simultaneous reversal of all four space-time axes. The proof is analogous to that above, since the transformation of the fields under the action of PT has the form:

$$\varphi_a(x) \leftrightarrow \varphi_c(-x), \ \dot{\varphi}_a(x) \leftrightarrow \dot{\varphi}_c(-x).$$

Thus the theory is invariant with respect to inversions of the following types: CP, PT, and CT (since CT = CP · PT). The theory is not invariant with respect to the transformation CPT. There is nothing surprising in the fact that this theory violates the CPT theorem of Pauli,[2] since the proof of this theorem is based on the ordinary type of quantization of fields, in which the CPT transformation has the form

$$\psi(x) \to i\gamma_5\dot{\psi}(-x).$$

Using the invariance of the theory with respect to the transformation PT, we shall show that the masses of the particles must be real. We shall consider the weak-interaction Hamiltonian $H_W$ as a perturbation. Suppose the state of an unperturbed stationary particle is characterized by the rest mass $m_0$. The state in question is degenerate as to the spin directions, but since the Hamiltonian $H_W$ is invariant with respect to space rotations, the degeneracy as to the spin direction is not removed by the action of the perturbation. Thus the perturbed state is characterized by a single mass value $m = m_0 + \delta m$. We now apply the operation PT to the state in question. Since the total Hamiltonian is invariant with respect to this transformation, the original state goes over into some other state of the same particle, characterized by a mass $m^*$ (the operation PT includes in itself complex conjugation). Since there exists only one value of the mass of the particle, $m^* = m$, i.e., the total mass is real.

If instead of the transformation PT we use the combined inversion CP, we can prove by similar considerations the precise equality of the masses of particle and antiparticle.

Because of the non-Hermitian character of the weak-interaction Hamiltonian $H_W$, in this theory there is no detailed balancing for reactions with the weakly interacting particles. On the basis of the PT invariance we can assert only the equality of the probabilities of direct and reversed processes (in the sense of PT) — the analogue of the reciprocity theorem. After averaging over the spins of the interacting particles, however, the probabilities of the direct and inverse processes do turn out to be equal.

Without question the introduction of the non-Hermitian Hamiltonian $H_W$ into the theory is a serious infraction of the formal foundations of quantum mechanics. Therefore the term "Hamiltonian" must in this case be understood in a provisional sense. In this paper we regard $H_W$ as a phenomenological quantity, by means of which one can extract results in the framework of the perturbation theory. Later on the author proposes to develop a certain quantum-mechanical scheme which permits the non-Hermitian Hamiltonian $H_W$ to be introduced into the theory in a way free from contradictions.

## 4. COMPARISON OF THE THEORY WITH EXPERIMENT

We begin the consideration of the concrete results of this theory with $\beta$-decay. Figure 2 shows the diagrams: 1 — for electron $\beta$-decay, 2 — for positron $\beta$-decay, and 3 — for K-capture. The

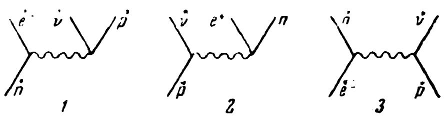

FIG. 2

forms of the corresponding terms in the Hamiltonian $H_W$ are, for $\beta^-$-decay

$$g\,(\dot{\varphi}_{cp}\varepsilon\dot{\varphi}_{c\nu})\,(\dot{\varphi}_{ce}-\varepsilon\dot{\varphi}_{an}), \qquad (4.1)$$

and for $\beta^+$-decay

$$g\,(\varphi_{cn}\varepsilon\varphi_{ce^+})\,(\dot{\varphi}_{c\nu}\varepsilon\dot{\varphi}_{ap}). \qquad (4.2)$$

The expressions (4.1) and (4.2) differ from each other in the types of fields occurring in them. If we transform these expressions to the ordinary form of the $\beta$-decay theory, we find that the $\beta^-$-decay involves the S, T, and P variants of the theory, whereas the $\beta^+$-decay involves the A and V variants.

Using the explicit forms of the fields (2.2) and (2.3) we can easily calculate the probabilities of the various processes. We confine ourselves to allowed $\beta$-transitions. The angular correlation between the electron and neutrino is given by the well known expression $1 + \lambda v \cos\theta$, but, unlike the case of the usual theory, the coefficient $\lambda$ has opposite signs for the $\beta^+$ and $\beta^-$ decays:

$$\lambda = \pm(\gamma^2 - 1/3)/(1+\gamma^2) \quad (\text{for } \beta^\pm\text{-decay}) \qquad (4.3)$$

where $\gamma^2 = |M_F|^2/|M_{GT}|^2$ is the ratio of the squares of the nuclear matrix elements for Fermi and Gamov-Teller transitions. This result is in agreement with the experiments on the $\beta^-$-decay of $He^6$ (reference 3) and the $\beta^+$-decay of $A^{35}$ (reference 4). The values of $\lambda$ for the decays of other nuclei are known with considerably less accuracy, but they also agree qualitatively with the theoretical values. The average longitudinal polarization of the electrons is $\pm v$ (for $\beta^\pm$-decay). This result is the direct consequence of the rule of polarization of lines, and is confirmed by a large number of measurements. The values of the asymmetry coefficient in the angular distribution of the electrons from the $\beta$-decay of oriented nuclei are also in qualitative agreement with the experimental data.[5-8]

An interesting experiment on the capture of a K electron by the $Eu^{152}$ nucleus[9] shows that the neutrino emitted in the K-capture is polarized opposite to the direction of motion. This result is in agreement with the theory, since according to diagram 3 (Fig. 2), in the K-capture process the field $\dot{\varphi}_{c\nu}$ corresponds to the neutrino.

The decay of $\mu^\pm$ mesons goes according to the diagrams of Fig. 3. In both cases the two neutrinos emitted in the decay are differently polarized, which leads to the value $\rho = 3/4$ for the Michel parameter, which is in agreement with experiment.[10]

The decay of $\pi^\pm$ and $K^\pm$ mesons occurs by way of virtual pairs of heavy particles. The relative fraction of $\pi^\pm \rightarrow e^\pm + \nu$ decays cannot be calculated without an accurate treatment of the part played by the strong interactions. It is curious,

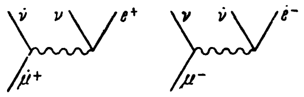

FIG. 3

however, that different variants of the weak-interaction theory are involved in the $\pi \rightarrow \mu$ and $\pi \rightarrow e$ decays. Figure 4 shows the corresponding lowest-order diagrams, from which it can be seen that the decay $\pi^\pm \rightarrow \mu^\pm + \nu$ goes through the pseudoscalar variant of the theory of the Fermi interactions, and the decay $\pi^\pm \rightarrow e^\pm + \nu$ through the pseudovector variant. When higher-order virtual processes are

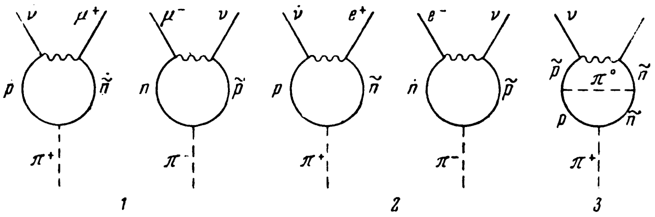

FIG. 4

taken into account, the decay $\pi^{\pm} \to e^{\pm} + \nu$ can go through the pseudoscalar variant (cf. diagram 3 of Fig. 4).

## 5. CONCLUDING REMARKS

The main feature that distinguishes the proposed theoretical scheme from the usual schemes is the rule of polarization of lines (Sec. 2). Therefore a direct experimental check of this rule is desirable. An exact measurement of the polarization of the electrons from $\beta$-decay would be very useful for this purpose, and also measurement of the polarization of the $\mu^+$ mesons from the $K^+_{\mu 3}$-decay.

In formulating the rules for the construction of the Hamiltonian of the weak interactions (Sec. 2) the writer has tried to give the briefest possible expression of all the experimental data. Such a problem of course does not have a unique solution, and the choice of one procedure or another is to a considerable extent arbitrary. On the other hand, the rules must necessarily provide an extrapolation of the experimental data into a very broad uninvestigated domain. It is quite possible that the concrete rules presented in Sec. 2 will be contradicted by experiment and will have to be changed. It is to be specially emphasized that the literal content of these rules is not to be regarded as a final result.

The main idea of this entire construction, in the writer's opinion, is that the system of rules considered here leads to a theoretical scheme of a new type.

The writer expresses his sincere gratitude to B. L. Ioffe for exceptionally valuable discussions.

## APPENDIX

We shall establish the connection between the two-component fields (2.2) and (2.3) and the four-component spinor field $\psi(x)$, which satisfies the Dirac equation. Let us consider the expansion of $\psi(x)$ in plane waves

$$\psi(x) = \sum \left(u(\mathbf{p})\, a(\mathbf{p})\, e^{-ipx} + v(\mathbf{p})\, b^+(\mathbf{p})\, e^{ipx}\right), \tag{1}$$

where $u(\mathbf{p})$ and $v(\mathbf{p})$ are matrices of four rows and two columns which satisfy the relations

$$\hat{p}u(\mathbf{p}) = mu(\mathbf{p}), \quad \hat{p}v(\mathbf{p}) = -mv(\mathbf{p}). \tag{2}$$

$$a(\mathbf{p}) \equiv \begin{pmatrix} a_1(\mathbf{p}) \\ a_2(\mathbf{p}) \end{pmatrix} \quad \text{and} \quad b^+(\mathbf{p}) \equiv \begin{pmatrix} b_1^+(\mathbf{p}) \\ b_2^+(\mathbf{p}) \end{pmatrix}$$

are the operators for annihilation of a particle and for creation of an antiparticle.

Let us determine the explicit form of $u(\mathbf{p})$ and and $v(\mathbf{p})$ in a representation of the matrices $\gamma_\mu$ in which $\gamma_5$ is diagonal. In this representation the matrices are written down in the following "separated" form:

$$\gamma_\mu = \begin{pmatrix} 0 & \sigma_\mu \\ \sigma^\mu & 0 \end{pmatrix}, \quad \gamma_5 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix},$$

where $\sigma_\mu = (1, \boldsymbol{\sigma})$, $\sigma^\mu = (1, -\boldsymbol{\sigma})$ are two-row matrices. From this it is easy to find the form of the operator $\hat{p}$:

$$\hat{p} = \begin{pmatrix} 0 & E - \sigma\mathbf{p} \\ E + \sigma\mathbf{p} & 0 \end{pmatrix} = m \begin{pmatrix} 0 & \left(\frac{1-\sigma\mathbf{v}}{1+\sigma\mathbf{v}}\right)^{1/2} \\ \left(\frac{1+\sigma\mathbf{v}}{1-\sigma\mathbf{v}}\right)^{1/2} & 0 \end{pmatrix}. \tag{3}$$

Using Eq. (3), we find the solution of the first of the equations (2) in the "separated" form:

$$u(\mathbf{p}) = \begin{pmatrix} \sqrt{(1-\sigma\mathbf{v})/2} \\ \sqrt{(1+\sigma\mathbf{v})/2} \end{pmatrix}. \tag{4}$$

The factor $2^{-1/2}$ is introduced for normalization: $u^+(\mathbf{p})\, u(\mathbf{p}) = 1$. For $v(\mathbf{p})$ we take the quantity which is charge-conjugate to (4):

$$v(\mathbf{p}) = cu^*(\mathbf{p}) = \begin{pmatrix} 0 & \varepsilon \\ -\varepsilon & 0 \end{pmatrix} \begin{pmatrix} \sqrt{(1-\sigma\mathbf{v})/2} \\ \sqrt{(1+\sigma\mathbf{v})/2} \end{pmatrix}^* \tag{5}$$

$$= \begin{pmatrix} \sqrt{(1-\sigma\mathbf{v})/2}\,\varepsilon \\ -\sqrt{(1+\sigma\mathbf{v})/2}\,\varepsilon \end{pmatrix}.$$

Substituting Eqs. (4) and (5) into Eq. (1) and comparing with Eqs. (2.2) and (2.3), we find the expression for $\psi(x)$ in terms of the two-component fields:

$$\psi(x) = \begin{pmatrix} \varphi_a(x) + \varphi_c'(x) \\ \dot{\varphi}_a(x) - \dot{\varphi}_c'(x) \end{pmatrix}, \tag{6}$$

where the prime means that the field $\varphi$ refers to the antiparticle.

Using the relation (6) and knowing the law of transformation of $\psi(x)$, one can easily find the transformation properties of the two-component fields considered in Sec. 3.

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# *POLARIZATION CORRELATION OF BETA PARTICLES AND GAMMA QUANTA IN ALLOWED DECAY OF ORIENTED NUCLEI*

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Formulas are obtained for the correlation between the polarization of particles and the circular polarization of the subsequent gamma quanta in allowed beta decay of oriented nuclei.

THE extensive study of angular and polarization correlation in beta transformations, undertaken recently, have made it possible to gather much important information on beta interactions. It was established that the assumed A-V interaction in parity nonconservation is apparently not in contradiction with existing experiments. However, there are clearly not enough data for an unambiguous statement. This is why the determination of the type of beta interaction remains the most important problem in the theory of beta decay. It is also desirable to know the values and the relative signs of the $\beta$-interaction constants. To explain these problems, it is desirable to study all aspects of the beta transformations and, in particular, to investigate the polarization correlation between the $\beta$-particles and subsequent gamma quanta in beta decay of oriented nuclei. The advantages of such experiments is that they can yield complete information on the $\beta$-interaction constants. The pseudoscalar interaction does not make a noticeable contribution in allowed beta transitions. This leaves therefore eight (generally speaking complex) constants $c_S$, $c_T$, $c_V$, $c_A$ and $c'_S$, $c'_T$, $c'_V$, and $c'_A$ for the scalar, tensor, vector and axial-vector beta interactions, which must be determined experimentally. The quantities $c'_i$, unlike $c_i$, enter into those interaction terms that vanish when parity is conserved (these terms contain an additional matrix $\gamma_5 = \gamma_1\gamma_2\gamma_3\gamma_4$, where $\gamma_4 = -\beta$). A study of the correlation considered here, in accordance with (1), makes it possible to determine the real and imaginary parts of eight independent combinations of $c_i$ and $c'_i$. The information obtained in this manner will actually be complete. Let us remark however that the quantity $\operatorname{Im}(c_S c'^*_V + c'_S c^*_V)$ enters only with a small multiplier $\alpha Z/E$, where $\alpha = 1/137$, $Z$ is the charge of the nucleus, and $E$ the total energy of the beta electron (we use units in which $\hbar = m = c = 1$). Therefore, if the experimental accuracy is insufficient to discern quantities of order $\alpha Z/E$ from quantities of order $p/E \equiv v/c$, we obtain not 16 but only 15 independent relations for the 16 real quantities. In practice however, this causes no complications, for it is enough to take into account the results of any of the already-performed independent experiments to obtain more relations than necessary.

Since the procedural aspect of the calculation of the sought correlation has been treated in an earlier work by this author,[1] we merely cite the end results.